DEVELOPMENT AND TESTING OF A SCREENING TOOL FOR MINE WORKERS WITH POSSIBLE HAND ARM VIBRATION SYNDROME

by

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Hand Arm Vibration Syndrome (HAVS) is a collective term for the symptoms arising from the prolonged use of vibrating hand tools. An investigation into the literature on available screening tools for HAVS was conducted. A screening tool is used for the quick identification of certain symptoms without a full medical check up, and is for use by mine medical personnel for the determination of workers with HAVS symptoms and those without. Twenty-two non-exposed volunteers were tested with the screening tools and forty-two rock drill operators. Only the rock drill operators had a medical examination and standardised tests for HAVS diagnoses, to determine their HAVS diagnosis and severity. This diagnosis was used as the standard for the evaluation, of existing screening tools and for developed screening tool, sensitivity for the detection of HAVS symptoms. The screening tools chosen were a traditional tuning fork, a similar tuning fork but mounted into a box with a set excitation unit and a two-point discriminator set a 3mm, 6mm, and 10mm apart. The results showed that a screening questionnaire that specifically focuses on the symptoms of HAVS has better sensitivity and specificity to identify cases. A two-point discriminator with variable distance points, where patients have to distinguish between one pin prick and two, was able to identify HAVS cases when the distance was set at 3mm. However, the sensitivity of the two-point discriminator was lower than the sensitivity of the questionnaire.

Keywords: Hand Arm Vibration Syndrome, screening, diagnosis, tuning fork, two point discriminator, frequency, rock drill operators, sensitivity, specificity, questionnaire.

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ONTWIKKELING EN TOETSING VAN 'n SIFTINGS APPARAAT VIR MYNWERKERS MET MOONTLIKE HAND ARM VIBRASIE SINDROOM

deur

Elsjebe Sampson

Hand Arm Vibrasie Sindroom (HAVS) is 'n term vir 'n groep simptome wat ontwikkel met aanhoudende gebruik van vibrerende handgereedskap. 'n Ondersoek in die literatuur vir huidige siftingsapparaat was gedoen, gevolg deur die toetsing en evaluasie van die gekose apparaat. Die siftingsapparaat is vir die gebruik deur myn mediese personeel vir die sifting van werkers met HAVS simptome teen die sonder sulke simptome. Twee en twintig proefpersone sonder vibrasie blootstelling is getoets as 'n kontrole groep en twee en veertig rotsboor operateurs was ondersoek. Slegs die rotsboor operateurs het 'n volle mediese ondersoek en standard toetsing vir HAVS ondergaan, vir die bepaling van die ergsheidgraad van HAVS. Die diagnose was gebruik as die standard waarteen die siftings-apparate se sensitiwiteit bepaal is. Die apparaat wat gekies is vir evaluasie is 'n stemvurk, 'n stemvurk gemonteer in 'n houer met 'n reaksie eenheid en 'n twee punt resultante diskriminator gestel op afstande van 3mm, 6mm en 10mm. Die resultate het getoon dat 'n vraelys gefokus op die simptome van HAVS, het 'n höer sensitiviteit en is meer spesifiek as die ander apparate getoets. Die twee punt diskriminator gestel op 3mm het ook goeie resultate getoon met die identifikasie van HAVS pasiente, met die 6mm afstand meer ingestel op die identifikasie van patiente sonder die sindroom.

Sleutelterme: Hand Arm Vibrasie Sindroom, siftingsapparaat, diagnoseer, stemvurk, twee punt diskriminator, freqkwensie, rots boor operateurs, sensitiviteit, spesifiek, vraelys.

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List of abbreviations and terms

CPT - Cold provocation test

CTS - Carpal Tunnel Syndrome

Digital artery - Blood vessels in the finger

Fibrosis - Development of excess fibrous connective tissue

HAVS - Hand Arm Vibration Syndrome

HSE - Health and Safety Executive

Hypertrophy - Enlargement or overgrowth of the blood vessels

Hz - Hertz

Neuropathy - Any and all diseases or malfunctions of the nerves

NIHL - Noise Induced Hearing Loss

Peripheral Neuropathy - Problems with functioning of the nerves, outside the spinal cord. Symptoms may include numbness, weakness, burning pain, and loss of reflexes

Perivascular - Around the blood vessels

SD – Standard deviation

Spasm - Sudden constriction

TA - Thermal aesthesiometry

Vasoconstrictor - Any agent that causes a narrowing of the blood vessels; examples are cold, stress, and nicotine.

VTT - Vibration threshold test

1 Introduction

1.1 Background information

Hand Arm Vibration Syndrome (HAVS) is a group of symptoms related to the use of vibrating hand tools. Symptoms range from vascular and neurological to musculoskeletal and affect different parts of the hand arm system. These symptoms are fully described in Section 2 of this report. HAVS is caused by the frequent use of hand-held power tools over an extended period of time. The hand arm vibration (HAV) is defined as the transfer of vibration from a hand tool to an operator's hands and arms. The amount of HAV is characterised by the acceleration level of the tool when grasped by the operator, and is typically measured on the handle of the tool (Bernard, 1997). The quantity of absorbed energy is not only influenced by vibration intensity but also by several other factors, such as frequency, transmission direction, grip and feed forces, hand-arm postures and individual factors (Burstrom et al., 1998).

The first documented research on HAVS in South Africa was a literature study written in 1987 (Franz et al., 1987). The paper recommended that a study should be undertaken to establish the status of vibration-induced trauma in the South African mining industry, and it was hoped that if this condition was indicated, preventative measures could be taken before the condition reached a critical stage.

It was also mentioned in the report that an increase in the stability of the labour force meant that workers extended their periods of service in the mining industry, increasing the risk of developing some form of vibration disorder. Hehrens (et al., 1982) reported that incentive work is a factor in the prevalence of vibration disorders, workers being paid according to number of operations show a higher incidence of HAVS than hourly paid workers.

