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**Exposure to hand-arm vibration and its effects on workers at a mine
rock drill repair and maintenance workshop**

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(B.Sc.; B.Sc. Hons)

Mini-dissertation submitted in partial fulfillment of the requirements for the degree
Master of Science (Occupational Hygiene) at the Potchefstroom Campus of the
North-West University.

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2012

Potchefstroom

Then Daniel praised God of heaven, saying: “Blessed be the name of God forever and ever, for He alone has all wisdom and all power. World events are under His control. He removes kings and sets others on their thrones. He gives wise men their wisdom, and scholars their intelligence.

Holy Bible, Daniel 2: 20-21

Acknowledgements

I would like to thank the following people for their contributions in making this project possible:

- My supervisor Mr PJ Laubscher, North-West University, Potchefstroom Campus, for his guidance and support.
- My assistant supervisor Mr MN van Aarde for his guidance and support.
- My assistant supervisor Mr JJ van Staden for his time and effort spent in the completion of this project and valuable guidance and support.
- Anglo Platinum, Rustenburg for allowing me to conduct this project on their premises, and special thanks to Mr Deon Wiit for making my work possible.
- Professor JM van Rooyen for the use of a Finometer.
- Dr G Koekemoer from the Statistical Consultation Service, North-West University for his help with the statistical analysis of the data, and his time and willingness to help over weekends.
- Ms Anneke Coetzee, information specialist at the North-West University (Potchefstroom Campus) for her help in the sourcing for scientific articles.
- My loving parents for their emotional and financial assistance, without them, none of this would have been possible.
- To my beautiful wife Reinette, for her emotional and moral support, without her assistance none of this would have been possible.
- Mr Martin de Beer for his valuable information on vibration and the effective measurement thereof.
- Prof Lesly Greyvenstein for the language editing of this thesis.

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Author's contribution

This study was planned and carried out by a team of researchers. The contribution of each researcher is given in Table 1. This mini-dissertation is presented for the partial fulfillment of the degree *Master of Science in Occupational Hygiene* at the School of Physiology, Nutrition, and Consumer Sciences of the North-West University, Potchefstroom Campus. It was decided to use the article format for the purpose of this study. Therefore, Chapter 3 is a manuscript in the form of an article. Although the appropriate and relevant literature background is discussed in the manuscript, Chapter 2 serves as a literature study and gives an additional, more elaborate literature background. Chapter 4, the concluding chapter, provides a summary of the main findings, confounders are discussed, conclusions are drawn and recommendations are made.

Table 1: Research team

Name	Contribution
Mr. D.P. Visagie	Responsible for: Personal monitoring of Hand-arm vibration, conduction of diagnostic tests. Literature research and writing of the article. Writing of Mini-dissertation
Mr. P.J. Laubscher	Supervisor Assisted with the design and planning of the study, approval of the protocol used in the study, review of the dissertation and interpretation of the obtained results

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Name	Contribution
Mr. J.J. van Staden	Assistant-supervisor Assisted with the planning and design of the study, with the approval of the protocol and review of the article. Provided immense support and assistance with required instrumentation and organising of the study.
Mr. M.N. van Aarde	Supervisor Assisted with the design and planning of the study.

The following is a statement from the co-authors' roles in the study:

I declare that I have approved the article and that my role in the study as indicated is a true reflection of my actual contribution and that I hereby give my consent that it may be published as part of Daniel Visagie's M.Sc. (Occupational Hygiene) mini-dissertation.

Mr. P.J. Laubscher

Mr. J.J. van Staden

Mr. N van Aarde

List of Abbreviations

BMI:	Body Mass Index
CGRP:	Calcitonin-gene-related peptide
CTS:	Carpal Tunnel Syndrome
DNA:	Deoxyribonucleic acid
EAV:	Exposure Action Value
ELV:	Exposure Limit Value
ET1:	Endothelin 1
EU:	European Union
FSBP:	Finger Systolic Blood Pressure
FST:	Finger Skin Temperature
HAV:	Hand-arm Vibration
HAVS:	Hand-arm Vibration Syndrome
HTV:	Hand-transmitted Vibration
ISO:	International Organization for Standardization
NA:	Noradrenaline
NO:	Nitric Oxide
RP:	Raynaud's Phenomenon
RMS:	Root Mean Square
TVR:	Tonic Vibration Reflex
VWF:	Vibration induced White Finger

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Preface

Chapter 3, the article is written in the format of an article as required by the *Scandinavian Journal of Work, Health and Environment*. As the mini-dissertation will be submitted for examination purposes, deviations from the requirements of the *Scandinavian Journal of Work, Health and Environment*, may occur for the sake of comprehensiveness. Referencing in the rest of the mini-dissertation will be done in accordance with the Harvard referencing style.

Summary

In many occupations, exposure to hand-transmitted vibration (HTV) over a prolonged period causes various disorders involving the vascular, neural and musculoskeletal systems, collectively known as the hand-arm vibration syndrome (HAVS). It is a complex and potentially disabling chronic disorder of the upper extremities, especially of the hands. Numbness, tingling, reduced tactile discrimination, and impaired manipulative dexterity are often reported by workers exposed to HTV. The precise pathophysiological mechanism responsible for vascular injuries in HAVS has not yet been fully clarified; it seems to be multifactorial and highly complex. Interaction of neural signals, hormones, mediators and changes in the blood vessel itself appear to contribute to the development of such vascular injuries. This study aims to assess the risk of the hand-transmitted vibration exposure during pneumatic impact wrench operation in a rock drill repair and maintenance workshop at a South African platinum mine. A total of 8 workers working on a day to day basis with impact wrenches were available for this study. For each of the workers a control (not exposed to vibration) was selected on the basis of gender, ethnic group, smoking habits, age and body mass index (BMI). Grip force, dexterity and hand-eye co-ordination were tested on the workers and control group before and after work. Finger systolic blood pressure (FSBP) was also measured after cold provocation of the worker and control groups. Results have shown a statistically significant difference between the two groups with respect to grip force, hand-eye coordination, dexterity and FSBP after cold provocation. Vibration measurements shows three workers had values above the suggested ELV of 5 m/s^2 for an eight hour A (8) workday.

With regards to dexterity, workers were capable to manipulate small objects better with their dominant right (vibration exposed) hand after work than before work. In contrast, it seems that the number of pegs correctly inserted by the controls is not uniformly affected by their 8 hour workday. The worker group showed a greater grip force than that of the control group, both before and after work. There was a statistically significant difference between the control and worker group with respect to the number of mistakes during the mirror trace and the time to complete this test *only* for the right hand. The difference in FSBP after cold provocation between the control and worker group observed is of medium importance when compared with effect sizes, however, there was no statistical significant difference. In this study, it was very difficult to make valid conclusions due to the limitations of a small sample size. A longitudinal study should be conducted preferably using newly appointed workers with no prior exposure to vibration and a sufficient control group to eliminate the effect of other confounding variables such as general working conditions.

Keywords: Hand-transmitted vibration (HTV), hand-arm vibration syndrome (HAVS), pneumatic impact wrench, grip force, dexterity, hand-eye coordination, finger systolic blood pressure (FSBP).

Opsomming

In baie beroepe veroorsaak langdurige kroniese blootstelling aan hand-oorgedraagde vibrasie (HOV) verskeie afwykings met betrekking tot die vaskulêre, neurale en muskuloskeletale stelsels, saam bekend as hand-arm vibrasie sindroom (HAVS). Dit is 'n baie komplekse en potensiëel stremmende kroniese afwyking van die boonste ledemate, veral van die hande. Simptome soos gevoelloosheid, nælde en spelde, verlaagde aanrakings diskriminasie en 'n afname in manipulasievaardigheid word gereeld gerapporteer deur werkers wat blootgestel is aan HOV. Die presiese patofisiologiese meganisme verantwoordelik vir vaskulêre skade in HAVS is nog nie bekend nie, maar dit blyk om multifaktoriaal en hoogs kompleks te wees. Interaksie van neurale seine, hormone, mediatore en veranderinge in die bloedvatwande self blyk om by te dra tot die ontwikkeling van sulke vaskulêre skade. Die studie beoog om die risiko van die HOV te assesser tydens die hantering van 'n pneumatiese impak moersleutel in 'n rotsboor herstel en onderhoud werkwinkel by 'n Suid Afrikaanse platinum myn. 'n Totaal van 8 werkers wat op 'n daaglikse basis met impak moersleutels werk was beskikbaar vir die studie. Vir elk van die werkers is 'n ooreenstemmende kontrole persoon gewerf (wat nie aan vibrasie blootgestel was nie) op grond van geslag, etniese groep, rook gewoontes, ouderdom en liggaams massa indeks (LMI). Greepkrag, handvaardigheid en hand-oog koördinasie is getoets op die werkers en die kontrole groep voor en na werk. Vinger sistoliese bloeddruk (VSBD) is ook gemeet na koue ontlokking van bloedvatvernouing vir beide die werker en kontrole groepe. Die resultate van die studie toon 'n verskil tussen die twee groepe met betrekking tot greepkrag, hand-oog koördinasie, handvaardigheid en VSBP na koue uitlokking. Vibrasie metings wys drie werkers het waardes bo die voorgestelde BLW van 5m/s^2 vir 'n agt uur A(8) werkdag. Met betrekking to handvaardigheid was werkers se vermoë om klein voorwerpe te manipuleer beter met hul dominante regter (vibrasie blootgestelde) hand na werk as voor werk. In teenstelling, blyk dit dat die hoeveelheid pennetjies reg geplaas deur die kontroles nie uniform geaffekteer is deur hul 8 uur werkdag nie. Die werker groep het 'n groter greepkrag as die kontrole groep gewys, beide voor en na werk.

Daar was 'n statistiese betekenisvolle verskil tussen die kontrole groep en die werker groep met betrekking tot die hoeveelheid foute gemaak gedurende die spieël afteken toets en die tyd geneem om die toets te voltooi slegs vir die regterhand. Die verskil in VSBD na koue uitlokking tussen die kontrole en werker groep waargeneem is van medium belangrikheid wanneer vergelyk word met effek grotes, daar was egter geen statistiese belangrikheid nie. In die studie, was dit baie moeilik om geldige afleidings te maak, as gevolg van die beperking van 'n klein steekproef grote. 'n Longitudinale studie moet egter uitgevoer word, verkieslik met nuut aangestelde werkers met geen vorige blootstelling aan vibrasie, asook 'n voldoende kontrole groep om die effek van ander faktore soos werk omstandighede wat nie vibrasie insluit nie te buffer.

Sleutelwoorde: Hand-oorgedraagte vibrasie (HOV), hand-arm vibrasie sindroom (HAVS), impak moersleutels, greepkrag, handvaardigheid, hand-oog koördinasie, vinger sistoliese bloed druk (VSBD).

CHAPTER 1

General Introduction

1.1 Introduction

Many workers in numerous industries use hand-held vibrating tools that generate both vibration and noise every day. Exposure to hand-transmitted vibration (HTV) and noise are important risk factors for different types of occupational illnesses (Björ *et al.*, 2007). Various types of impact wrenches or nut runners with impact action expose workers to vibration and the repetitive forces necessary to hold the tool, engage the nut or bit, and resist the torque reaction forces (Xu *et al.*, 2008).

Depending on the type and place of work, vibration can enter one arm only, or both arms simultaneously, and may be transmitted through the hand and arm to the shoulder. The vibration of body parts and the perceived vibration are frequently a source of discomfort and possibly reduced proficiency. Continued, habitual use of many vibrating power tools has been found to be connected with various patterns of diseases affecting the blood vessels, nerves, bones, joints, muscles or connective tissues of the hand and forearm (ISO, 2001).

The vibration exposures required to cause these disorders are not known precisely, neither with respect to vibration magnitude and frequency spectrum, nor with respect to daily and cumulative exposure duration. The guidance given is derived from limited quantitative data available from both practical experience and laboratory experimentation concerning human response to HTV, and on limited information regarding current exposure conditions (ISO, 2001).

European Directive 2002/44/EC establishes the minimum health and safety requirements' regarding the exposure of workers to the risks arising from vibration, and states that the vibration transmitted to the hand–arm system is to be measured in accordance with the International Standard ISO 5349-1/2, 2001(European Directive 2002/44/EC).

Article 3 of Directive 2002/44/EC establishes the following safety limits for HTV in a work day of 8 hours:

-Exposure limit value (ELV) = 5 m/s² and

-Exposure action value (EAV) = 2.5 m/s².

The ELV is the maximum amount of vibration an employee may be exposed to in any single day (based on an 8 hour exposure). It represents a high risk above which employees should not be exposed. The EAV is the daily amount of vibration exposure above which employers are required to take action to reduce exposure or to provide regular health checks for the workers involved (Vergara *et al.*, 2008).

Occupational exposure to HTV has detrimental effects on the vascular, neurological and musculoskeletal systems in the upper limbs of the exposed workers. Numbness, tingling, reduced tactile discrimination, and impaired manipulative dexterity are often reported by workers exposed to HTV (Rui *et al.*, 2007).

The prevalence of vascular symptoms among workers using hand-held vibrating tools can be as high as 70% or more, depending on the type and duration of exposure (Harada & Mahbub, 2008). Follow-up studies have shown that such effects are likely to be long-lasting and clearly apparent after several years (Banister & Smith, 1972).

Hand-arm vibration syndrome (HAVS) is a complex and potentially disabling chronic disorder of the upper extremities, especially of the hands. The costs for compensation, treatment and other indirect costs associated with this disorder are high in developed countries (Harada & Mahbub, 2008).

In addition, HTV can cause permanent damage to nerves, blood vessels (vibration induced white fingers (VWF)), muscles, and bones in the upper limbs (Björ *et al.*, 2007). These disorders may manifest individually or collectively. The symptoms vary for different substructures of the system. The most extensively studied and best known component is VWF (Dong *et al.*, 2007).

VWF is a recognised occupational disease, which occurs in users of vibrating tools. VWF is medically classified as a secondary form of Reynaud's phenomenon and is characterised by finger blanching usually triggered by exposure to cold (Bovenzi *et al*, 2007).

Workers exposed to hand-transmitted vibration may complain of episodes of pale or white finger, usually triggered by cold exposure. This disorder, due to temporary abolition of blood circulation to the fingers, is called Raynaud's phenomenon (after Maurice Raynaud, a French physician who first described it in 1862). 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 emphasize the role of vibration-induced local changes in the digital vessels. Various synonyms have been used to describe vibration induced vascular disorders: dead or white finger, Raynaud's phenomenon of occupational origin, traumatic vasospastic disease, and, more recently, VWF. In many countries VWF is a recognized occupational disease (ISO, 2001).

The mechanisms responsible for the pathology of VWF are still evolving and the precise pathophysiological mechanisms responsible is not yet fully understood or clarified, it is highly complex and multifactorial. Increase in sympathetic activity along with exaggerated vasoconstrictor responses of digital vessels to cold and vasodilatory mechanisms have been implicated in the pathogenesis of VWF. Interaction between neural signals, hormones, mediators and changes in the blood vessel itself contribute to the development of such vascular injuries (Harada & Mahbub, 2008).