A comprehensive attempt to measure vibration levels of a variety of tools and equipment used in the South African mining industry followed in 1999 (Van Niekerk et al., 1999). The study objective was to determine the potential risk to the health of workers and operators of vibration tools, and highlight vibration tools that had a high risk associated with their use. The conclusion from the study was that vibration levels on hand-held rock drills, pavement breakers, jackhammers and certain workshop tools had sufficiently high levels of vibration to enhance the risk of vibration-induced disease.

The first epidemiological study on the prevalence of HAVS, in 2000 (Nyantumbu et al., 2002) was conducted almost 13 years after the initial recommendations made by Franz (et al., 1987). In this epidemiological study the occurrence of HAVS was confirmed and a prevalence of 15% in rock drill operators at a South African gold mine was found.

HAVS is an occupational disease in South Africa, which is mentioned in Schedule 3 of the Compensation for Occupational Injury and Disease Act, Act 130 of 1993. However, in spite of the reported 15% prevalence, to date no compensation has been paid for HAVS in South Africa.

Van Niekerk (et al. 1999) estimated that the vibration levels of pneumatic and hydraulic rock drills used in the South African mining industry exceeded the European Union (EU) exposure action limits by a factor of ten. Employers are required to take action to reduce vibration-exposure once the action limits are reached. The EU Directive 2002/44/EC gives guidelines for the minimum health and safety requirements of workers exposed to hand-arm and whole-body vibration.

For hand-arm vibration the exposure values, assuming an eight-hour working day, are:
Exposure action value: 2.5 m/s^2 A(8)
Exposure limit value: 5.0 m/s^2 A(8)
These values represent the sum of vibrations measured in three different directions (x axis, y axis and z axis). Member states of the EU have three years to implement the directive from 6 July 2002.

1.2 Motivation

There are still many challenges remaining in the measurement, evaluation, and assessment of hand-transmitted vibration. The mechanism of injury is not fully understood and even the full range of injuries is not agreed upon. There remains uncertainty about methods of predicting the effects of vibration, from measurements of exposure to vibration.

HAVS is diagnosed through a medical evaluation of the patient's occupational and medical history and a physical examination consisting of three standardised objective tests. This evaluation is a time-consuming process which takes between two to three hours, if symptoms are sever or if patients find it difficult to understand the procedures this timing can be extended further.

The standardised objective tests are conducted by specially trained technicians, and an occupational health physician has to complete the medical examination, which adds to the evaluation time. Not only are there few trained technicians, but the specialised equipment is expensive and needs regular calibration to ensure reliable results.

Owing to the limited resources in terms of expertise and equipment for the standardised objective tests and the large number of mine workers exposed to HAVS, a screening tool to determine those most likely to have HAVS must be developed.

Recommendations made by Nyantumbu (et al., 2002) included the screening of mineworkers for HAVS who operate vibrating tools for HAVS. A suitable screening tool and questionnaire that are quick and easy to use and not expensive would be ideal if used as part of the annual medical surveillance of mineworkers.

1.3 Objectives

The study objectives are to research literature, on possible screening tools for the screening of HAVS, as well as the development and evaluation of possible screening tools that could be used in the mining industry.

2 Vibration and its physiological effects

2.1 Vibration

2.1.1 Definition of vibration

A motion that repeats itself after an interval of time is called a vibration or oscillation, (Rao, 1995). This motion is usually repeated around a stationary point.

2.1.2 The measurement of vibration

Vibration is measured using the magnitude of the vibration (Kroemer et al., 2001). This magnitude is the displacement of vibration and its derivatives, namely velocity and acceleration. The displacement of an object is the maximum amplitude the mass displaces above or below a stationary point.

2.1.3 Vibration exposure limits

At present, no South African standard governs limits for occupational vibration exposure. In the United Kingdom, limits have been set for eight-hour working periods, and legislation that sets daily exposure limits and action levels is being considered (Franz & Phillips, 2001).

2.2 The physiological effects of vibration

The human body reacts to vibration in different ways, with different body parts reacting differently, even under the same excitation (Kroemer et al., 2001). Of particular interest in vibration studies are the responses of the spinal column, the head and the hands. The head and spinal column are affected by vibration that is transmitted through the body, called whole body vibration. Hand arm vibration is a local vibration only transmitted through the hands. The wide variety of effects caused by vibration is dependent on the intensity and direction of the vibration. Vibration affects the comfort and health of workers.

2.2.1 Whole body vibration

Whole body vibration occurs when a person stands or, most commonly, sits on a vibrating surface. Delivery vehicles, forklifts, trucks, buses and loaders are all vehicles that transmit vibration through the seat to the whole body of the occupant (Franz & Phillips, 2001). The consequences of whole body vibration are still unknown. The most frequently reported symptom is lower back pain, with other less documented symptoms of gastrointestinal tract disturbances and dizziness.

2.2.2 Hand arm vibration

Hand arm vibration is a local vibration transmitted to the hand by the use of vibrating power tools and equipment. With prolonged exposure to this local vibration a disease of the upper limb associated with the use of vibrating hand power tools has been recognised. The disease is known as hand arm vibration syndrome (HAVS). The disease has been described in several countries and in a variety of industries, including mining and quarrying (Franz & Phillips, 2001).

2.2.2.1 HAVS symptoms

HAVS is a condition that causes vascular damage, neurological damage and musculoskeletal problems in the fingers, hands and arms. The blood vessels, nerves, muscles, bones and joints can all be affected.

2.2.2.1.1 Vascular symptoms

Vascular damage results in circulation disturbances with episodic blanching of the fingers after exposure to cold environments or cold water. A cold sensation in the fingers may be felt long before the occurrence of blanching (i.e. white fingers) (Metabo et al., 1995). This blanching is due to the temporary occlusion (i.e. spasm) of digital blood flow through the digital arteries.

Fingers go through three stages when blanching occurs. In stage one, fingers turn white and feel cold. This is due to the small blood vessels narrowing and is induced by a temperature change. In stage two the fingers appear to have a blueish tint. This is a result of the oxygen being depleted from the reduced blood supply of the narrowed blood vessels. In stage three the fingers turn red, caused by the blood vessels dilating and the return of blood to the fingertips. At this stage, three patients feel tingling and pain in their fingers.

During a blanching attack the fingers feel numb to the touch, and temperature sensitivity is greatly reduced. The fingers may also feel painful, especially with re-perfusion.

The duration of these blanching attacks can be from minutes to hours, and attacks usually disappear with warming of the hands. In more severe cases the fingers remain in stage two and after some time develop gangrene. These severe cases are, however, not very common.

The vascular component is either absent or less pronounced in temperate climates (Falkiner, 2003), and could be the reason for low prevalence of HAVS in South Africa.

It should be remembered that the symptoms of finger blanching can also occur in the general population independently of vibration exposure. This is known as primary Raynaud’s Syndrome which is hereditary. The diagnosis of HAVS is suggestive if there is (i.e. Rayaud's phenomenon) a history of hand arm vibration exposure and the absence of any other underlying diseases.

2.2.2.1.2 Neurological symptoms

Damage to the nerves is also thought to be a direct result of vibration. Swelling of adjacent nerve tissue due to the trauma of vibration may play a role in compressing nerves (Guild et al., 2001). Neurological damage results in symptoms of numbness, tingling, pain, loss of discrimination to light touch and temperature changes, as well as reduced grip strength and manual dexterity (Guild et al., 2001).

These symptoms may be mild, affecting only the fingertips, and are usually worse in the dominant hand (Falkiner, 2003). Symptoms are initially intermittent, becoming continuous with continuous vibration exposure. In severe cases, permanent numbness exists in the affected fingers. In some patients only one finger may have severe symptoms with other fingers having mild symptoms.

Carpal Tunnel Syndrome (CTS) is also associated with vibration exposure where workers usually have repetitive strain injuries due to hand held tools. A higher prevalence of CTS has been reported in vibration-exposed workers (Falkiner, 2003). Table 2-1 indicates the similarities and differences between HAVS and CTS.

Table 2-1 Sensor neural symptoms of HAVS and CTS (Falkiner, 2003)

Symptoms	HAVS	CTS
Median nerve signs in hand and/or forearm	Yes	Yes
Ulnar nerve signs	Yes	Yes, rare
Night waking with neurological symptoms	No	Yes
Reduced grip strength in later stages	Yes, with no muscle wasting	Yes, with thenar wasting
Occupational Raynaud's Disease	Yes	No

Numbness of fingers and reduced grip strength may causes clumsiness and difficulty in performing fine tasks, such as buttoning a shirt or handling coins, screws or nails. This numbness, including tingling and pain in the arms, wrist and hands, may interfere with sleep, waking a patient during the night. An early sign of peripheral neuropathy, is seen in the impairment of vibration sensibility, starting distally in the limbs (Goldberg et al., 1979).

2.2.2.1.3 Musculoskeletal symptoms

Musculoskeletal disorders result in damage to bone, muscles, and joints, causing aches and pains in the hands and lower arm. The symptoms experienced from bone and joint damage are pain and stiffness in the hand, joints of the wrist, elbow and shoulder (Guild et al., 2001).

The vibration energy from vibrating hand tools is not restricted to the fingers and the wrist joint, but is also transmitted to the elbow and upward through the forearm to the shoulder. The vibration transmitted to the hand, upper limb and shoulder is gradually attenuated over the joints (Sakakibara et al., 1993). A resonance of 10-20 Hz occurs in the upper limb indicating that lower frequencies are more transmissible, to the upper limb than other frequencies, allowing more damage to the musculoskeletal system. Guild (et al., 2001) indicated the use of hand-held vibrating tools in the frequency range between 2 and 1500 Hz to be a primary cause of HAVS. The quantity of this transmitted vibration is also influenced by the frequency, transmission, direction, grip and feed forces, hand-arm posture and individual factors (Burstrom et al., 1998).

Osteoarthritis and bone cysts occur in workers who are exposed to vibration but the evidence that bone and joint problems are specifically caused by vibration is inconclusive (Guild et al., 2001).

Malchaire (et al., 2001) indicated that the prevalence of Upper Limb Disorders (ULD) is two to five times higher in workers exposed to vibration than workers exposed to force constraint during repetitive work. Grip strength in the hands is also greatly reduced by HAVS, as well as dexterity. In the operation of hand power tools, the operator has to grip the tool (with weight ranging from 5-30 kg), usually with a bent arm. This affects the upper limb by static and dynamic forces, a strenuous posture and transmitted vibration.

3 Literature review of possible screening tools for HAVS

3.1 Introduction

A screening tool is a tool used for quick and easy identification of certain symptoms of a disease. The tool is not used in a diagnosis but only for the identification of prone individuals. The individuals with possible symptoms can then be sent for extensive tests for the complete diagnosis of a disease.

The annual screening of vibration-exposed workers will help in the early detection of HAVS symptoms and allow for intervention to stop the progression of HAVS. The screening tool should form part of the annual medical examination of mine workers and would be performed by mine staff.

In evaluating screening tools to be used on a daily basis, various aspects need to be considered, such as the size of the tool, the duration of the examination, the demand on patients' cooperation, the reliability for quantifying impairment and the cost of the screening tool (Martina et al., 1998). The tool should also provide a base line from which newly recruited or current workers can be assessed for any signs of progression of the disease.

Other considerations are:

- Ease of administration;
- Consistency in the presentation of the test;
- Minimal interaction between the test administrator and the patient;
- Suitability for repeated test protocols;
- Ease of reporting of results;
- Accessibility to all mine health centres; and
- Infrequent calibration required.