An imbalance between the parasympathetic and the sympathetic part of the autonomic nervous system has been suggested as a possible cause of VWF, an imbalance that also disturbs other autonomic regulated functions such as heart rate and breathing patterns. A possible mechanism for autonomic dysfunction is the physical stress caused by vibration exposure either by itself or in combination with other stressors such as noise (Björ *et al.*, 2007).

Employers of persons who develop these disorders may not be considered negligent if they had not known that a disorder would ensue, or if they were incapable of preventing the disorder without taking unreasonable precautions. Where an employer should have anticipated a risk and failed to take reasonable measures that would have reduced the risks, the employer can be considered negligent (Griffin, 2008).

This study will focus on a group of eight workers responsible for mine rock drill repair and maintenance, at a South African Mine. This group of workers work with vibrating tools (impact wrenches) on a daily basis. Due to the lack of information regarding the exposure of rock drill maintenance and repair workers to hand-arm vibration this study was formulated to address the gap in scientific literature.

1.2 Aim and objective

The aims and objectives of this study can thus be outlined as follows:

- 1.) The aim of this study is to determine the extent of hand-arm vibration exposure of these workers,
- 2.) The objective of this study is to determine the physiological effects (hand eye coordination, grip force, manipulative dexterity and finger systolic blood pressure after cold provocation) of this vibration (if any), and to what extent workers possibly have effects and/or symptoms of HAVS.

1.3 Hypothesis

Hypothesis 1: Rock drill repair and maintenance workers are exposed levels of hand-arm vibration that exceeds the suggested ELV of 5 m/s^2 .

Hypothesis 2: Rock drill repair and maintenance workers have a lower finger systolic blood pressure (FSBP) after cold provocation.

1.4 References

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CHAPTER 2
Literature Study

Literature study

2.1. HAV and its overall effects in the industry

Thousands of workers throughout the world are exposed to hand-arm vibration (HAV) in various industries such as mining, construction, trucking, logging and steel. Vibrating tools utilized that result in direct HAV include grinders, saws, drills, riveting guns and pneumatic tools (Schweigert, 2002).

Exposure to HAV over a prolonged period could cause various disorders involving vascular, musculoskeletal and neural systems, collectively known as HAVS (Harada & Mahbub., 2007). Perhaps more importantly, HAV could cause permanent damage to nerves, blood vessels, muscles and bones in the upper limbs of exposed workers (Björ *et al.*, 2007). HAVS, also known as vibration-induced white finger (VWF) is a secondary form of Raynaud's phenomenon and is of occupational origin (Bovenzi *et al.*, 2007). Over time, hand function may be severely impaired, which could have a detrimental effect on the patient's activities of daily living and ability to work, and presently there is no effective treatment for it (Rosén *et al.*, 2008). Follow-up studies have shown that the effects of HAVS are clearly apparent after several years and likely to be long-lasting (Banister & Smith., 1972).

In developed countries the financial implication for compensation, treatment and other indirect costs associated with these disorders are high (Harada & Mahbub., 2008). Persons suffering of HAVS probably represent the largest group of workers in the world claiming compensation for any single industrial related disease or injury (Proud *et al.*, 2003).

Little work investigating the impact of HAVS on performance of everyday activities has been published. The effects of HAVS on functionality and quality of life may be important not only on an individual's ability to continue in their job, but also their proper functioning in home and social life (Poole & Mason, 2005). Disability depends on the impact of the disease on the current and future employment of individuals and also their leisure activities (Griffin, 2007).

It has been shown that workers are not aware that levels of vibration transmitted to their hands may exceed safe limits, which represents an additional risk. Workers exposed to HAV should at least be informed about the possible effects that these vibrations may have (Vergara *et al.*, 2007).

2.2. Vascular effects of HAV

Vascular disorders in the hand depend on the intensity and frequency of vibration, but also to a significant extent depend on the way in which the vibrating tools are used. During the use of many vibratory tools the vibration is not uniformly distributed over all the fingers or equally to both hands. If one hand is not exposed, it would not be expected to see symptoms or signs caused by HAV on the non-exposed hand. Similarly, the fingers that are most exposed where substantial grip and push forces have to be applied to the hand-held tools may be more at risk (Inaba *et al.*, 1996).

The occurrence of VWF can be predicted based on the cumulative exposure to HAV in accordance with the international standard ISO 5349. A dose–response relationship has been established between exposure to HAV and the risk of VWF based on several epidemiological studies (Suani *et al.*, 2009). Vibration contributes to operator fatigue, which, stretched over a period of months and years, may cause physical and psychological health problems (Tewari & Dewangan, 2009).

The main vascular symptom observed in HAVS is blanching of the fingers especially in response to cold (Poole & Mason, 2005). Acute inflammation in the hands and fingers may occur after use of vibrating tools, and with continued use of these tools, chronic vascular symptoms characterized by episodic vasospasm and blanching of the fingers during exposure to cold or even emotional stress may occur. As the condition progresses, vasospasms may occur even at room temperature (White *et al.*, 2003).

VWF is the most prominent vascular component of HAVS; however, continuous cold sensation of the hands and fingers is not an uncommon vascular symptom amongst patients with this disorder (Harada & Mahbub, 2008). Attacks of VWF arise from abnormal response to cold. It seems likely that these abnormal responses to cold occur before the first attack of finger blanching, which could explain the “cold fingers” often reported by users of vibratory tools (Griffin, 2007).

2.2.1 Causes of vascular symptoms

The cause of the VWF phenomenon is an abrupt disruption in blood flow, in particular the superficial cutaneous capillaries in the finger. This sudden decrease in blood flow could possibly be caused by hyperactivity of the sympathetic nervous system and also by a local mechanism such as hypertrophy of arterial walls (Harada, 2002).

However, the mechanisms responsible for the pathology of VWF are still evolving and the precise pathophysiological mechanisms responsible are not yet fully clarified or understood. It is highly complex and multifactorial. An increase in sympathetic activity together with exaggerated vasoconstrictor responses of digital blood vessels to cold and vasodilatory mechanisms have been implicated in the pathogenesis of VWF. Complex interaction between neural signals, hormones, mediators and changes in the blood vessel itself may contribute to the development of vascular injuries (Harada & Mahbub, 2007).

An imbalance between the sympathetic and the parasympathetic part of the autonomic nervous system has also been suggested as a possible cause of VWF, an imbalance that also disturbs other functions such as heart rate and breathing patterns. A possible mechanism for autonomic dysfunction may be the physical stress caused by vibration exposure either by itself or in combination with other stressors such as noise (Björ *et al.*, 2007).

The combined effect of exposure to noise and vibration causes larger temporary shifts of the hearing threshold at certain frequencies than the single effect of noise exposure. A possible explanation for this may be the vibration transmission from the handle along the hand-arm system up towards the head. Particularly in the frequency region of about 4 kHz a good vibration transfer along the hand-arm system towards the head exists, which may even be supported by resonance phenomena (Inaba *et al.*, 1996).

There is some debate as to whether or not VWF is reversible and a small number of observational studies have indicated a relationship between vibration exposure, severity of VWF and reversibility of VWF (Futatsuka *et al.*, 2000).

2.2.2 Possible mechanisms for vascular symptoms

Vibration is characterized by rapidly changing expansive and compressive mechanical forces. Inside the fluid environment of the vasculature, such mechanical forces may expose the endothelial monolayer to mechanical deformation and also to rapid changes in fluid shear stress. Fluid shear stress is the frictional force generated parallel to the luminal cell surface as the mass of the blood cells is moved through its liquid environment. When rapid changes in fluid shear stress occur, two stimuli must be considered: the magnitude of the change in shear stress, and the temporal change in shear stress. These temporal gradients in shear stress can be defined as the localized change in shear stress over a small period of time at any given point. Temporal gradients in fluid shear stress have been shown to stimulate specific and distinct biochemical pathways in human endothelial monolayers. Large temporal gradients in fluid shear due to the change of shear direction have been linked to the pathogenesis of other endothelial and vascular disorders such as atherosclerosis and intimal hyperplasia (White *et al.*, 2003).

Apart from increased plasma levels of thrombomodulin and Von Willebrand factor attributed to shear stress and endothelial damage, erythrocyte hyper-aggregation and hypo-deformability, platelet activation, impaired fibrinolysis, decreased plasma thiol levels, elevated concentrations of thromboxane A₂ and intercellular adhesion molecules may possibly contribute to vasospastic attacks associated with VWF.

The vasospasm in HAVS causes persistent decrease in blood flow; insufficient vasodilatation together with hypersensitivity to cold could also play a role (Harada & Mahbub, 2007).

Some evidence suggests that vascular symptoms in the lower extremities are associated with individuals who have been established to have upper extremity vascular effects. This is supported by symptoms of coldness, investigations of skin temperature and pathological findings (Schweigert, 2002). The main pathophysiological mechanism is possibly an imbalance between endothelin-1 (ET1), a potent vasoconstrictive peptide, and calcitonin-gene-related peptide (CGRP), a powerful vasodilator present in digital cutaneous perivascular nerves (Noël, 2000).

Impaired endothelial release of nitric oxide (NO) and elevated levels of plasma ET-1 have been reported in patients with HAVS. This rise in plasma ET-1 is thought to be a specific endothelial response to vibration, and not just a simple marker of endothelial damage. Current research implicates an imbalance between ET-1 and localized deficiencies of CGRP, which acts directly on the blood vessels by stimulating the release of NO from the endothelium as the main pathophysiological mechanism responsible for the vasospastic phenomenon in HAVS (Noël, 2000; White *et al.*, 2003).

Enhanced sympathetic activation together with exaggerated vasoconstriction, especially in response to cold plays a major role in the appearance of VWF attacks. Studies with whole-body cooling tests among vibration exposed subjects with and without VWF as well as healthy controls, revealed plasma epinephrine levels during exposure to cold to be highest in VWF subjects and significantly different from healthy controls. These plasma levels of epinephrine attributable to peripheral nerve release and release by the adrenal medulla was significant especially amongst the subjects with appearance of blanching during the cold exposure test (Harada & Mahbub, 2007).

Furthermore, catecholamines are excreted in urine; studies have also indicated that in those with VWF, urinary catecholamine levels are higher than in control groups, even prior to cold exposure (Schweigert, 2002). Narrowing of the arterial lumen with medial smooth muscle hypertrophy enhancing vasoconstriction has also been observed in some patients with HAVS. The latter is described as increased sympathetic activity with vasoconstrictor response to cold, endothelin-1 and plasma catecholamine release, increased α 2-adrenoreceptor reactivity and decreased vasodilatation, therefore relating to inadequate release of NO and CGRP (Harada & Mahbub, 2007).

An additional complication of vibration exposure is possibly arterial thrombosis in the upper extremities. Due to anatomical reasons, the ulnar arteries are usually more exposed to vibrating equipment. Resonance phenomena are transmitted to the ulnar artery by adjacent bony structures, especially the hamulus of hamate and the pisiform bone. In the initial phase, the arterial thrombosis is limited to the digits or to the hypothenar region. In advanced cases, thrombosis can extend further up to the forearm and can be responsible for digital necrosis. The traumatic effect of vibration on the vascular endothelium is probably responsible for the coagulation activation and for the thrombotic phenomenon observed in the digital and forearm arteries of vibration exposed workers (Noël, 2000).

2.2.3 Finger systolic blood pressure and it's relation to HAVS

Changes in finger systolic blood pressure (FSBP) before and after cold provocation have been shown to be related to finger blanching. It has high specificity, suggesting that it may be a useful diagnostic test in ruling out vascular abnormality, but its sensitivity has tended to be lower, suggesting that it may not be suitable as a screening tool (Poole *et al.*, 2004).

The international standard ISO 14835-2, describes methods for measuring FSBP during local cold provocation together with procedures for conducting measurements which are suggested to assist in the collection of data for a quantitative evaluation of cold-induced changes in finger circulation (ISO, 2005).

The measurement of FSBP before and after local cooling is also a laboratory testing method which can be used in either clinical studies or epidemiological surveys to confirm objectively a subjective history of VWF (Bovenzi *et al.*, 2007). FSBP is related to the tone of the digital blood vessels, so that during cold provocation the blood vessel constricts and FSBP falls (Poole *et al.*, 2004). Most studies of VWF and vascular reactivity to cold provocation are of cross-sectional type. Very few longitudinal studies exist of the cold response of digital arteries in healthy vibration-exposed workers or patients affected with VWF (Bovenzi *et al.*, 2007).

2.3 Musculoskeletal and neurological effects of HAV

The main musculoskeletal and neurological symptoms of HAVS are tingling and numbness in the hands, weakened grip strength, changes in sensory perception and also impaired manual dexterity. The affected workers may report difficulties in manipulating small objects or even executing simple actions such as writing or buttoning and unbuttoning clothes (Rui *et al.*, 2007). Muscle weakness that specifically affects grip strength has been reported after exposure to vibration and there have also been reports of reduced intrinsic muscle strength in persons exposed to vibration (Necking *et al.*, 2002). Some experimental studies have shown changes in muscle fibers of vibration exposed workers. Especially exposure to impulse vibration has been found to be associated with musculoskeletal symptoms in the upper extremities (Suani *et al.*, 2008).

Additionally, the pathology of those with HAVS in the upper and lower extremities have been studied and revealed thickening of the medial muscular layer of the small arteries or arterioles, together with an increase of collagen fibers in the connective tissue, especially in the perivascular region of the fingers and toes (Schweigert, 2002). Biopsies from the abductor pollicis brevis muscle in workers exposed to long-term vibration have shown extensive muscle pathology (Necking *et al.*, 2002).

There is also a possibility of a vibration induced carpal tunnel syndrome (CTS) and muscle weakness without VWF, which may also be included in the vibration syndrome complex (Kattel & Fernandez, 1998).

Knowledge about the relation between the musculoskeletal injuries and vibration is limited. It is known that mechanical vibration applied to a muscle belly or a tendon can elicit a reflex muscle contraction known as tonic vibration reflex (TVR). It is believed that the mechanisms behind TVR are lower recruitment thresholds of motor units when vibration is induced in the muscle. Muscular fatigue caused by this vibratory evoked muscular activity has been suggested as one effect of vibration exposure (Aström *et al.*, 2007). These symptoms may develop within 2-5 years of vibrating power tool use (Govindaraju *et al.*, 2007).

2.3.1 Dexterity

Previous cross-sectional studies have shown an impaired manual dexterity in workers with occupational exposure to HAV (Rui *et al.*, 2007). Although reduced tactile sensibility is regarded as the main reason for dexterity loss in the hands of these patients, reduced muscle strength in both the thumb and index finger should not be overlooked as an important factor for the reduction of manipulative skills as integrated sensory and motor functions are essential for manual dexterity (Necking *et al.*, 2002).

The hand function may be tested by means of the pegboard, which is considered to be an objective and repeatable test of manual dexterity in patients affected by neurological disorders, resulting from exposure to HAV. It can also be utilized as a pre-employment test for personnel engaged in jobs requiring high hand-movement performance (Rui *et al.*, 2007). The value of the test for diagnosis, however, depends on the differences between responses of those affected by HAV and those not affected by HAV (Lindsell & Griffin, 2001).

2.3.2 Neural pathology

Pathological studies have shown demyelinating neuropathy in the fingers of workers exposed to vibration, and nerve conduction measurements have also showed reduced nerve conduction velocities in the digits and hands of vibration exposed workers. Skin biopsies from the fingers of patients with HAVS have shown fewer axons, disrupted myelin sheaths as well as degenerated Schwann cells in peripheral

nerves. These nerve changes are observed in the digits and in nerves proximal to the wrist (Govindaraju *et al.*, 2008).

Studies have indicated skin-collagen content increased and elastic fibers destroyed. Additionally, muscular layers of the arteries revealed an intense thickening, with a strong hypertrophy of individual muscle cells without intimal fibrosis. With electron microscopy it was distinguished that a thickened perineurium with an increase in fibroblasts and collagen was present (Noël, 2000).

Neurological and circulatory disturbances probably occur independently by unrelated mechanisms. Vibration could directly injure the peripheral nerves, nerve endings and mechanoreceptors, producing symptoms of numbness, tingling, pain and reduced sensitivity (Suani *et al.*, 2009).

Peripheral neurological effects of vibration may not only be restricted to the upper limbs, vibration of the lower limbs may produce similar effects. Similarly, vibration of other parts of the body, either directly by vibration to those parts or as a result of the transmission of vibration from other areas of the body, may have the potential to cause injury to those parts (Griffin, 2007).

Currently, there is little evidence of a dose–response relationship between the exposure to HAV and neurosensory symptoms. It has been suggested that the relationship would be weaker than for VWF and not as linear as for vascular symptoms. However, the neurosensory symptoms are more complex to study because the symptoms are less defined than vascular symptoms, also various clinical conditions may simulate the sensorineural component of HAVS, which contributes to the difficulty of being studied. Especially the symptoms of carpal tunnel syndrome (CTS) are difficult to differentiate from those of HAVS. The cumulative lifetime vibration dose may be associated with VWF, sensorineural symptoms, CTS and musculoskeletal symptoms in the upper limbs and neck. However, neurological symptoms seem to be the most strongly associated with vibration dose (Suani *et al.*, 2008).

2.3.3 Hand-eye coordination

Visual control of hand movement is essential in occupational activities requiring precise manipulation. Coordination of eye and hand movements is required in these tasks. Hand vibration has been shown to alter continuous manual control and oculo-manual coordination. Studies have shown impairments of hand pointing and eye gaze and that hand and eye movements are generally more strongly affected by 100 Hz than 200 Hz vibration which show that hand vibration can affect the precision of hand movement and hand-eye coordination. They also showed that changes in performance observed during and after vibration exposure when the hand is masked underline the role of the visual feedback in vibratory environments, and persistence of the constant error of the hand movements 10 min after vibration exposure only when the hand is masked indicates that vibration may lead to a loss of the proprioceptive reference that is not compensated by a visual input (Inaba *et al.*, 1996). However, when the hand was placed in the visual field, tracking performances are less affected by vibration. These findings explicitly show that HAV can perturb oculo-manual coordination control (Martin *et al.*, 1991).

2.4 Bone and joint disorders

Vibration-induced musculoskeletal injuries affecting bone and joints have been reported in several studies. There is limited evidence that exposure to HAV and musculoskeletal symptoms of the upper extremities and neck and shoulder region are related, and only some recent studies have suggested a dose–response effect. Although the ergonomic stress caused by hand-held vibrating tools may contribute to the pain in upper limbs, the vibration exposure may be related to muscle and joint symptoms (Suani *et al.*, 2009).

Studies have shown that exposures with predominantly lower frequencies (< 50 Hz) caused a greater load on the elbow and shoulder joints than exposures with higher frequencies (> 100 Hz) did. Exposure with predominantly higher frequencies caused a greater load on the hand and fingers. Thus, it is better to use a tool that needs low grip and push forces if the tool can do the job efficiently.

It is thought that, in addition to vibration, joint overload due to heavy manual work and constitutional susceptibility play an important role in the etiopathogenesis of degenerative bone and joint disorders in the upper limbs of users of percussive tools. This effect from impact tools may be one of the contributing factors that cause the reported injuries at the elbow and wrist joints (Kihlberg, 1994).

An excess risk for wrist osteoarthritis, elbow arthrosis and osteophytosis has been reported in workers exposed to shocks and low frequency vibration of high magnitude from percussive tools. Workers who are exposed to HAV have at least a two times higher risk of CTS. It has been suggested that vibration exposure may damage the median nerve in the carpal tunnel by causing myelin breakdown and interstitial and perineural fibrosis, but nerve entrapment in the carpal tunnel is another possibility and may be related to repetitive and forceful wrist movements (Sauni *et al.*, 2009).

It should be noted that acknowledged risk factors for CTS include biodynamic, personal and demographic factors, and levels of vibratory exposure (Cherniack *et al.*, 2007). It has been shown that exposure of smooth muscle cells to cyclic mechanical strain induces cellular growth by way of the platelet-derived growth factor, the fibroblast growth factor-2, and possibly the local renin-angiotensin system. Endothelin-1 seems also to be implicated in DNA synthesis of vascular smooth muscle cells (Noël, 2000).

It has been suggested that vibration exposure may damage the median nerve in the carpal tunnel by causing myelin breakdown and interstitial and perineural fibrosis, but nerve entrapment in the carpal tunnel is another possibility and may be related to repetitive and forceful wrist movements (Suani *et al.*, 2009).

Because of the vibration interference, a higher grip force is often applied to such tools to maintain stability in performing tasks. Whereas the impact torque could directly cause injuries, the repetitive forceful actions combined with the vibration exposure could significantly increase the incidence of carpal tunnel syndrome and other injuries and disorders (Xu *et al.*, 2008).

2.5 Diagnosis of HAVS

The diagnosis of disorders caused by hand-transmitted vibration is potentially complex, requiring consideration of many factors additional to a report of the patient's symptoms and the results of tests. Even so, many users of vibratory tools are currently diagnosed from a report of their symptoms, a history of vibration exposure, and the absence of any obvious alternative explanation for their reported symptoms (Griffin, 2007).

The diagnosis of VWF is based on a positive history of cold induced episodes of finger whiteness occurring after the start of occupational exposure to hand-transmitted vibration, providing that primary Raynaud's disease or other causes of secondary Raynaud's phenomenon are ruled out (Bovenzi *et al.*, 2007). Thus, a diagnosis of Raynaud's phenomenon is basically made on a history of finger whiteness reported by the patient. It has been suggested that the reliability of the medical history depends on the patient's ability to understand the physician question properly and to report clearly the symptoms and signs which occur during a finger blanching attack (Negro *et al.*, 2007), therefore diagnosis depends on a reliable description of the symptoms given by the sufferer, for there are rarely any signs to be seen at the time of the clinical consultation (Proud *et al.*, 2003).

When compensating for the consequences of exposures to hand-transmitted vibration it is useful to distinguish between the *disease* (i.e. physiological changes induced by the vibration), the *impairment* in function arising from the disease (e.g. reduced sense of touch), the consequent *handicap* (preventing the performance of a range of possible activities), and any resulting *disability* (e.g. inability to perform a specific job and reduced earning ability) (see Fig. 1), (Griffin, 2007).

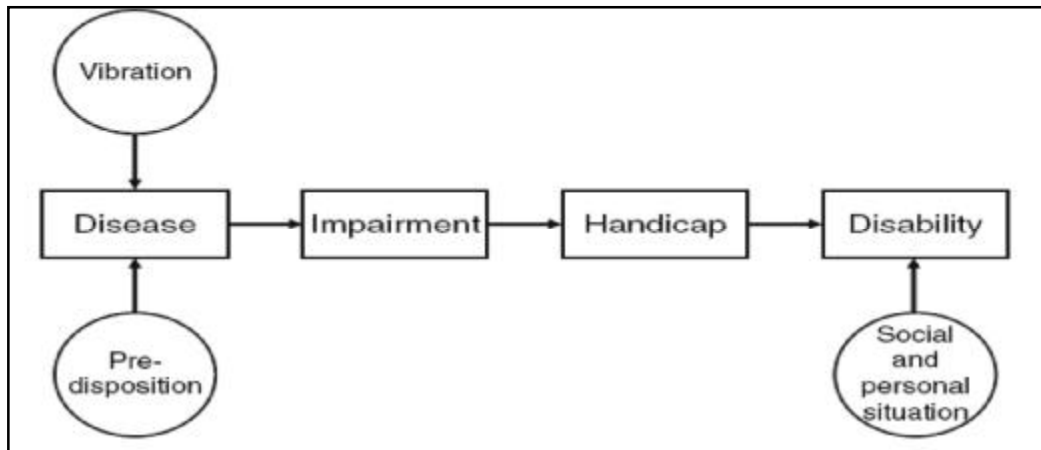


Figure 1: Description of stages from disease to disability (Griffin, 2007).

The standardized tests include finger skin temperature measurement during hand(s) immersion in cold water (FST test) and finger systolic blood pressure measurement during local cold exposure (FSBP test). Despite some discrepancies between the results with FST and FSBP tests, they are pointed out to be useful diagnostic methods in distinguishing patients with vascular injuries in HAVS (Harada & Mahbub, 2007).

For the cold provocation test, conditions favoring the induction of maximal vasoconstriction and minimal severing of the subjects have been recommended. Immersion of the hand(s) in water of less than 10°C can cause cold-induced vasodilatation or hunting phenomenon and subjects suffering pain. Cutaneous blood flow is strongly influenced by the different environmental conditions, therefore, such factors need to be controlled strictly (Harada & Mahbub, 2007).

The FSBP test method is based on detecting the circulatory impairment in digital arteries proximal to the location of sensors by identifying the extent of vasoconstriction in response to cold provocation produced by finger cooling. Systolic blood pressure in fingers is independent of age in healthy subjects not exposed to hand-transmitted vibration. Studies have indicated that the changes in digital systolic blood pressure in response to cooling are closely related with the severity of vasospasm in RP. FSBP test indicates the extent of vasoconstriction.

It is supposed that the applied 5-min cooling period during the FSBP test is short enough to escape the cold-induced vasodilatation/hunting phenomenon. Furthermore, the sensitivity and specificity of FSBP test reported in the literature is comparatively high. Considering all these, the FSBP test seems to be superior to other objective diagnostic methods in distinguishing VWF patients and controls (Harada & Mahbub, 2007). For the optimal provocation and discrimination of patients and controls, the FSBP test has been standardized, which includes reference measurement at 30°C followed by finger cooling at 15 and 10°C without or with additional body cooling (ISO, 2005).

FSBP after finger cooling is usually measured using strain gauge plethysmography, photoelectric plethysmography or laser-Doppler method. Most of the available studies on vibration-exposed subjects reported measurement of digital circulation by using plethysmography. Though FSBP test appears to be helpful in distinguishing VWF patients from healthy controls, recent research has questioned the diagnostic power of FSBP for the vascular component of HAVS. To identify patients with RP, cooling-induced FSBP responses of digital arteries have been suggested as a useful method over a long period of time. The test of FSBP measurement with simultaneous measurements on multiple test fingers using the thumb of the test hand as the reference seems to be a useful objective method in diagnosing vascular injury of HAVS patients. As there is no single test with satisfactory diagnostic performance for VWF, it is reasonable to use the cold provocation tests as a part of comprehensive approach to evaluate HAVS patients, also comprising neurological tests together with medical interview and physical examination. From the available and credible research literature, the FSBP test appears to be a useful laboratory test for diagnosing VWF (Harada & Mahbub, 2007).

2.6 Measurement of vibration magnitude

Various standards, guides and research reports suggest how the consequences of exposures to hand-transmitted vibration depend on the magnitude of vibration and the duration of exposure. Some of these documents have been produced with the express purpose of influencing employers to take precautions to reduce the risks from hand-transmitted vibration.

However, the science underpinning current understanding of the factors influencing the development of disorders caused by hand-transmitted vibration is weak (Griffin, 2007).

The conventional method for the measurement and risk assessment of hand-transmitted vibration exposure has been standardized (ISO, 2001). This method requires measuring the vibration on a tool in the hand contact or grip areas using tri-axial accelerometers. Whereas the acceleration spectra or vibration values measured with the conventional method in the dominant vibration axis have been reported, little information on the vibration in the other axes or the total vibration spectra can be found in the literature. The reported tool acceleration spectra may reasonably represent the vibration hazard at the hand–tool interface, but they could be significantly different from that actually transmitted to each anatomical structure of the hand-arm system (Xu *et al.*, 2008). HAV is defined as the transfer of vibration from a tool to a worker’s hand and arm. The amount of HAV is characterized by the acceleration level of the tool when grasped by the worker and in use. The vibration is typically measured on the handle of tool while in use to determine the acceleration levels transferred to the worker (ISO, 2005). Because the transmitted vibration is likely to be more closely associated with the vibration-induced health effects, it is important to characterize and understand the transmitted vibration. Whereas the vibration transmissibility in the hand-arm system excited from a single-axis vibration exciter has been studied in controlled laboratory conditions by many researchers, the characteristics of multi-axis vibration transmissibility, especially those under real working conditions, have not been sufficiently investigated. Little information on the vibration transmitted to the hand-arm system during the operations of impact wrenches is available. Although the ISO frequency weighting for the risk assessment is established based on subjective sensation data that must be influenced by the transmitted vibration, the exact relationship between the ISO-weighted acceleration and the acceleration at a specific location of the hand arm system has not been sufficiently investigated (Xu *et al.*, 2008).

Almost all hand-held vibrating tools can affect the vascular, sensorineural, and musculoskeletal structure of workers' upper limbs (Yoo *et al.*, 2005). Vibration power absorption into the hand–arm system is one of the most important biodynamic measures that can be used to quantify the vibration exposure for assessing its potential effects. Although the exact relationship between the amount of absorbed power and the cell or tissue damage remains unknown, the vibration power absorption can be simply regarded as a physical measure of vibration-induced mechanical stimulus that acts directly on the cells and tissues (Dong *et al.*, 2007).

Many epidemiological studies reported that the vibration exposure duration was an essential factor associated with HAVS (Xu *et al.*, 2008). The ISO-standardized method also requires quantifying both daily and life-time exposure durations for the risk assessment (ISO, 2001). The durations have usually been estimated on the basis of the workers' claims of exposure duration, which may not be considered reliable. Several studies reported that workers tend to overestimate the exposure duration (Xu *et al.*, 2008).

Mechanical vibrations in a machine are caused by the moving components of the machine. Since a machine may consist of many such moving components, the overall vibrations transmitted to the human body in contact with the machine are made up of vibrations of different frequencies occurring simultaneously. Human response to vibration is highly dependent on the frequency of vibration. In the ISO 5349 recommendations, the most important quantity used to describe the magnitude of the vibration transmitted to the operator's hands is root-mean-square (rms) frequency weighted acceleration expressed in m/s². The frequency weighted vibration is expressed as:

$$a_{h,w} = \left[\sum_{j=1}^n (k_j a_{h,j})^2 \right]^{1/2}$$

where k_j is the weighting factor for the j^{th} octave; $a_{h,j}$ is the rms acceleration measured in octave bands used in m/s², and n is the number of frequencies used in the octave band.

The weighted value should be determined over the eight octave bands (i.e., $n = 8$) from 8 to 1000Hz or over the 24 one third octave bands (i.e., $n = 24$) from 6.3 to 1250 Hz. The one third octave band is very common and is adopted in the ISO 5349-1 (2001).