No one tool is able to determine the abnormalities in different symptoms of HAVS. Screening tools are therefore divided into the group of symptoms they test, e.g. vascular, neurological or musculoskeletal.

3.2 Vascular component

Symptoms of damaged arterial flow in the extremities can be highlighted by screening tools that highlight these symptoms. The two best known tests in this regard are the (finger) nail compression test and finger skin temperature test. These tests evaluate the reperfusion of blood into the hands and fingers, or symptoms related to the blood flow.

3.2.1 Nail compressions test (Lewis Prusik test)

The nail compression test tests the digital flow when occlusion of blood to the fingertip has taken place (Matoba & Sakurai, 1987). The examiner uses their index finger and thumb to apply pressure to the patient's finger. After the pressure has been applied for a few seconds, the grip is released and the time is recorded for the nail to regain its normal colour.

The disadvantage of this type of test is the reliability of the test procedures, given that the compression force on the finger may not always be the same, and repeating the test may result in different outcomes. This might change the time taken for the finger to regain its normal colour (Matoba & Sakurai, 1987). The test administrator has to be trained to perform the test and be able to recognise any abnormality.

3.2.2 Finger skin temperature

Damaged arterial blood flow results in fingers with lower temperatures than normal. The finger skin temperature is taken with a thermistor. Healthy fingers are 30 °C or more, and abnormal values are lower than 30°C. Patients have to be acclimatised to the room conditions for a minimum of fifteen minutes before skin temperature can be taken.

When carrying out the standardised objective test for the diagnosis of HAVS, finger skin temperature is also taken as a precautionary measure to ensure that the temperature is not below 22 °C. If a finger is below this temperature, tests are not done on the finger as pain might be inflicted during the tests.

3.3 Neurological component

The second group of tests are those related to neurological factors. Screening tools focussing on the neurological component uses the loss of nerve function as the indicator for possible HAVS. Light touch, pain sense, two point discrimination and vibration tests, all test the nerve function, specifically in the fingertips.

3.3.1 Light touch

Cotton wool is stroked lightly over the fingertips and the patient is asked if anything can be felt (Kent et al., 1998). This test is unreliable when calluses are present on the fingertips, as no sensation is felt through this part of the finger in any case. In a study by Kent (et al., 1998) 25% of an exposed group with symptoms were tested as abnormal with the light touch test, giving this test low sensitivity.

3.3.2 Pain sense

A disposable needle is pressed sharply against the fingertip, and the patient is asked if a sharp or dull sensation is felt. The stimulus can be varied by applying the pressure of the needle in a more controlled manner to induce a more dulled sensation.

This is an intrusive test and can cause severe pain if the test is not properly applied. The test cannot be repeated on a finger after the initial test. The sharpness or controlled manner in which a stimulus is applied can vary from administrator to administrator and is not fully described in the literature. Patients are not inclined to participate in this type of testing method.

3.3.3 Two-point discrimination

The two point discrimination test consists of a compass instrument where the distance between the pins can be set to any prescribed distance, an example shown in Figure 3-1. The test objective is to differentiate between two or a single point of pressure on the skin at variable distances. This test evaluates large nerve function in the fingertips. Patients are asked if they feel one point or two points. Patients with nerve damage will be unable to distinguish between two or one at certain distances.

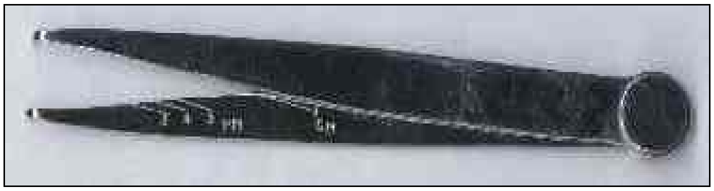

Figure 3-1 Two-point discriminator (www.medexamtools.com)

3.3.4 Monofilaments

This test determines whether patients have the ability to sense a point of pressure on the finger. The instrument consists of pressure-sensitive nylon filaments, of increasing calibre, that buckle at reproducible stresses. A certain calibre monofilament is pressed against the finger. If the patient is unable to feel the pressure point, a higher calibre is used until the patient is able to perceive the pressure. The calibre indicates the sensitivity of the patient perceiving a pressure point, giving an indication of neurological damage in the fingers.

Vileikyte (et al., 1997) studied peripheral neuropathy in diabetic patients with possible foot ulcerations using the monofilaments, vibration perception threshold using a biothesiometer, and a tactile circumferential discriminator (TCD). The TCD is a hand-held disc with protruding rods of increasing circumference similar to the two-point discriminator. The study found that the TCD had a sensitivity of 92,3% and the monofilaments a sensitivity of 86,6% for the identification of patients with significant neuropathy. The monofilament and the TCD are highly sensitive but are less specific and give more false-positives.

3.3.5 Vibration sense

Vibratory sensory testing has been used as a non-invasive diagnostic technique for a variety of disorders, including carpal tunnel syndrome (CTS), acute compartment syndrome and neuropathies (Grunert et al., 1990). Vibratory sensory testing has a well-documented history of application in nerve compression and dysfunction detection. The technique uses an instrument that vibrates, that is placed on a patient's finger. The patient is then asked whether they perceive this vibration.

Early vibratory-sensation loss is a means of detecting compression neuropathies and other nerve damage. Early detection of loss of vibration sensation can allow early intervention and increase the chances of reversing any or all symptoms. This also allows for the establishment of medical surveillance where a baseline can be assessed and recorded: later assessment will then be compared to the baseline to determine whether a neuropathy is developing.

The instruments that are used in this technique are the traditional tuning fork, the graduated tuning fork and the vibration sensimeter.

3.3.5.1 Traditional tuning fork

The traditional tuning fork, invented in 1711 by Johan Shore (Freeman et al., 2002), is still being used in the determination of neurological functioning. The tuning fork was originally used as an instrument that produced a note of constant pitch when vibrated.

In the 1920s examinations with the tuning fork were performed by holding it over a joint or bone while it vibrated at 128 Hz. Patients were instructed to respond when the vibration stopped or a decrease in vibration sensation was felt. Figure 3-2 shows the traditional tuning fork.

Figure 3-2 Traditional tuning fork

The fork is hit against an object which causes the arms to vibrate at the pre-set frequency. The foot of the fork is then placed on the testing area while the patient closes his eyes or looks away. The patient is asked if any vibration is perceived at the test site. This test indicates the presence or absence of vibration perception.

3.3.5.2 Graduated tuning fork

Rydel Seiffer introduced the graduated tuning fork in 1903. This fork gives a quantitative degree of dysfunction of vibration perception.

The arms of the fork bear calibrated weights. One arm is painted white and the other is black. A scale on both arms is marked from "0" to "8". When the fork vibrates, double triangles, one black and the other white, appear on the arms. At the intersection of these virtual triangles a reading on the arm is taken which gives the vibration threshold. The triangles move with a change (decrease) in vibration amplitude from 0 to 8 on the scale, Figure ***3-3***.

When the patient indicates that no more vibration is perceived, the reading at the intersection of the triangles is taken at that instance. A reading of 0 indicates normal perception, and values of 6 to 8 indicate lowered vibration perception, where 1 to 5 indicates the start of vibration perception loss.

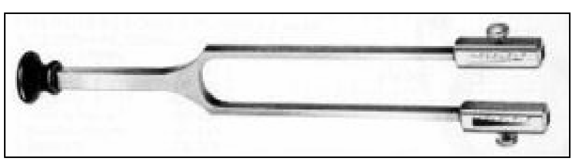

Figure 3-3 Seiffer Tuning Fork (www.usneurologicals.com)

Martina (et al., 1998) noted that tests conducted with the Rydel Seiffer tuning fork took 5 minutes to complete, whereas tests with a vibrameter (Section 3.3.5.3) took between 10 and 15 minutes to complete. A good correlation between the results of the tuning fork and those of the Vibrameter was also found.

The tuning fork is small, does not require long periods of attention from patients, and measurements are taken in only a couple of minutes. Martina (et al., 1998) found that the tuning fork provided an objective and reliable measure for vibration sense testing. This method was shown to be the most sensitive objective measure of dysfuntioning for CTS by Dellon (et al., 1980).The apparatus is simple, quick to use and tests are easily understood by patients.

3.3.5.3 Vibration sensimeter

This is an electronic version of the traditional tuning fork. A few registered products are available, such as the Vibrameter™ and the vibration threshold test (VTT) meters. A description is given in Section 5.2.1.1.2.

These tests tend to be time consuming and require the patient's attention for long periods. The equipment tends to be bulky, is expensive and requires weekly calibration and a full calibration annually.

The VTT is part of the standardised objective testing for the diagnosis of HAVS and will not be considered as a screening tool.

3.4 Musculoskeletal component

The measure of weakened muscle and loss of dexterity is used by tools for indications of HAVS. These tools include the grip force, pinch force, finger tapping and Moberg pick up test.

3.4.1 Grip force

Grip strength is tested with a dynamometer, where the patient is asked to exert the maximum force, keeping the forearm horizontal and the elbow bent at 90 degrees.

This test forms part of the physical assessment in the medical evaluation for the diagnosis of HAVS, and is described in Section 5.2.2.7 in detail.

3.4.2 Pinch force

Finger strength may also be affected by vibration exposure. The patient pinches the arm of a pinch meter between the thumb and index finger. A normal value is 5 kg or more.

3.4.3 Finger tapping test

The test assesses fine motor speed and dexterity. The patient is asked to tap a finger on a lever. The number of taps in ten seconds is recorded using a tapping meter. A normal number is 45 taps and above.

Age was shown to have a significant effect on finger tapping results (Cousins et al., 1997). In an elderly workforce no distinction could be made between the influence of age or vibration on test results.

3.4.4 Moberg pick up test

Patients are required to pick up a series of 10 to 12 small objects of various sizes from a table surface and place them in a small container. The time taken to perform this task is recorded. Not much information has been published on this test and it was considered similar to the Purdue pegboard test (Section 5.2.2.6) that forms part of the diagnosis of HAVS.

4 Development of a screening tool

4.1 Concept idea for tuning box

One of the main concerns with the tuning fork is its inconsistency as different individuals excite the fork with varying force. The tuning fork is a valuable tool which is easy to use and inexpensive, and participants understand the procedure easily. This led to the concept of keeping the exciting force constant, and in effect the vibration energy constant.

A fork was mounted in a box and held in place by silicone so as not to damp any vibration. A hammer was used to excite the fork, this hammer was set at the same distance from the fork and released under spring tension. The tuning fork mounted in the tuning box was a Sheffield RAGE, 128 Hz aluminium fork.

4.1.1 Test procedure for tuning box

The hammer, as indicated in Figure 4-1, is locked in place by pushing **Lever 1** inwards towards the box. A click sound indicates that the hammer has been loaded. To release the hammer and start the vibration, **Lever 2** is pushed towards **Lever 1**. This releases the hammer which hits the tuning fork. The back of the tuning fork is then placed against the patient's finger to see if the vibration is perceived. The hammer has to be loaded after each test.