2.7 Measurement of vibration transmitted to the exposed worker

Exposure of humans to HAV is complex. Vibration occurs in three translational axes. The vibration frequencies may extend over a wide range. The vibration received by an operator depends on his technique and varies according to the dynamic response of his fingers, hands and arms (Dewangan & Tawari, 2008).

The evaluation of vibration exposure in accordance with ISO 5349 is based on a quantity that combines all three axes. This is the vibration total value a_{hv} (vector sum) and it is defined as the r.m.s of the three component values:

$$a_{hv} = \sqrt{(a_{hwx})^2 + (a_{hwy})^2 + (a_{hwz})^2}$$

where a_{hv} is the total rms acceleration in the handle in m/s^2 ; a_{hwx} is the rms acceleration in the X-axis in m/s^2 , a_{hwy} is the rms acceleration in the Y-axis in m/s^2 , and a_{hwz} is the rms acceleration in the Z-axis in m/s^2 . Therefore, the vector sum of vibration intensity is virtually independent of the orientation of the coordinate system (Dewangan & Tawari, 2008).

A convenient and reliable direct reading method for monitoring the exposure at workplaces is also desired to help achieve effective control of the vibration exposure. Because the accelerometers and their fixtures required in the standardized measurement method must occupy some space in or near the hand contact areas, they could interfere with the hand grip and wrench operation. Such interference may be tolerable if the measurement lasts for a short period of time, but continuous interference may annoy and unsafely impede the tool operator (Xu *et al.*, 2008).

It is known that the vibration entering the hand contains contributions from all three measurement directions. Therefore, the measurement should preferably be made for all three directions simultaneously. Fig. 2 illustrates an anatomical and basicentric co-ordinate system for measurement of hand–arm vibration exposure as defined in ISO 5349-1 (2001) (Dewangan & Tawari, 2008).

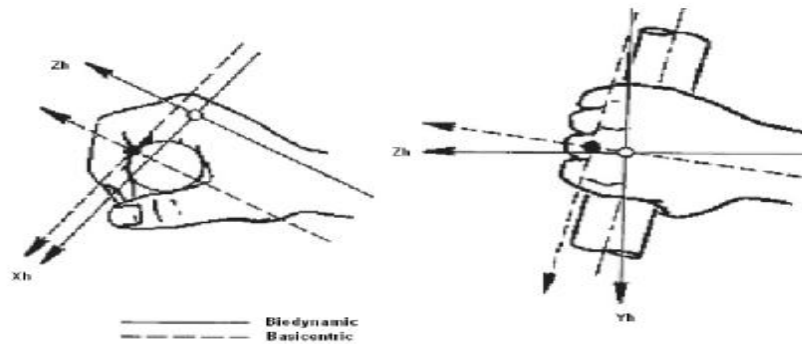


Figure 2: Basicentric co-ordinate system of the hand (ISO, 2001).

In practice, measurements are usually obtained with respect to a basicentric co-ordinate system centered on (or adjacent to) the vibrating surface. The coordinate system will then be defined as (ISO 5349-1, 2001): Z-axis, directed along the third metacarpus bone of the hand; X-axis, perpendicular to the palm surface area (both these axes are normal to the longitudinal axis of the grip); and Y-axis, parallel to the longitudinal axis of the grip (Dewangan & Tawari, 2008).

Vibration-induced damage to the hands is proportional to the vibration dose received; various standards define harmful exposure. “Safe” levels of vibration are described in ISO 5349-3, in which the frequency weighted acceleration level does not reach 1 m/s^2 . When a vibration dose is 2.8 m/s^2 or more for an 8-h working day – the A(8) figure “action” level has been exceeded. The 4-h value A(4) equivalent to this A(8) figure is 3.9 m/s^2 . Medical surveillance should be implemented at these levels. The action level should not be confused with the safe level. Tools used in the mining industry often lie at high frequency weighted acceleration levels (Proud *et al.*, 2003).

The European Union (EU) Commission has suggested exposure levels for hand-transmitted vibration within the proposal of a directive for the protection of workers from the risks arising from physical agents. In the proposal of the EU directive the exposure levels are expressed in terms of A(8) and the threshold level is established at 1 m/s², the action level, at 2.5 m/s², and the exposure limit value, at 5 m/s²; (Bovenzi, 1998).

2.8 Possible measures to eliminate/minimize the effect of HAV

Ideally, all risks from hand-transmitted vibration would be eliminated. There is no known safe exposure to HTV, so the elimination of all risks is only possible if all work involving hand-transmitted vibration is eliminated, either by introducing machinery that eliminates human contact with vibration or by eliminating the need for work involving hand-transmitted vibration. Where a job requires exposure to hand-transmitted vibration, the risks can be reduced by reductions in vibration magnitude (by tool selection and maintenance, and tool operation), by reductions in exposure duration (by rotation of work or the imposition of exposure limits), and by other methods (Griffin, 2007).

Vibration power absorption into the hand–arm system is one of the most important biodynamic measures that can be used to quantify the vibration exposure for assessing its potential effects. Although the exact relationship between the amount of absorbed power and the cell or tissue damage remains unknown, the vibration power absorption can be simply regarded as a physical measure of vibration-induced mechanical stimulus that acts directly on the cells and tissues. The vibration power absorption can take into account not only the vibration hazard measured on a tool but also the physical response of the hand–arm system. The effects of some of the influencing factors, such as hand and arm postures, applied hand forces, and tool handle sizes, can also be automatically reflected in such a measure. Therefore, the use of vibration power absorption of the entire hand–arm system has been advocated to assess the risk of the most common hand–arm vibration syndrome component: VWF.

It has also been suggested that the total vibration power absorption could yield a better estimate of exposure than the ISO frequency weighted acceleration for risk assessment of hand-transmitted vibration (Dong *et al.*, 2007).

Vibration transmitted to the operator's hand can also be reduced by modifying the mass and stiffness of handles. The performance of an isolator is judged by its elastic stiffness and damping coefficient which determines the transmissibility characteristics of the isolators. The isolation characteristic under dynamic conditions varies with the amplitude and frequency of excitation (Tewari & Dewangan, 2009).

Reducing the magnitude of the vibration transmitted from a tool to the hand has been viewed as a potential effective approach to prevent hand–arm vibration syndrome. In recent years, anti-vibration gloves have been increasingly used to help minimize vibration exposure for tool operators. The effectiveness of these gloves, however, has not been well studied. Such knowledge is required to develop guidance regarding whether to recommend these gloves as well as for the proper selection and use of these gloves (Dong *et al.*, 2007).

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1. Schneider T. Improving exposure assessment requires measurements and modeling [editorial]. *Scand J Work Environ Health*. 2002;28:367-70.
2. Ketola R, Toivonen R, Häkkänen M, Luukkonen R, Takala E-P, Viikari-Juntura E, *et al*. Effects of ergonomic intervention in work with video display units. *Scand J Work Environ Health*. 2002;28:18-24.

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5. Miettinen OS. Theoretical epidemiology in evolution, 1972-2002. In: Nurminen M, editor. 30 years of epidemiology for the benefit of occupational health: proceedings of the symposium, Sven Hernberg symposium. Helsinki: Finnish Institute of Occupational Health; 2002. p 25-9. People and work research reports, no 50.

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CHAPTER 3
Article

Exposure to hand-arm vibration and its effects on workers at a mine rock drill repair and maintenance workshop

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ABSTRACT

Objectives: To determine the amount of Hand-arm Vibration (HAV) workers at a mine rock drill repair and maintenance workshop are exposed to through the use of pneumatic impact wrenches, and if their vibration exposure exceeds that of the recommended exposure limit values (ELV's). Also, we investigated the possible neurological, vascular and musculoskeletal effects the vibration has on the hand-arm component of the operators.

Methods: HAV was measured in accordance with ISO 5439. Manipulative dexterity, grip force and hand-eye coordination tests were performed on workers and their selected controls. Finger systolic blood pressure (FSBP), was measured according to ISO 14835-2, 2005. The results were statistically analysed for acute and long term influences.

Results: Three workers have values above the suggested ELV of 5 m/s^2 for an eight hour A (8) workday. Workers were capable to manipulate small objects better with their dominant right (vibration exposed) hand after work than before work. In contrast, it seems that the number of pegs correctly inserted by the controls is not uniformly affected by their 8 hour workday. The worker group showed a greater grip force than that of the control group, both before and after work. There was a statistically significant difference between the control and worker group with respect to the number of mistakes during the mirror trace and the time to complete this test *only* for the right hand. The difference in finger systolic blood pressure (FSBP) after cold provocation between the control and worker group observed is of medium importance when compared with effect sizes, however, there was no statistical significant difference.

Conclusions: There is a difference between the two groups with respect to grip force, hand-eye coordination; dexterity and FSBP after cold provocation. Due to the limitation of a small sample size, it is difficult to make valid conclusions. A longitudinal study should be conducted preferably using newly appointed workers with no prior exposure to vibration and a sufficient control group to eliminate the effect of other confounding variables such as general working conditions.

Keywords: Pneumatic impact wrenches, Vibration induced white finger (VWF), Finger systolic blood pressure (FSBP), dexterity, hand-eye coordination, grip force.

INTRODUCTION

In several occupations, exposure to hand-transmitted vibration (HTV) caused by the use of vibrating hand tools over a prolonged period causes various disorders, collectively known as hand-arm vibration syndrome (HAVS) (1). HTV could even cause permanent damage to nerves, blood vessels, muscles and bones in the upper limbs of exposed workers and may cause acute effects such as elevated blood pressure and changes in peripheral vascular contraction (2).

These health effects from vibration by the use of vibratory tools may be divided into two types. The first is the direct effect of vibration on the peripheral tissues exerted by conductance of the vibration. The second is the effect exerted through the nervous system by the impulse generated from a peripheral neurotransmitter receptor under vibration stimulus. Additionally, certain factors in tool usage (weight, noise, and cold) enhance both of these effects (3). A significant topic with regard to the cause of HAVS is whether or not the second effect has an influence on the function of the sympathetic nervous system. Research on the postsynaptic effects has made it clear that the direct effect of vibration on blood vessel walls serves to enhance the noradrenaline (NA) reactivity in the peripheral vessel smooth muscle (4). The fact that the key focus in studies is on the pre-synaptic effect is confirmation of the existence of the influence mediated by the sympathetic nerve centres (5).

Neurological symptoms may cause a greater disability than vascular symptoms and may also remain after exposure has ceased, whereas the vascular symptoms decrease after reduction of exposure with a reversion to normal circulatory status. Therefore, neurological symptoms should be evaluated at an early stage (6).

HAVS, also known as vibration-induced white finger (VWF) is a secondary form of Raynaud's phenomenon and is of occupational origin (7). The mechanisms responsible for the pathology of VWF are still evolving and the precise pathophysiological mechanisms responsible are not yet fully understood or clarified, it is highly complex and several factors contribute to the development of VWF. An increase in sympathetic activity, along with exaggerated vasoconstrictor responses of digital vessels to cold and vasodilatory mechanisms have been implicated in the pathogenesis of VWF. Interaction between neural signals, hormones, mediators and changes in the blood vessel itself contribute to the development of such vascular injuries (1).

The vascular component is controlled by the autonomic nervous system as well as by functional and histological changes in the smooth muscles of blood vessels. If circulation of blood and tissue fluid in perineural and neural tissues is disturbed, neurologic disturbances may increase. Nocturnal pain and tingling of hands and arms may be due to increase of inner pressure from stagnation of tissue fluids at night (5). Neurologic changes appear alone without blood circulatory disturbances in the early stage. In severe cases these take the form of polyneuropathy of the glove and stocking type (loss of sensation compared to the feeling of wearing a thin glove or stocking) which is promoted by a repeated decrease in blood flow over a long time (8).

The main vascular symptom observed in HAVS is blanching of the fingers especially in response to cold (9). Acute inflammation in the fingers and hands may occur after heavy use of vibrating tools, and with continued use of vibrating devices, chronic vascular symptoms characterized by episodic vasospasm and blanching of the fingers during exposure to cold or even emotional stress may occur. As the condition progresses, vasospasms may even occur at room temperature (10).

Changes in finger systolic blood pressure (FSBP) with cold provocation have been shown to be related to finger blanching. It has been shown to have high specificity, suggesting that it may be a useful diagnostic test in ruling out vascular abnormality, but its sensitivity has tended to be lower, suggesting that it may not be suitable as a screening tool (11).

From a study of biopsies in fingers of patients, the pathologic picture of finger skin in vibration syndrome has been reported as follows: The main characteristic changes lie in three tissues: the blood vessels, nerves, and connective tissues. First, muscular layers of the arteries revealed intense thickening with hypertrophy of individual muscle cells without intimal fibrosis. Periarterial fibrosis was also noted. Arteriosclerosis with foamy cells, lipid deposition, and fibrous sclerosis were occasionally observed. The second main feature was demyelinated neuropathy in the peripheral nerves in which a marked loss of nerve fibres had occurred. There was also an increase in the number of Schwann cells and fibroblasts with strong collagen formation. Severe loss of myelin sheath frequently occurred, and relatively smaller axons without myelin, which appeared to have regenerated, were observed. Perineural fibrosis was also noted, forming an onion-layer shape.

The third main change was increased connective tissues with collagen, not only in the perivascular and perineural lesions, but especially in the dermis of the skin. The elastic fibres there were often destroyed. The combination of these three principal pathologic changes is useful for the histopathologic diagnosis of vibration syndrome. These changes explain well why the skin temperature is lower even in warm weather and why the skin sensation threshold is higher for a long period in the recovery stage (5).

The main musculoskeletal and neurological symptoms experienced by patients with HAVS include numbness in the hands, weakened grip in the hands, changes in sensory perception as well as loss of manual dexterity (12). Decreased muscle power of the hand may be due to neurogenic changes of motor nerves (5). Affected workers have reported difficulties in manipulating small objects or executing simple actions as writing or buttoning and unbuttoning clothes (12). Vibration-induced musculoskeletal injuries affecting bone and joints have been reported in several studies. There is limited evidence that exposure to HAV and musculoskeletal symptoms of the upper extremities and neck and shoulder region are related, and only some recent studies have suggested a dose–response effect. Studies have indicated that neurological symptoms seem to be the most strongly associated with vibration dose (13).

Although the ergonomic stress caused by hand-held vibrating tools may contribute to the pain in upper limbs, the vibration exposure may be related to muscle and joint symptoms (13). Change in the elbow joint may also appear which is characterized by limited stretching of joints, and is sometimes painful (14).

There has been little work published investigating the impact of HAVS on performance of everyday activities. The effects of HAVS on functionality and quality of life may be important in not only determining an individual's ability to continue in their current job but also their appropriate functioning in home and social life (9). Disability depends on the impact of disease on the current and future employment of individuals and their leisure activities (15).

Sufferers of HAVS probably represent the largest group of workers in the world claiming compensation for any single industrial disease or injury (16). In developed countries the costs for compensation, treatment and other indirect costs associated with these disorders are high (1).

It has also been shown that workers are not aware that levels of vibration transmitted to their hands exceed safe limits, which represents an additional risk. Workers exposed to HAV should at least be informed about the damaging effects that these vibrations can have to the nerves, muscles, bones and joints in the upper extremities (17).

Various standards, guides and research reports suggest how the consequences of exposures to HTV depend on the magnitude of vibration and the duration of exposure. Some of these documents have been produced with the express purpose of influencing employers to take precautions to reduce the risks from hand-transmitted vibration. However, the science underpinning current understanding of the factors influencing the development of disorders caused by HTV is weak (18).

Vibration power absorption into the hand–arm system is one of the most important biodynamic measures that can be used to quantify the vibration exposure for assessing its potential effects. Although the exact relationship between the amount of absorbed power and the cell or tissue damage remains unknown, the vibration power absorption can be simply regarded as a physical measure of vibration-induced mechanical stimulus that acts directly on the cells and tissues (19).

This study was designed to investigate the amount of HAV exposure of mine rock drill repair and maintenance workers that use pneumatic impact wrenches during their daily work activity. Further, this study aims to identify possible symptoms of HAVS, and to identify if exposure to vibration has caused vascular, musculoskeletal and neural influences in workers exposed to vibration during their work duties. This will be tested by using test methods such as measurement of the Finger Systolic Blood Pressure (FSBP) during cold provocation, dexterity tests, hand-eye coordination and grip force tests.

MATERIAL AND METHODS

Experimental design

The work group was situated in a workshop where rock drills used in underground mining are repaired and serviced. These rock drills go through a wash process, where after they are stripped (using pneumatic impact wrenches), parts are replaced (if need be) and then put together again (using pneumatic impact wrenches).

Each worker (W) numbered 1-8, had a specific control (C) person selected according to age, BMI, race, gender and smoking habits also numbered 1-8. The control group consisted of employees that were not exposed to vibration during their routine daily activities in their occupations. Before commencement of the study each of the participating workers and control persons was informed on the duration of the study, the study goals and objectives as well as their roles. Each worker and control gave their written consent.

The study was a cross-sectional study in which tests/measurements to determine possible signs of HAVS were conducted. Measurements such as FSBP after cold provocation of workers and additionally other factors (i.e.; dexterity, grip force and hand-eye coordination) were measured before and after work for both workers and controls whilst simultaneously measurements of exposure to the disease cause (vibration exposure) on workers was measured. Hence, each participant served as its own control to measure the acute effect and influence of vibration. The worker group was also compared to the control group to determine the long term effects of vibration.

Medical questionnaire

Each worker and control was interviewed and a screening questionnaire on symptoms of white finger episodes, numbness and tingling of the hands, decreased grip force or manual dexterity, or musculoskeletal symptoms of the upper extremities, neck or shoulder, current exposure to HAV, as well as personal data of workers and controls were answered by each subject. This data (age, ethnic group, number of years in occupation, current medication etc.) were used for reporting purposes (Questionnaire included in the Addendum).

Measurement of hand- arm vibration

In this study a Quest *HAV pro* vibration monitor was used. The vibration produced by the pneumatic impact wrenches was determined by attaching the accelerometer to the handle of the tool (see Figure 1) according to the procedure described in ISO 5349-1, 2001 (20). The operator was then required to use the tool under normal working conditions as described by the ISO 5349-2, 2001 (see Figure 2). Work tasks included: Tightening and loosening of pressure rods, rock-drill nuts, and valve control bolts. The root-sum-of-squares of the frequency-weighted r.m.s. acceleration values for the x-, y- and z-axes (a_v) was calculated for each tool and the associated task. Daily vibration exposure was assessed in terms of 8-h energy-equivalent frequency-weighted r.m.s. acceleration magnitude, $A(8)$, according to the ISO 5349-2 procedure (21).



Figure 1: Accelerometer attachment

(The accelerometer was attached to a lightweight (aluminum) mounting block by means of epoxy glue in order to insure proper response. The accelerometer and mounting block was mounted to the tool handle with a metal clamp in order to ensure that any resonance frequencies of the mounting assembly are high enough above the upper limit of the measurement frequency range).



Figure 2: Accelerometer position

(Accelerometer position during impact wrench operation as described by the basicentric co-ordinate system; the z-axis (i.e. hand axis) is defined as the longitudinal axis of the third metacarpal bone and is oriented positively towards the distal end of the finger. The x-axis passes through the origin, is perpendicular to the z-axis, and is positive in the forwards direction when the hand is in the normal anatomical position (palm facing forwards). The y-axis is perpendicular to the other two axes and is positive in the direction towards the fifth finger (thumb). In practice, the basicentric co-ordinate system is used: the system is generally rotated in the y-z plane so that the y-axis is parallel to the handle axis.)

The total daily vibration exposure for each worker is calculated according to the formula:

$$A(8) = \sqrt{\frac{1}{T_0} \sum_{i=1}^n a_{hvi}^2 T_i}, \text{ where}$$

T_0 is the reference duration of 8 hours (28800s), T_i is the exposure time to vibration, and n is the number of operations.

The estimated vibration total value is given by

$$a_{hvi} = \sqrt{a_{hwxi}^2 + a_{hwyi}^2 + a_{hwzi}^2}, \text{ which is calculated from the measured acceleration of}$$

the vibration in the x, y, and z direction of the basicentric co-ordinate system.

In order to determine the combined total daily vibration exposure where a worker performs different tasks the following formula was used:

$$A(\mathbf{8}) = \sqrt{\sum_{i=1}^n A_i^2(\mathbf{8})}$$

Manipulative Dexterity

Manipulative dexterity was investigated by means of the Lafayette pegboard testing method (see Figure 3). The test was administered according to a standardized test procedure according to the protocol for epidemiological studies of hand-transmitted vibration (15). Prior to performing the test, the conductor explained how to perform it, using standardized verbal instructions and a quick demonstration. The subject had the possibility to practice before the beginning of the test. Starting with the preferred hand, the subject had to pick up pins from a cup on the corresponding side of the board and place as many pins in the holes as possible within 30 seconds. The subject completed the test once for each hand and once for both hands together. Manipulative dexterity was scored on the basis of the number of pegs placed in the holes with the dominant and non-dominant hands as well as with both hands together, each picking up one pin at a time.



Figure 3: Manipulative dexterity method

Shirt button-unbutton test: For the button-unbutton test subjects were required to stand in an upright position wearing an oversized shirt with 6 plastic buttons, each 12mm in diameter. The subjects were then asked to button and unbutton the shirt from top to bottom as fast as possible (see Figure 4). The total time taken for each button-unbutton cycle for each subject was recorded.



Figure 4: Button-unbutton test

Grip force

Grip strength was measured using a Lafayette hand dynamometer. Subjects stood in an upright position with the arms in a relaxed position besides the body to perform the grip force test (see Figure 5). Prior to performing the test, the purpose was explained using verbal instructions. Subjects were instructed to squeeze the dynamometer three times with each hand with a 10 second interval between each attempt. The average value of the three grip strength attempts was recorded in kilograms.



Figure 5: Grip force test method.

Hand-eye co-ordination

Subjects sat on a height-adjustable office chair to perform the hand-eye co-ordination test by means of a Lafayette Automatic mirror trace (Figure 6). The instrument was placed on a horizontal bench. A “star” was traced with an electronic pen whilst looking at the star in the mirror. The numbers of mistakes are electronically calculated and the time taken for each subject to complete the trace was noted.

Prior to performing the test, the purpose was explained using verbal instructions. Subjects were instructed to use each hand separately to trace on the “star” whilst looking in the mirror. A practice was performed with each hand prior to the test. The test was completed once for each hand.

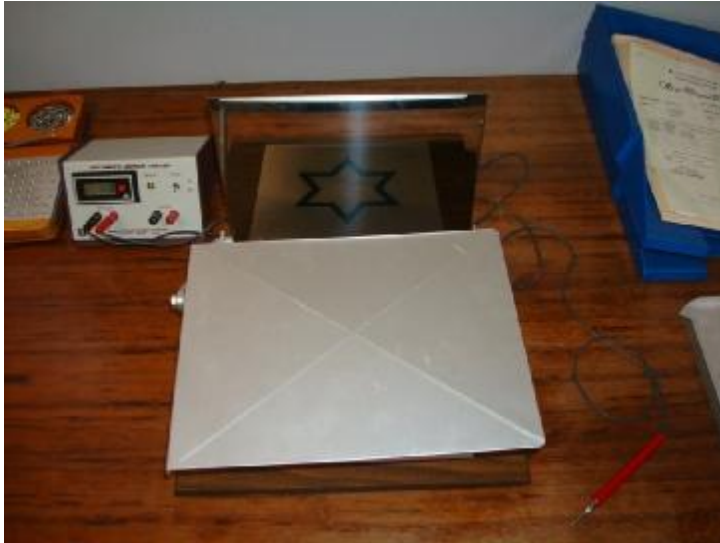


Figure 6: Automatic mirror trace for hand-eye co-ordination.

Cold provocation and finger systolic blood pressure (FSBP)

Studies have indicated that the changes in digital systolic blood pressure in response to cooling are closely related with the severity of vasospasm in VWF (1). Cold provocation was done and FSBP measured in accordance with ISO 14835-2:2005 (22). Assessing FSBP before and after local cooling can help to identify the presence and extent of vasoconstriction of the digital arteries in response to cold provocation produced by appropriate finger cooling.

A low FSBP following local cooling compared to that measured before cooling can indicate digital arterial vasoconstriction caused by an exaggerated response to cold. The amount of any change in FSBP following local cooling can reflect the degree of arterial vasoconstriction.

In this study we selected the middle finger (test finger) of the subjects' most vibration exposed hand in accordance with ISO 14835-2:2005 (22). The test finger was tested in each subject for signs of peripheral vascular damage. At the proximal phalanx of test finger a pressure cuff was fitted which was connected to a blood pressure monitor. On the middle phalanx of the test finger a cooling cuff was fitted which was connected to a pump that could supply water (from water baths set at 30°C and 10°C) at a constant flow rate. The distal phalanx of the test finger was connected to an infrared plethysmograph which sent the data to a computer.

In order to obtain a reference reading a Finometer was used. The thumb only has two phalanges and its blood circulation is hardly modified by vascular disorders; Raynaud's phenomenon typically does not affect these fingers (23), thus in accordance with ISO 14835-2:2005 the thumb was used as the reference digit.

According to ISO 14835-2:2005, it is not known if daily variations have a significant effect on FSBP, for this reason examinations took place between 09:00 and 18:00 in order to have avoided potential effects of circadian biorhythm.

Measurement

A typical measurement consists of applying an occluding pressure of 50 mmHg above the subject's arm systolic pressure (provided by the Finometer) to the proximal phalanx of the test finger (Figures 7). Thereafter water at 30°C was pumped through the cooling cuff at a constant flow rate around the middle phalanx of the test finger for a period of 5 minutes. Thereafter the pressure was reduced at a constant rate of 2 mmHg/ s and at the moment when blood flow was detected by the plethysmograph the pressure reading was noted (see Figure 8). This process was repeated with a cold water temperature of 10°C. During these measurements the Finometer provided the reference pressure readings in the subjects' thumb in order to compensate for any changes in FSBP that is not related to the test procedure.



Figure 7: Plethysmography method.

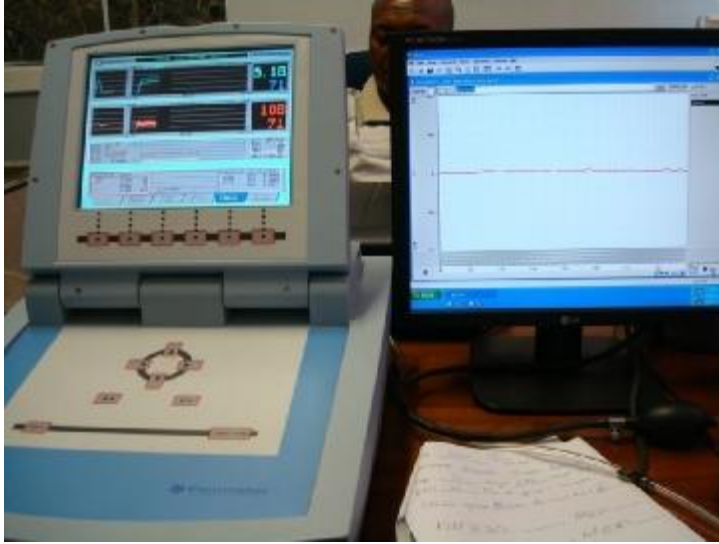


Figure8: Finometer and plethysmograph display.

In order to assess the extent of peripheral vascular damage the percentage of change in FSBP between the tests conducted at 30°C and 10°C respectively had to be calculated.

The percentage FSBP at 10°C was calculated as follows:

$$F_t = \frac{F_{test,10^{\circ}C}}{(F_{test,30^{\circ}C} - (S_{ref,30^{\circ}C} - S_{ref,10^{\circ}C}))} * 100, \text{ where}$$

F_t is the percentage FSBP at 10 °C;

$F_{test, 10^{\circ}C}$ is the FSBP of the test finger after thermal provocation at 10 °C;

$F_{test, 30^{\circ}C}$ is the FSBP measured on the test finger after thermal provocation at 30 °C;

$S_{\text{ref}, 30^{\circ}\text{C}}$ is the systolic blood pressure measured at the reference site after thermal provocation of the test finger at 30 °C;

$S_{\text{ref}, 10^{\circ}\text{C}}$ is the systolic blood pressure measured at the thumb as the reference site after thermal provocation of the test finger at 10 °C.

Statistical methods

The following statistics were calculated: mean, median, and standard deviation. For graphical representation box plots and line plots were used.

To compare the initial state of the groups, independent sample t-tests and the non-parametric Mann-Whitney test were performed using the pre-work data. The t-test and Mann-Whitney test were performed at a 10% level of significance, on recommendation of the statistician. If statistical significance was observed the practical significance was also calculated in the form of an effect size. Effect sizes were calculated as follows:

$$d = \frac{|\bar{X}_1 - \bar{X}_2|}{\max(S_1, S_2)}$$

where \bar{X}_i represents the mean and S_i the standard deviation of group i .

To compare the medians $r = Z/\sqrt{n_1 + n_2}$, was used, where n_1 and n_2 are the group sizes and Z is the standardized value of the normal approximation of the Mann-Whitney test statistic. The reader is referred to Steyn & Ellis (2003) and Field (2005) for a discussion of the above mentioned effect sizes.

These effect sizes can be interpreted on the following scale:

d: small <0.2 ; medium ≈ 0.5 ; large >0.8

r: small <0.1 ; medium ≈ 0.3 ; large >0.5

Hence, the effect size of 0.8 and 0.5 represent a practically important difference between the two groups in terms of mean and median respectively.

To compare the groups with respect to influence of their workday a paired sample t-test was used followed by a Mann-Whitney test on the differences of after work – (minus) before work data. Effect sizes were again calculated as described above but by using these differences as input values.

All statistical analysis was performed using IBM SPSS Statistics version 21.

RESULTS

Table 1: Demographic characteristics of the workers and controls.

	Controls (n=8)			Workers (n=8)		
	Mean	Median	Std Dev	Mean	Median	Std Dev
Age	38.12	36.5	7.52	38.75	38	7.55
BMI	24.62	22.5	4.8	24.25	23	3.95
Years of HAV exposure	•	•	•	10.25	4	10.47

Daily vibration exposure

The total daily vibration exposure [A(8)] and all accompanied data for each worker in the study population are presented in Table 2 on the following page. Each work cycle was measured for a period of at least 60 seconds to ensure an averaging time (Ti) of greater than 60 seconds, where TPR-Tightening pressure rod; LPR- loosening pressure rod; LRD-Loosening of rock drill nut; TRD-Tightening of rock drill nut; LVC- Loosening of valve control; TVC- Tightening of valve control.