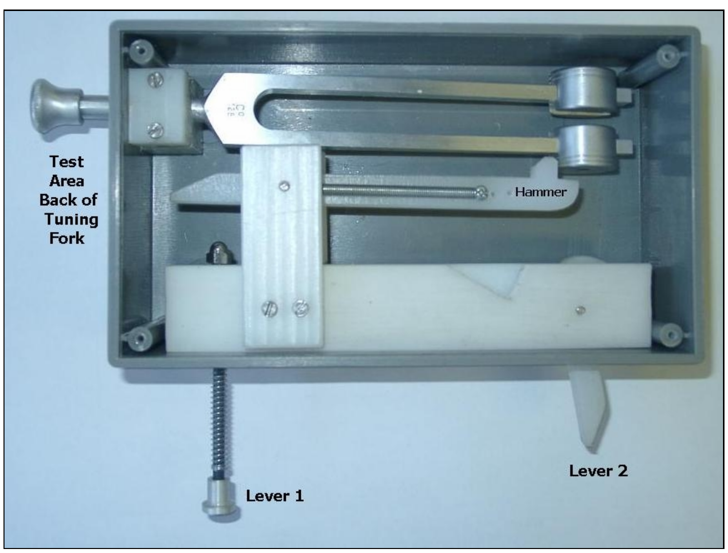

Figure 4-1 Tuning box with lever indications

4.2 Two-point discriminator

The tool used as a two-point discriminator is a standard vernier, where the internal diameter reading mechanism is used as the two tactile points (Figure 4-2). These points are an average diameter of 3mm at the connection point with the finger. Three distances were decided on after consultation with industry specialists and according to information found in the literature, namely 3mm, 6mm and 10mm.

Kent (et al., 1998) defined abnormal discrimination as the inability to detect a gap of 7 mm or more. This contradicted other studies where a finite element model of a fingertip was analysed in a two-point tactile discrimination simulation (Wu et al., 2004). The study results indicated that the normal strain (horizontal and vertical strains) and strain energy density developed in the skin at the contact points varied little with a decrease in the distance from 4mm to 3mm. Considerable decreases in strain were noticed at distances between 3mm and 2mm, indicating that 3mm and 2mm were perceived as one pressure point. Lars Barregard also indicated that distances between 2 and 10mm should be used in an evaluation. The smallest distance of 3mm was decided on when test runs at this distance were performed on workers not exposed to vibrations, and all indicated that 3mm was the first distance at which they could perceive two pin pricks.

Three verniers were set at the predetermined distances, and glued into position to ensure that no variance in distances occurred during testing.

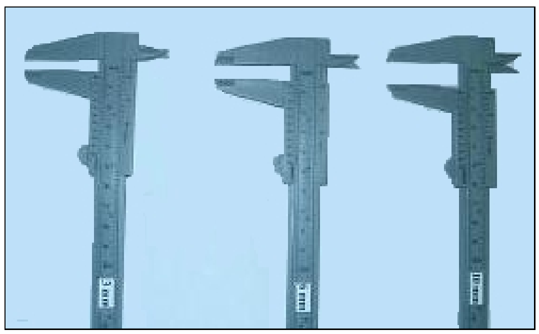

Figure 4-2 Verniers used as the screening tools

4.3 Screening questionnaire

A questionnaire used in the initial study of HAVS in South Africa (Nyantumbu et al., 2002) highlight symptoms highly specific to HAVS.

A screening tool that was based on the initial questionnaire was designed and used in conjunction with all the screening tools identified for the current study. The questionnaire was to ensure that workers tested with the screening tools have had relevant vibration exposure. This questionnaire should also indicate any HAVS symptoms that might be experienced by the workers and must be short and concise and still contain enough information to reveal any possible HAVS cases. Hill (et al., 2001) indicated prevalence for the use of a questionnaire-based study, indicating that questionnaires could be a valuable source of information on HAVS.

Some of the questions in the screening tool questionnaire duplicate some questions in the medical examination questionnaire. The reason for this is that the medical section is completed by a trained medical professional who might prompt a patient in different areas of some questions, whereas the screening questionnaire will more likely be completed by an employee of a mine medical centre who might not elicit the same response. The questionnaire used in the current study is given in Appendix H.

5 Methodology

The current study formed part of a Safety In Mines Research Advisory Committee (SIMRAC) study (Health 806), conducted to establish the progression of HAVS in workers diagnosed with HAVS in 2000 (Nyantumbu et al., 2002) and to determine the prevalence of HAVS in a cooler working environment. A cooler mine is described by Stewart (1982) as a mine with a workplace wet-bulb temperature below 27,5 °C. The current study combined results for the progression and cooler mine groups to evaluate the screening tools.

Before the study began, the research team received training on all standardised test equipment from Mrs Busi Nyantumbu. Mrs Nyantumbu received training on all aspects of HAVS assessment from the Health and Safety Laboratory (HSE) in the United Kingdom, and she was also the project leader of the initial study in 2000 (HEALTH 703) to determine the prevalence of HAVS in the South African gold mining industry.

Two translators were trained, one to take down the occupational history and to translate during the medical examination, and the other to help explain the standardised objective testing procedures to participants.

Three technicians were also trained to administer the standardised objective tests according to the HSE guidelines.

The study was approved by the local ethics committee from the University of the Witwatersrand Committee for Research on Human Subject – Clearance Certificate Number M03-07-06. All participants in the study were volunteers under the understanding that they could refuse to participate and withdraw from the study at any time. Written consent was obtained from all the participants (see consent form in Appendix B). No invasive procedures or tests were used during the study. The mines participating in the study paraded workers to take part in the study. Parading is the calling up a worker from duty for the day to report at the medical station.

5.1 Study groups

The participants tested in the current study were from three different groups, namely a pilot group, a progression group and a cooler mine group. The location where the assessments took place was different for each group, as they worked at different institutions.

5.1.1 Pilot group

The pilot group was assessed in the study primarily to determine the degree of difficulty of the screening tests and to filter out any problems in the test procedures, before using the tool on vibration exposed workers.

5.1.2 Vibration exposed group

The vibration exposed group consisted of group from two different mines the first (progression group) was a group previously diagnosed with HAVS, early HAVS or CTS in the HEALTH 703 study, and were re-assessed in the current study. The participants were brought to CSIR Miningtek's premises in Johannesburg, Auckland Park, where an air-conditioned room was used to perform all assessments. The participants had no vibration exposure for at least 16 hours before testing.

The second (cooler mine group) was a group of rock drill operators from Harmony Gold Mine formed part of the cooler mine group. This mine was considered as a cooler mine due to its workplace wet-bulb temperature less than 27 °C.

Only rock-drill operators were selected. Human-Resource Managers selected machine operators at random from the different stopes. The managers were not aware of the objectives of the study and therefore it can be assumed that they were unbiased in their selection of machine operators. Medical examinations, occupational history, standardised objective testing and screening tools were used in the assessments.

The study was first done at the medical centre of Harmony Gold Mine so that assessments could be done of any rock drill operators who came for their periodical medical examinations. Unfortunately, few rock drill operators had medical examinations scheduled at the time that the study was done at the medical centre, and it was decided to move the study to a specific shaft on the mine. The Cooke 3 shaft was decided upon and the medical clinic housed the equipment. Participants were first called up for participating in the morning before their shift, to be assessed for HAVS. This was considered to be a problem as it interfered with working hours, so it was decided by management that the rock drill operators would be paraded right after their shift.

Although the participants did not have 16 hour free from vibration in the current study, and this could result in a temporary vibration threshold shift, it would not alter the outcomes for the screening tools. The reason for no interference is that the screening tools were evaluated right after diagnosis for HAVS was performed and the vibration threshold shift will be remain the same.

5.1.3 Participants demographics

The pilot group consisted of 22 workers without any vibration exposure, and were only assessed using the screening tools. The group consisted of males of varying cultures; one Asian, four white and seventeen black. The average age and standard deviation can be seen in Table 5-1 for this group.

A total of 42 vibration-exposed study participants were assessed for HAVS, and assessed with the screening tools in this study. This vibration exposed group consisted of 21 from the progression group that were previously assessed and diagnosed with HAVS or CTS (Nyantumbu et al., 2002), and the other half was from the cooler mine where no previous assessments had been performed. The average ages and standard deviation for the individual groups and the combined vibration-exposed group can be seen in Table 6.1. All the participants in the groups were black males.

Table 5-1 Mean age, standard deviation and range of groups tested (years)

	Pilot	Progression	Cool Mine	Vibration Exposed
Mean Age	40.5	42	44	43.3
±SD	10.1	6.5	8	7
Range	23 - 60	30 - 52	28 - 57	28 - 57

The progression group were all right handed except for one participant that was ambidextrous. In the cooler mine group 81% were right handed with 14% left handed and the last 5% ambidextrous.

5.1.4 Evaluation of the screening tools

In the evaluation the pilot group results were included to increase the sample size, making statistical analysis of the data more reliable. All comparisons were done on participants diagnosed with HAVS and without. Table 5-2 indicates the sizes of the group exposed to vibration and the pilot group used in the analysis.

Table 5-2 Test groups used in screening tool analysis

Groups	Count	%
Vibration exposed group	42	65,6
Pilot group	22	34,4
Total	64	100

5.1.5 Occupations for vibration exposed group

The progression group were working at the mine for a mean (±SD) of 15.5 (±6.1) years, with a service range of 7-27 years. The cooler mine group had 15 (±6) years with a service range of 2-25 years. Table 5-3 lists the occupations of the participants during the study.

All participants at the cooler mine were rock-drill operators, except one who was a rock drill operator assistant, who claimed to often do the job of a rock drill operator.

Table 5-3 Occupations of study participants assessed in 2004

Occupations	Progression	Cooler Mine
Rock drill operator	15	20
Rock drill assistant		1
Driver	2	
Lamp room attendant	1	
Boiler maker	1	
Fitting shop	1	
Water services	1	
Total	21	21

5.2 Evaluation methods for the diagnosis of HAVS

Diagnosis of HAVS is based on symptoms and exposure history, examination and testing, as described by McGeoch (et al., 2005). The testing consists of three standardised objective testing methods, which form part of the evaluation of HAVS for possible compensation. No single test can accurately determine symptom severity in patients with HAVS, and therefore it has been recommended that a number of complementary tests be used (Coughlin et al., 2001).

HAVS can only be diagnosed if there is a history of vibration exposure and the presence of one of the aforementioned symptoms (Section 3).

5.2.1 Standardised objective testing

The technicians who received training applied the standardised objective testing. The tests were done according to the protocol used in the United Kingdom for the compensation of HAVS. In order to keep inter-operator variance constant, specific technicians conducted tests on only one machine where possible.

The pilot group was not evaluated using the standardised objective testing and no medical examinations were done. The standardised objective testing and medical examinations were only performed if there was a history of vibration exposure. Normative values for these tests have been studied and are published (Section 5.2.1.1 & 5.2.1.2).

The room temperature during the evaluation was kept at 22 ± 2 °C. The participants were allowed to acclimatise to the room conditions while they were informed of the study procedure and gave written consent. A requirement for assessment for HAVS is that participants should have had at least 16 hours free from any vibration exposure.

Participant finger skin temperature is taken for both hands before tests proceed. This is to ensure that finger skin temperature is not below 20°C. All standardised tests results were recorded and the outcomes were scored, indicating whether test results were normal or abnormal.

5.2.1.1 Neurological functions

The Thermal Aesthesiometry and Vibrotactile Threshold tests were done to evaluate neurological damage.

The fingers tested were the little and index fingers of both hands. These fingers are used to test both the ulnar and median nerves for abnormalities. Figure 5-1 shows the locations that can be used to test the ulnar and median nerves. If either the little or index fingers have been amputated, the ring and middle fingers are tested respectively. These fingers will still allow the different nerve functions to be tested for any abnormalities. The thumb is not tested as it has been observed that only in a small minority of cases is the thumb involved in attacks of white finger (Gösta et al., 1987).