Table 2: Total daily vibration exposure (A8) for each worker- W1 to W8.

WORKER	TASK	RMS X (m/s ²)	RMS Y (m/s ²)	RMS Z (m/s ²)	a _{hvi} (m/s ²)	T _i (s)	A(8) (m/s ²)
W1	TPR	9.81	86.2	14.3	87.62	80	6.72
	LPR	8.83	64.52	21.73	68.48	100	
	TVC	9.06	35.23	8.2	37.19	60	
	LVC	9.25	38.36	11.73	41.05	80	
W2	TPR	11.99	107.05	13.13	108.22	80	9.45
	LPR	11.86	121.91	13.4	123.07	100	
	TVC	6.11	23.6	8.36	25.69	60	
	LVC	6.52	28.25	14.33	32.22	80	
W3	TRD	5.36	38.57	8.49	39.79	240	3.63
W4	TRD	6.34	9.62	9.15	14.65	240	1.34
W5	LRD	11.66	14.87	14.36	23.66	320	2.49
W6	LRD	6.4	7.38	9.35	13.49	80	1.08
	TRD	9.66	8.96	11.91	17.71	60	
W7	TPR	6.59	53.89	26.3	60.14	80	3.74
	LPR	4.18	4.46	5.02	7.89	100	
	TVC	8.16	37.9	9.92	39.9	60	
	LVC	6.13	5.26	8.39	11.61	80	
W8	LRD	7.36	50.57	7.39	51.47	320	5.43

From Table 2 it is evident that each worker has a specific designated task(s), therefore some workers only do one task repeatedly during the workday, and other more than one task. From Table 2 it is also evident that three workers namely; **W1**, **W2** and **W8** had an A(8) HAV exposure above the suggested exposure limit value (ELV) of 5 m/s², for the measurements taken at the time. Furthermore, the data show a value greater than the exposure action value (EAV) of 2, 5 m/s² for workers **W3** and **W7**.

In the following section the control group and the worker group will be compared in two ways: First, the groups will be compared before work. Note that we did not pool the before and after data for this comparison. This comparison gives us an indication of how dispersed the groups are. Secondly, the effect of an 8-hour work shift is investigated by comparing the difference between the after work and before work measurements of workers and controls. This comparison will give an indication of the effect of work during a single work shift.

Dexterity

Table 3, on the next page indicates the amount of pegs the worker and control groups could insert into the pegboard during a 30 second period before work with their left and right hands, as well as with both hands simultaneously. It also depicts the time taken to complete the shirt button-unbutton test for dexterity.

Table 3: Dexterity results

Before Work		Controls			Workers			Mann-Whitney P-value	r	T-Test P-Value	d
		Mean	Median	Std Dev	Mean	Median	Std Dev				
Pegboard Test (pegs)	Left	11.00	11.00	1.31	10.75	11.00	1.16	0.743	•	0.693	•
	Right	12.38	12.50	2.33	11.38	11.50	2.20	0.216	•	0.392	•
	Both	16.38	16.00	3.07	13.63	12.50	2.97	0.064	0.46	0.090	0.90
Shirt BU test time (s)		24.25	25.00	3.41	28.50	26.00	7.13	0.220	•	0.159	•

Table 3 shows a statistical significant difference when referring to the Mann-Whitney ($p= 0.06$) and t-tests ($p= 0.09$) between the worker and control groups for the test of

dexterity in using both hands together to insert the pegs into the pegboard. Thus it is evident that workers had a weaker performance in not being able to insert as many pegs into the correct place when using both hands as the control group did. Also a practically significant difference of medium effect in relation to the Mann-Whitney test and a practically large significant effect when referring to the t-test is observed.

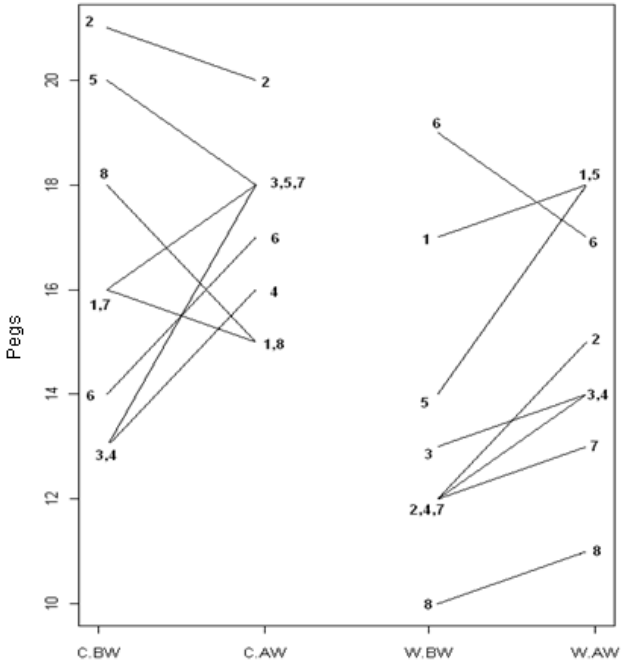


Figure 9: Schematic presentation of dexterity.

Figure 9 represents the number of pegs inserted correctly with both hands during the pegboard test for dexterity. The controls were numbered 1-8 and the workers also numbered 1-8 as a specific control was chosen for each worker. Where C.BW & C.AW = Control before and after work, and W.WB & W.AW = Worker before and after work.

When referring to Figure 9 and Table 3, it is evident that the control group had a better overall performance during this test. We can see that controls **C1, C2, C5** and **C8** had a lower score in the test after work when compared to that before work, whereas **C3, C4, C6** and **C7** had a better score. With the exception of **W6**, all the workers performed better in this test after work than compared to before work. It is evident that workers had a weaker performance in not being able to insert as many pegs into the correct place when using both hands as the control group did.

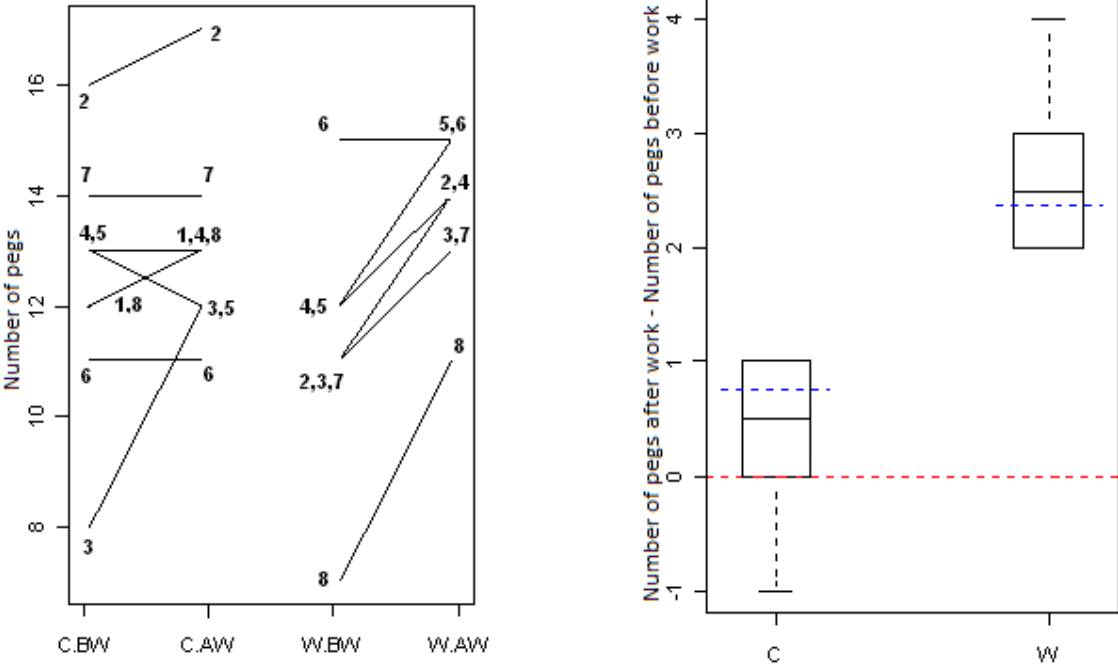


Figure 10 A and B: Before and after work comparison for dexterity.

Figure 10 A depicts the number of pegs inserted correctly within the 30 second period by the controls C(1-8) and workers W(1-8) with the right hand before and after work.

Figure 10 B is a line and box plot for pegs inserted correctly with the right hand for controls (C) and workers (W), it depicts the difference between the number of pegs inserted for workers and controls respectively. The mean of each group is overlaid on the box plot with a dotted line. Also, the zero reference line is depicted with a dotted line. Furthermore it is clear that the workers insert more pegs correctly with their right hand after work when compared to before work. In contrast, it can be seen that the number of pegs correctly inserted by the controls is not uniformly affected by their 8 hour workday (non-vibration).

Table 4: Descriptive statistics to compare the effect of vibration (8 hour exposure).

Pegboard	Controls			Workers			Mann-Whitney P-Value	r	T-Test P-Value	d
	Mean	Median	Std Dev	Mean	Median	Std Dev				
Left	1.25	1.00	1.04	0.63	1.00	1.60	0.579	•	0.369	•
Right	0.75	0.50	1.49	2.38	2.50	1.19	0.033	0.53	0.030	1.09
Both	0.75	0.50	2.87	1.38	1.00	1.77	0.750	•	0.609	•
Shirt BU	-1.88	-2.00	1.36	-2.13	-1.50	4.73	0.915	•	0.889	•

In Table 4 the difference between the after and before work dexterity measurements are used in order to establish if there was an influence on the workers' dexterity after vibration exposure. It is evident that there was an increase in the amount of pegs handled (better dexterity) before and after the work day, this difference is highly significant ($p = 0.03$) for the right hand of the exposed group only which indicated a positive effect of vibration over a work day.

Grip force

Table 5: Descriptive statistics for Grip Force

Before work		Controls			Workers			Mann-Whitney P-Value	r	T-Test P-Value	d
		Mean	Median	Std Dev	Mean	Median	Std Dev				
Grip force (Kg)	Left	34.75	30.00	11.75	39.79	42.67	9.27	0.318	•	0.357	•
	Right	34.00	30.00	10.70	42.83	44.50	7.27	0.059	0.47	0.074	0.83

In Table 5 it can be seen that the grip force of the control group is approximately the same for both hands. The grip force in the right hand of the workers is significantly greater ($p=0.07$) than that of the left hand. When the grip force of the two groups is compared, it is evident that the grip force of the worker group is significantly greater than that of the control group.

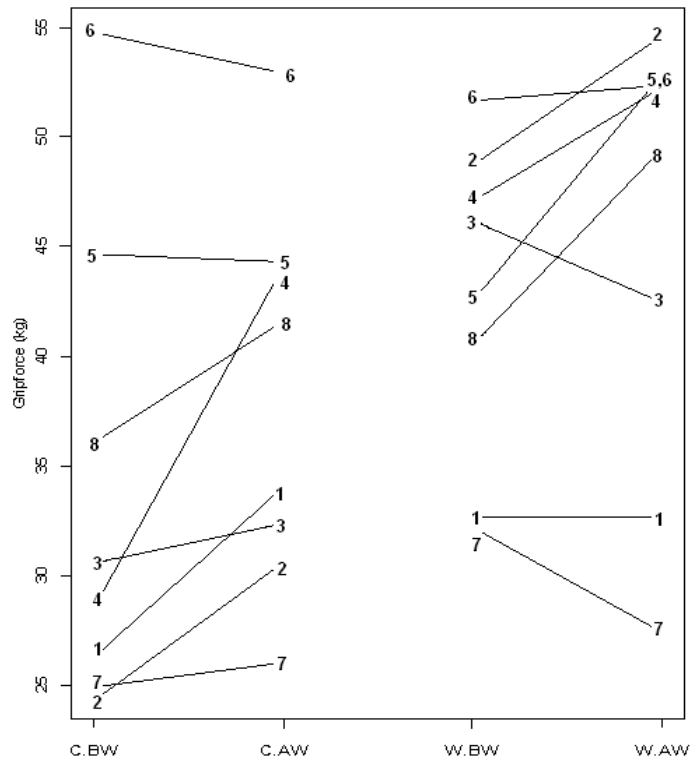


Figure 11: Performance in the grip force test for workers and controls with their right hand before and after work.

In Figure 11 it can be seen that with the exception of **C 5** and **C 6** all the subjects within the control group performed better after work when compared to before work. Similarly, with the exception of **W1**, **W3** and **W7**, all the subjects in the workers group also had a greater grip force after work when compared to that before work. Where C.BW & C.AW = Control before and after work, and W.WB & W.AW = Worker before and after work.

Table 6: Descriptive statistics to compare the effect of vibration (8 hour exposure) on the grip force of workers.

Grip force	Controls			Workers			Mann-Whitney P-Value	r	T-Test P-Value	d
	Mean	Median	Std Dev	Mean	Median	Std Dev				
Left	2.12	3.17	4.27	1.83	0.17	3.51	0.599	•	0.844	•
Right	4.04	3.33	5.04	2.54	2.67	5.07	0.600	•	0.563	•

In Table 6 above, the difference between the grip force measurements after work compared to that before work is represented. When comparing the difference no statistical significant difference can be observed.

Hand eye coordination

Table 7: Descriptive statistics for hand-eye coordination.

Before work		Controls			Workers			Mann-Whitney P-Value	r	T-Test P-Value	d
		Mean	Median	Std Dev	Mean	Median	Std Dev				
Mirror Trace (Mistakes)	Left	15.63	16.00	12.34	27.88	18.00	26.89	0.342	•	0.261	•
	Right	32.75	24.00	32.62	124.63	138.50	93.83	0.036	0.53	0.029	0.98
Time (s)	Left	55.50	39.00	34.39	73.88	54.00	50.54	0.372	•	0.410	•
	Right	92.38	84.00	61.81	244.38	294.50	152.04	0.046	0.50	0.027	1.00

Table 7 depicts the total number of mistakes made before work during the test for both the left and right hands of workers and controls respectively. Also indicated is the time taken for the two groups to complete the test in seconds. A statistical significant difference in the hand-eye coordination for the right hand of workers when compared to the control group, both for the number of mistakes during the test as well as the time taken to complete the test is observed. For both the Mann-Whitney and t-test we also observe large effect sizes.

In Figure 12 A the total number of mistakes made with the right hand during the automatic mirror trace test for hand-eye co-ordination for control persons and workers before and after work.

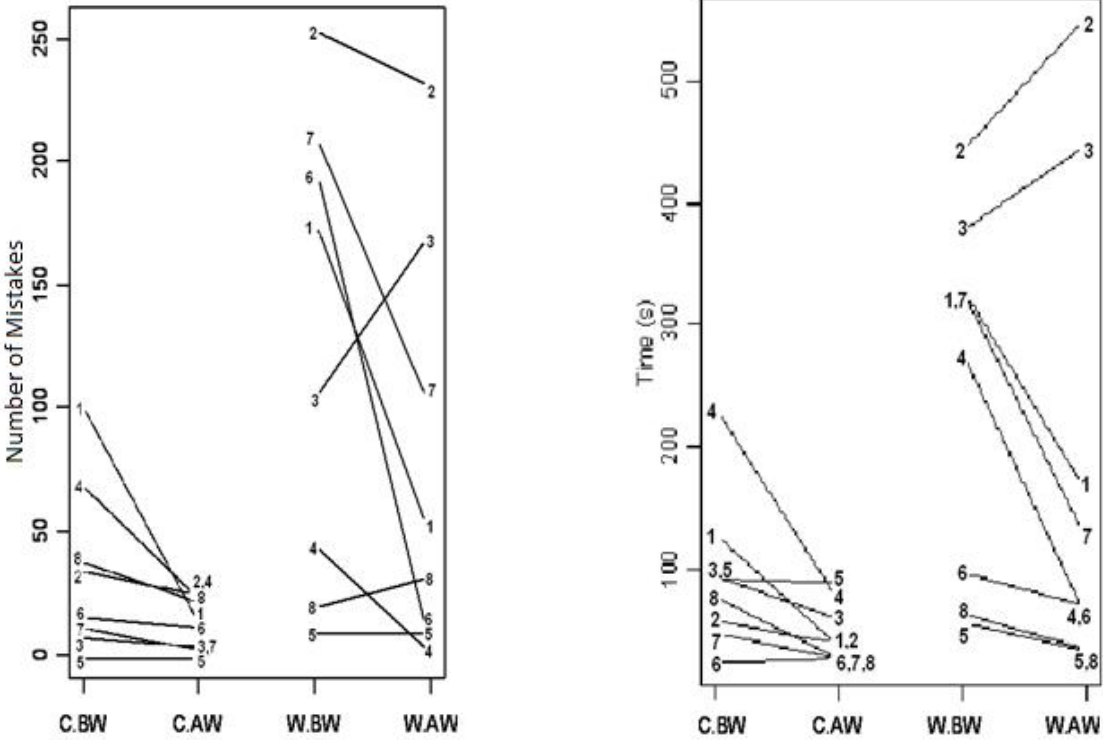


Figure 12 A and B: Hand eye coordination

Figure 12 B describes the time taken to complete the test for controls and workers before and after work respectively. From Figures 12 A, 12 B and Table 7 it is clearly evident that the worker group had an overall weaker performance in the test of hand-eye coordination when compared to the control group. This is evident in both the number of mistakes made during the automatic mirror trace and also the time taken to complete the test. Where C.BW & C.AW = Control before and after work, and W.WB & W.AW = Worker before and after work.

Table 8: Descriptive statistics to compare the effect of work.

		Controls			Workers			Mann-Whitney P-Value	r	T-Test P-Value	d
		Mean	Median	Std Dev	Mean	Median	Std Dev				
Mirror Trace (Mistakes)	Left	-1.63	-4.00	9.23	-7.50	-4.50	8.67	0.528	•	0.210	•
	Right	-19.50	-8.50	26.94	-47.75	-29.50	78.25	0.636	•	0.361	•
Time	Left	4.75	-5.00	27.46	-6.63	-3.00	17.18	0.875	•	0.337	•
	Right	-42.25	-25.50	48.62	-55.00	-26.00	110.80	0.674	•	0.772	•

When comparing the difference between the after and before work measurements for the control and work group respectively, no statistical significance was observed.

Finger systolic blood pressure

Table 9 contains the descriptive statistics necessary to calculate the percentage FSBP at 10 °C which is shown in the first row of this table.

Table 9: Finger systolic blood pressure percentage (Ft) at 10°C for workers and controls.

	Controls			Workers			Mann-Whitney P-Value	r	T-Test P-Value	d
	Mean	Median	Std Dev	Mean	Median	Std Dev				
Ft (%)	99.83	98.96	10.01	72.24	91.11	45.24	0.141	•	0.132	•
10°C	132.13	142.00	18.02	91.25	109.00	60.41	•	•	•	•
Ref 10°C	116.75	119.00	9.05	116.25	121.50	14.61	•	•	•	•
30°C	131.75	128.00	14.36	116.75	117.00	18.97	•	•	•	•
Ref 30°C	116.25	115.00	5.99	112.50	116.50	12.54	•	•	•	•

From Table 9 above we observe an overall lower percentage in FSBP of the worker group when compared to that of the control group. No statistical significance was observed with the Mann-Whitney and t-test.

DISCUSSION

Vibration

The association between VWF and occupations involving work with vibrating tools has clearly been established in epidemiology studies (24). Several investigators have reported data that indicate a trend toward an increasing occurrence of VWF with the increasing magnitude of hand-transmitted vibration, the duration of exposure, or various measures of cumulative vibration dose obtained from a combination of the vibration magnitude (frequency-weighted or unweighted acceleration) and the exposure time (years of tool use or total working hours) (25, 26).

In addition to the magnitude, frequency, and duration of vibration, other exposure variables are believed to influence the development of VWF; in particular, vibration impulsiveness, the direction of vibration, the intermittence of exposure, work methods, the contact force, and posture (27).

From our study it is evident that some rock drill repair and maintenance workers are exposed to levels of HAV exceeding the suggested ELV. Workers are continuously exposed to HAV for a period averaging 30 minutes per day, which, when calculated to an 8 hour exposure, the following was observed: out of the population of eight vibration exposed workers, three workers were exposed to levels above 5 m/s², and two workers were exposed to levels greater than the EAV of 2.5 m/s².

As it can be seen in Figure 13 derived from ISO 5349-1, 2001 (20), there is a relationship between years of exposure and vibration magnitude, in the risk of developing VWF. Although the mean exposures in years of our subjects are 10.25 years, there were only two cases of total occlusion of the finger arteries during the cold provocation test of two of the subjects.

It is important to note that although many of the workers perform similar tasks, it may not be assumed that workers are exposed to the same amounts of vibration, each worker has his own unique way of working with the impact wrench and, therefore, the amount of vibration a worker is exposed to should not be generalized in terms of the task that is being done by the worker. The assumption is that a higher quantity of absorbed energy per unit time (power) represents an increased risk of vibration injuries or reduction in comfort (28). The quantity of absorbed energy is not only influenced by vibration intensity but also by several other factors, such as frequency, transmission direction, grip force, hand-arm postures, and individual factors (29).

Additionally, it is important to note that not all the workers performed the same tasks and the amount of tasks; some of them have dedicated work stations where they only perform a specific task while others perform more than one task at their work station.

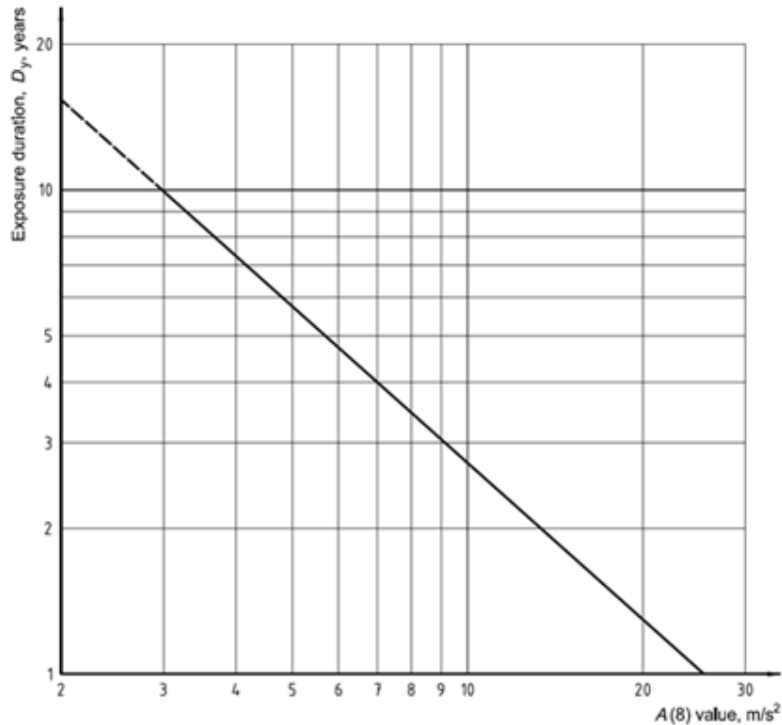


Figure 13: Vibration exposure for predicted 10% prevalence of vibration-induced white finger in a group of exposed persons derived from ISO 5349-1, 2001 (20).

Dexterity:

Many studies suggest an association between deterioration of manipulative dexterity and neurovascular symptoms in the fingers of HTV exposed workers (12, 30).

It has been shown that sensory perception and manipulative dexterity depend upon the integrity and/or functional capacity of various skin mechanoreceptors (Meissner's corpuscles, Pacinian corpuscles, Merkel cell neurite complexes, and Ruffini endings) and their afferent nerve fibers which are located in the epidermal and subcutaneous tissues of the glabrous skin of the fingers and hands (31, 32).

In particular, the Meissner afferents seem to play an important role in providing a neural image of motion signals from the whole hand which are essential to control grip force and to hold objects securely (31).

It has been suggested that vibration can induce changes in skin microcirculation and biomechanical properties of the skin and these adverse effects may contribute to the impairment of manual dexterity observed in users of vibratory tools (12).

Previous studies also reported that symptoms of impaired grip force and a tendency to drop things were associated with the progression of HAVS (12, 30, 31, 32). It is known that the sensitive response in FA-I and SA-I units plays an important role in precision of gripping or picking up objects. Damaged manipulation by patients with HAVS can result from impaired sensory feedback in their fingers and hands. Some studies investigated the effect of short term vibration exposure on manual dexterity and showed no temporary impairments on fine manual dexterity such as the Perdue pegboard test. This suggests that certain chronic damage in tactile perception and sensory afferents in the hands caused by prolonged exposure to HTV disturbed manipulative dexterity (30).

The results of this study do not support the role of vibration exposure in the deterioration of manipulative dexterity since there was no evidence for a significant decrease in the precise manipulation of small objects in either the dominant or non-dominant hands. There was, however, an effect when workers were required to use both hands together, which may suggest a hand-eye coordination influence rather than an impairment of manual dexterity.

Grip force:

Various studies have suggested that muscular fatigue is caused by vibratory evoked muscular activity was associated with vibration exposure. Muscle weakness that particularly affects grip strength has been reported after exposure to vibration (33, 34, 35).

Vibration-exposed workers may have complaints of muscular weakness and pains in hands and arms (36). Cutaneous, muscle spindle and joint receptors are sensitive to vibration exposure. The sensory receptors encode the mechanical stimulation and send these messages along exteroceptive and proprioceptive neural pathways to the motor neurons via peripheral loops and to the central nervous system via supraspinal loops (37). Cutaneous pathways have a strong facilitatory influence on motor neurons of flexor muscles. In addition, the primary and secondary endings of the muscle spindles, connected to Ia and II afferent fibres respectively, are very sensitive to the vibratory stimulus and their strong facilitatory influence activates the motor neurons (38). This vibration-induced contraction, mediated primarily by the Ia monosynaptic and polysynaptic pathways and cutaneous pathways is known as the tonic vibration reflex (39). The secondary endings and joint afferents, in addition to facilitating input to the motor neurons, send messages to the gamma motor neurons. These messages increase the sensitivity of the spindles, which increases the gain of the gamma loop and thus further increases facilitatory input to the alpha motor neuron (40).

All of these “positive feedback” systems act to facilitate motor neurons’ accessibility and increase contraction in the flexor muscles. Simultaneously, an increase in antagonist muscle co-contraction occurs in order to maintain the required grip force output, as observed in earlier studies. Hence, this reorganization of the motor command of peripheral and central origins increases the overall muscle tension and contributes to the development of fatigue (41, 42).

It is suggested that the use of vibrating tools be specifically evaluated in terms of physical exposure levels, such as vibration frequency and magnitude, grip force exertion, and work cycles to determine the potential influence and interactions of these parameters on muscle fatigue and fatigue accumulation (37).

The results of this study have shown that workers have much greater grip strength in their dominant hand when compared to controls. This is due to the much greater physical demand of the workers’ occupation, whereas the control group has less physically demanding occupations. This finding is consistent with previous findings where workers who previously worked as construction site workers had greater grip strength than those who worked previously as office workers (43). This may also be as a result of various contributors such as vibration dose and years of exposure and these are not sufficient to elicit a decrease of muscle strength.

Hand-eye coordination:

Previous studies have shown HAV to alter continuous manual control and oculo-manual coordination (36). In addition, vibration-induced alterations were found to be frequency dependent (44). Previous studies have used tendon vibration to investigate kinesthetic illusions in the isometric limb and end point control in the moving limb. These previous studies have shown that vibration distorts the perceptions of static joint angle and movement and causes systematic errors in the end point of movement (45).

The results of this study show that perhaps the greatest effect of our vibration exposed population was on their hand eye coordination ability. This is consistent with previous findings where the effects of high frequency HAV on simultaneous ocular and manual tracking performances were investigated. Results have shown that HAV significantly alters eye and hand tracking performances when the hand is out of sight. However, when the hand was placed in the visual field, tracking performances were less affected by vibration. These findings explicitly show that HAV can perturb oculo-manual coordination control (36, 46).

Finger systolic blood pressure:

To identify patients with VWF, cooling-induced FSBP responses of digital arteries has been advocated as a useful method over a long time (1). A reduction of finger systolic pressure to zero on cold-provocation testing will represent an objective sign of Raynaud's phenomenon with complete closure of the digital arteries (47).

The findings of this study show an overall lower FSBP in the workers (91.11%) when compared to the controls (99.83%). This is, however, not statistically significant. A low finger systolic blood pressure following local cooling compared to that measured before cooling can indicate digital arterial vasoconstriction caused by an exaggerated response to cold, and a limit of 60% is reported to be a useful indicator of digital arterial vasoconstrictor response to local cold provocation (1, 7).

The findings of this study are in accordance with previous studies where the prevalence of VWF in rammer operators working in an aluminum factory was only 13.2%, where the ISO-weighted acceleration was 22.6 m/s² (48). Additionally, according to the data reported by Xu *et al.* (48) and Tominaga (49), the average prevalence of VWF among rammer operators was 0.0% and 2.2%, and the corresponding ISO-weighted accelerations were 30.0 and 39.9 m/s², respectively.

There is clinical and epidemiologic evidence that symptoms and signs of VWF may be reversible after the reduction or cessation of vibration exposure. The reversibility of VWF seems to be inversely related to age, the duration of exposure, and the severity of the disorder at the time the vibration exposure ceases (50).

Even though our study suggests an overall lower FSBP in the work group, this is not statistically significant and other studies have shown a lower occurrence of VWF at higher vibration magnitudes than the present study.

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CHAPTER 4
Concluding Chapter

General recommendations:

Daily exposure action values are not suitable for distinguishing between negligent and non-negligent exposures because the risks of disorder from HTV depend on the years of exposure, not merely the equivalent daily exposure. Furthermore, daily exposure action values take no account of individual susceptibility or the practicality of reducing vibration exposures. The consequences of negligence may be quantified in terms of the delay in the onset of disorder that would have been achieved if the exposures had been the minimum reasonably achievable in the circumstances. This only requires decisions on the percentage reductions in vibration magnitude and exposure duration, if any, that would have been achieved by the reasonable employer. It seems to be a fair and reasonable method for both employers and employees. It also provides information needed to calculate the consequences of negligence on the worker - the period of their life with disease as a result of the negligence and, if appropriate, the period for which their employment is jeopardized as a result of the onset a disorder due to the negligence of their employer. Negligence of employers may not be confined to failure to delay the onset of disorders by reasonably achievable reductions in vibration magnitudes and exposure durations. Employers should provide workers with an understanding of the risks and their cause (i.e. warning), the means of preventing the risks (e.g. training), and prevent the progression of disorders by implementing suitable health surveillance.

Conclusion:

This study quantified the effects of vibration on rock drill repair and maintenance workers. According to ISO 5349-1 (2001), the onset of finger blanching would be expected in 10% of persons after 12 years at the EU EAV and after 5.8 years at the ELV. Clearly, the EAV and the ELV in the directive do not define "safe exposures" to HTV. Consequently, it does not seem reasonable to conclude that an employer fulfills all obligations to an employee in respect of exposures to HTV if the EU EAV is not exceeded.

Negligence is not only dependent on the vibration magnitude and exposure duration. It could be negligent if users of vibratory tools are not provided with information sufficient for them to understand the risks and the means of minimizing the risks. Knowing the effects of vibration and the possible influence of these effects on their occupation and leisure activities, some workers will choose to change job or change employer so as to lessen or eliminate exposure to HTV.

In conclusion, the present study reveals that there is a difference between the two groups with respect to grip force, hand-eye coordination; dexterity and FSBP after cold provocation, however, conclusions made has been limited by the small population size. The aims and objectives of this study have been achieved, and the hypothesis of this study has been accepted.

However, a longitudinal study (not limited by small population size) should be conducted preferably using newly appointed workers with no prior exposure to vibration and a sufficient control group to eliminate the effect of other confounding variables such as general working conditions.

Addendum

Medical Questionnaire

General patient information and history

Section 1 - Personal identification

Surname _____

Name _____

Serial number |_|_|_|_|_| Date |_|_|_|_|_|

Gender: M |_| F |_| Age |_|_|

Section 2 - Social history

2.1 *Nicotine consumption*

Do you smoke or have you ever smoked? No |_| Yes |_|

If yes, when did you start smoke regularly? 19 __

Do you still smoke? No |_| Yes |_|

If no, when did you give up smoking? 19 __

If yes, how much did/do you smoke? Cigarettes per day: |_|_|

Cigars per day: |_|_|

Pipe/rolling tobacco g per day: |_|_|

Do you snuff or chew tobacco regularly? No |_| Yes |_|

If yes, how many times per day? |_|_|

2.2 *Alcohol consumption*

Do you drink alcohol (wine, beer, etc.)? No |_| Yes |_|

How much do you drink daily? 0-1 unit |_| 2-3 units |_| more than 3 units |_|

How much do you drink weekly? 1-3 units |_| 4-6 units |_| more than 6 units |_|

Note: 1 unit = ½ pint of beer, glass of wine, or single spirit.

Section 3 – Medical history

3.1 Injury

Have you ever injured your hands , arms , shoulders , neck , back ?

If yes, specify (lacerations, fractures, etc.)

3.2 Surgical treatment

Have you ever received surgery in your hands , arms , shoulders , neck , back ?

If yes, specify

3.3 Medical treatment

Are you on any long-term medication for any chronic disease? No Yes

If yes, details

Section 4 - Symptoms

4.1 Color changes:

Have you ever experienced any color changes in your fingers? No Yes

If no, go to section 4.2

If yes, what colors? Blue white red

If you have experienced white finger, was the whiteness clearly demarcated? No

Yes

If yes, when did you first notice this? 19__

When did the last episode of white finger occur?

day(s) ago month(s) ago year(s) ago

Do any members of your family suffer from white finger? No Yes

(Only the blood relatives)

If yes, do they work with vibrating tools? No Yes

If you suffer from white finger, how often does it occur?

Several times a year Several times a month

Several times a week Several times a day

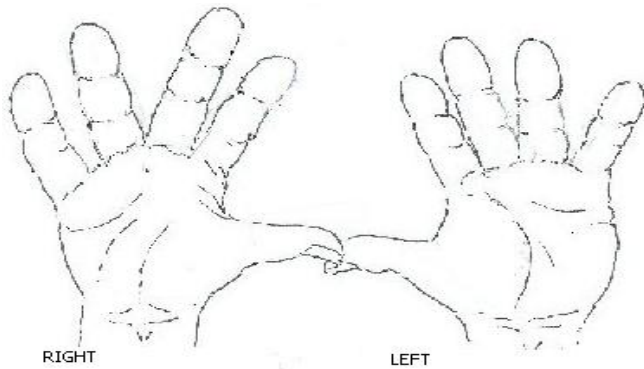
Does it occur in winter, summer or both? Winter summer both

Does any factor trigger it?: Cold condition Handling cold object

When feeling the vibration from vibrating tools

Others _____

Which fingers/thumbs are affected with whiteness?



(Indicate by shading the parts that go white on the diagram)

Does the condition interfere with any leisure activities? No Yes

Does the condition interfere with any work activities? No Yes

4.2 *Tingling:*

Have you ever experienced tingling in the fingers? No Yes

If yes, when did you first notice this? 19__

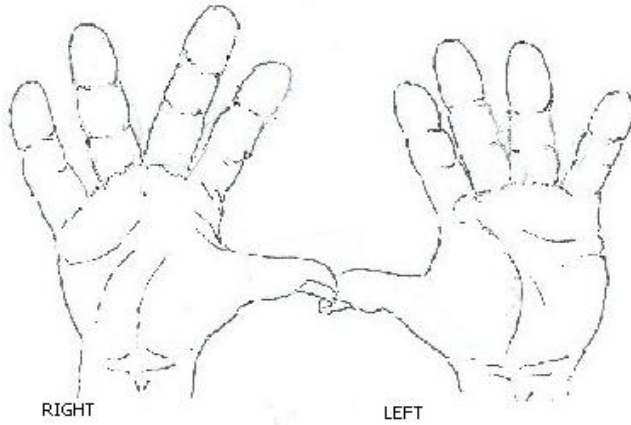
If yes, when?

While working with vibrating tools after working with vibrating tools

After exposure to cold during white finger after white finger

At night at other time _____

Which fingers/thumbs are affected with tingling?



(Indicate by shading the parts that get tingling on the diagram)

Does the condition interfere with any leisure activities? No Yes

Does the condition interfere with any work activities? No Yes

4.3 Numbness:

Do your fingers go numb? No Yes

If yes, when did you first notice this? 19__

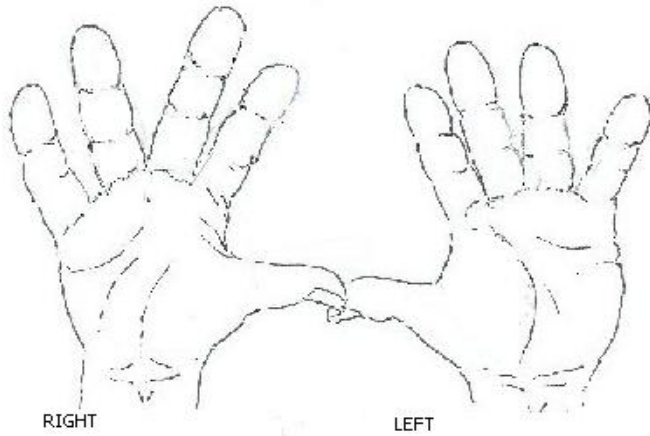
If yes, when?

While working with vibrating tools after working with vibrating tools

After exposure to cold during white finger After white finger

At night at other time _____

Which fingers/thumbs are affected with numbness?



(Indicate by shading the parts that get numbness on the diagram)

Does the condition interfere with any leisure activities? No Yes

Does the condition interfere with any work activities? No Yes

4.4 Musculoskeletal complaints in the upper limbs and neck:

Did/do you suffer from muscle/joint troubles in the upper limbs? No Yes

If yes, when: in the LAST 7 DAYS? , in the LAST 12 MONTHS? , or in the PAST?

Did/do you suffer from muscle/joint troubles in the neck? No Yes

If yes, when: in the LAST 7 DAYS? , in the LAST 12 MONTHS? , or in the PAST?

4.5 Effects of symptoms in the hands and fingers

In the PAST 12 MONTHS have symptoms in the hands caused any difficulty with the following activities?:

No difficulty Difficult but not impossible Impossible

	-----	-----	-----
Turn a door knob or lever	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Open a tight jar lid	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Put on a jacket or pullover	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fasten buttons	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Handling and picking up coins	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Pour from a jug or a pot

Did symptoms in the hands affect your work ability? No Yes

If yes, when: in the LAST 7 DAYS? , in the LAST 12 MONTHS?

Was there any reduction in your work output in the LAST 7 DAYS due to the above symptoms? (Color changes, coldness, tingling, numbness, pain, stiffness, weakness, swelling, limited movements)? No Yes

If yes, approximately how long would it take to make up for this reduction?

_____minutes

What symptom was the main cause of the reduced output?

Clinically administered questionnaire

Section 1 - Personal identification

Surname _____

Name _____

Address _____

_____ Post code |_|_|_|_|_|

Telephone number _____

Serial number |_|_|_|_|_| Date |_|_|_|_|_|

Gender: M |_| F |_| Date of birth |_|_|_|_|_| Age |_|_|

Ethnic group: European |_| African |_| Caribbean |_|

Asian |_| Other _____

Height: |_|_|_| cm Weight: |_|_|_| kg

Dominant hand: Left hand |_| Right hand |_|

Marital status: Single |_| Married |_|

Widow |_| Divorced |_|

Other |_|

Section 2 - Occupational history

2.1 *Present occupation (if any):*

Company _____ Work area

Job title

—

Description of work

When did you start your current job? 19 ____|____|

Does your current job involve the use of powered tools that vibrate your hands? No

Yes

If no, go to question 2.2

If yes, which tools are you using?

Duration tool is operated and hands are in contact with vibration

Tools used- Minutes per day- Days per week- Weeks per year- No. of years

1	_____	_____	_____	_____
2	_____	_____	_____	_____
3	_____	_____	_____	_____
4	_____	_____	_____	_____
5	_____	_____	_____	_____
6	_____	_____	_____	_____
7	_____	_____	_____	_____
8	_____	_____	_____	_____

2.2 Past occupations with exposure to hand-transmitted vibration

Duration tool is operated and hands are in contact with vibration

Job title name	Company	Tools used	Minutes per day	Days per week	Weeks per year	Calendar year
_____	_____	_____	_____	_____	_____	19__ 19__
_____	_____	_____	_____	_____	_____	19__ 19__
_____	_____	_____	_____	_____	_____	19__ 19__
_____	_____	_____	_____	_____	_____	19__ 19__
_____	_____	_____	_____	_____	_____	19__ 19__
_____	_____	_____	_____	_____	_____	19__ 19__
_____	_____	_____	_____	_____	_____	19__ 19__

Description of work with past exposure to hand-transmitted vibration

When did your first significant exposure to hand-transmitted vibration start?: 19__ at age ____

What are your hobbies? _____

In your spare time (i.e. outside work) have you ever regularly used a tool or machine that made your hands vibrate? No Yes

Duration tool is operated and hands are in contact with vibration

Tool names	Minutes per week	Weeks per year	No. of years
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Section 3 – Medical history

Have you ever had any serious disease of?:

4.1 *Heart or blood vessels* No Yes

If yes, specify

4.2 *Nerves* No Yes

If yes, specify

4.3 *Bones and joints* No Yes

If yes, specify

4.4 *Connective tissue (e.g. scleroderma, lupus)* No Yes

If yes, specify

4.5 *Other (e.g. diabetes, thyroid disease)* No Yes

If yes, specify

4.6 *Injury*

Have you ever injured your hands , arms , shoulders , neck , back ?

If yes, specify (lacerations, fractures, etc.)

4.7 *Surgical treatment*

Have you ever received surgery in your hands , arms , shoulders , neck , back ?

If yes, specify

4.8 *Medical treatment*

Are you on any long-term medication for any condition? No Yes

If yes, details

Hand dynamometer patient instructions:

When the person is seated comfortably at the table in the correct test posture, the following instruction should be given by the examiner, following a demonstration of the procedure by the examiner.

“The purpose of this is to test your maximum hand grip strength. You will be asked to repeat this three times with each side beginning with your right (or left if appropriate) side. Please hold the grip strength meter in a comfortable position and when you are ready squeeze the handle as hard as you are able. After one maximum squeeze relax your hand and I will take the meter from you and record the measurement”.

After recording the measurement the examiner will hand back the meter to the subject then give the following instruction:

“When I say ‘Begin’ I would like you to repeat the test you have just done by giving the meter another hard squeeze with your hand”.

This procedure will be repeated once more to give a total of three measurements per hand tested. Then the subject should change position to their other (non-dominant) hand and the whole test process is repeated.

Pegboard patient instructions:

When the person is seated comfortably at the table in the correct posture, the examiner should give the following instruction:

“This is a test to see how quickly and accurately you can work with your hands. Before you begin each part of the test, you will be told what to do and then you will have an opportunity to practice. Be sure you understand exactly what to do”.

Before each hand is tested, the required task is demonstrated. The examiner will begin by saying and demonstrating:

“Pick up one pin at a time with your right hand from the right hand cup. Starting with the top hole, place each pin in the right hand row. Now you may insert a few pins for practice. If during the testing time you drop a pin, do not stop to pick it up. Simply continue by picking another pin out of the cup”.

The examiner will then correct any errors made in placing the pins and answer any questions. When the subject has inserted three or four pins and appears to understand the operation, the examiner will say:

“Stop, now take out the practice pins and put them back into the right hand cup.”

Then the examiner will say: *“When I say ‘Begin’ place as many pins as you can in the right-hand row starting with the top hole. Work as rapidly as you can until I say ‘Stop’.*

“Are you ready? Begin”

Start timing when you say ‘Begin’. At the end of exactly 30 seconds, the examiner will say “Stop”.

Then the number of pins inserted will be counted and the score recorded for the right hand. This is the total number of pins the subject placed with the right hand. Directions for the left hand test and both hands test are similar to those for the right hand test.

Automatic mirror trace patient instructions:

When the person is seated comfortably at the table in the correct posture, the examiner should give the following instruction:

“This is a test to see how quickly and accurately you can work with your hands and eyes in co-ordination. Before you begin each part of the test, you will be told what to do and then you will have an opportunity to practice. Be sure you understand exactly what to do”.

Before each hand is tested, the required task is demonstrated. The examiner will begin by saying and demonstrating:

“While looking at the “star” in the mirror, trace along the black outline of the “star” as fast and as accurately as possible. Now you may practice. If during the testing time you make a mistake, do not stop to start over, and simply continue no matter how many mistakes you make”.

Then the examiner will say: *“When I say ‘Begin’ trace as far as you can trying to avoid mistakes”. Work as rapidly as you can until I say ‘Stop’.*

“Are you ready? Begin”

The examiner will then start timing when he says ‘Begin’. At the end of exactly 1 minute, say “Stop”.

The number of mistakes for the dominant hand will be recorded. Directions for the non-dominant hand are similar to those for the dominant hand test.