If any inconsistencies were found in a test, the test was repeated, but the test could only be repeated three times due to the sensitivity of the pulp of the finger.

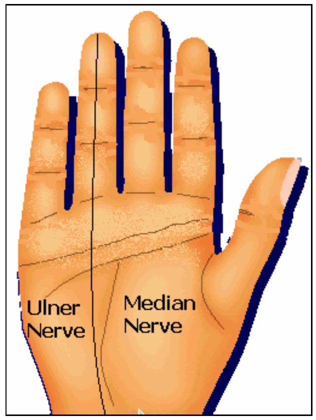

Figure 5-1 Ulner and median nerve location in fingers

5.2.1.1.1 Thermal aesthesiometery test

The apparatus for the thermal aesthesiometery test is used to determine the tactile thermal threshold, which gives an indication of sensorineural dysfunction in the fingertips.

The patient rests his finger on a metal plate while sitting comfortably with the elbow on a rest bench. Two consecutive tests are run per finger. In the first test the plate is heated from a reference temperature of 32,5 °C and in the second test it is cooled from the reference temperature. A response button is pressed by the technician when the participant indicates by saying "yes" that a change in temperature was felt. A thermal perception threshold was determined for both the hot and cold temperatures. The Thermal Neutral Zone (TNZ) is calculated by the difference between the hot and cold thermal thresholds and is the temperature range in which the participant is unable to feel any thermal variations. The software has a built-in safeguard to ensure that the participants are not injured: it returns to the reference temperature if the response button was not pressed before 55 °C or 10 °C was reached. The scoring of the test is given in Table 5-4.

Table 5-4 Scores for thermal aesthesiometry test

Thermal Neutral Zone	< 21°C	< 27°C	≥ 27°C
Score	0	2	4

A normal result is scored as 0 and an abnormal result is scored above >0 and ≤ 8. Both hands are scored separately.

A report is filled in by the technician for scoring the results and as a back-up of test results. The form is shown in Appendix G. Figure 5-2, and an example of the test results from the computer program that runs the testing procedure for the TA test is given.

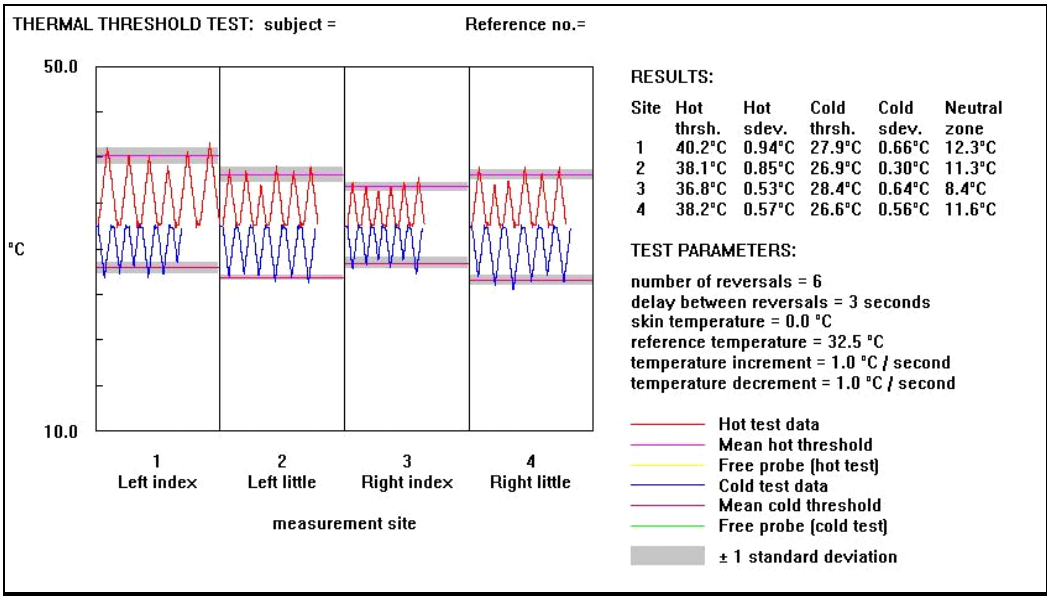

Figure 5-2 Test result example for thermal aesthesiometry test

5.2.1.1.2 Vibrotactile perception threshold test

Impairment of vibration perception is an early sign of vibration-induced nerve injury (Virokannas, 1992). The VTT is used for the determination of the tactile vibration threshold. The apparatus consists of an electrodynamic vibrator which drives a vibrating probe. The probe is connected to strain gauges that measure the force that the participant applies to the probe. The reading from the strain gauges is displayed on a voltmeter which indicates 1N. The participant is asked to keep the needle on this position throughout the test. The participant holds his finger on the probe while sitting comfortably and resting the elbow on an arm rest.

Two consecutive tests at 31,5 Hz and 125 Hz are performed per finger. The vibration of the probe is increased until the patient feels the vibration. When the patient perceives the vibration and acknowledges with "yes", the technician presses and holds a response button. The vibration of the probe is reduced and the response button is released when the patient acknowledges with "no" that no more vibration is felt.

A vibration perception threshold is calculated from the responses. The higher the vibration perception threshold, the more nerve damage is indicated in the hand and fingers. The scores for this test are given in Table 5-5.

Table 5-5 Scores for vibration threshold test

31.5 Hz	< 0.3 m/s^2	≥ 0.3 m/s^2 and < 0.4 /s^2	≥ 0.4 m/s^2
Scores	0	1	2
125 Hz	< 0.7 m/s^2	≥ 0.7 m/s^2 and < 1.0 /s^2	≥ 1.0 m/s^2
Scores	0	1	2

Each hand is scored separately. A score of 0 is normal and an abnormal test score is between >0 and ≤8. The technician completes a report for the score of results and as a back-up of the results. (see Appendix G).

Figure 5-3 shows test results from the computer program that runs the testing procedure for the VTT test.

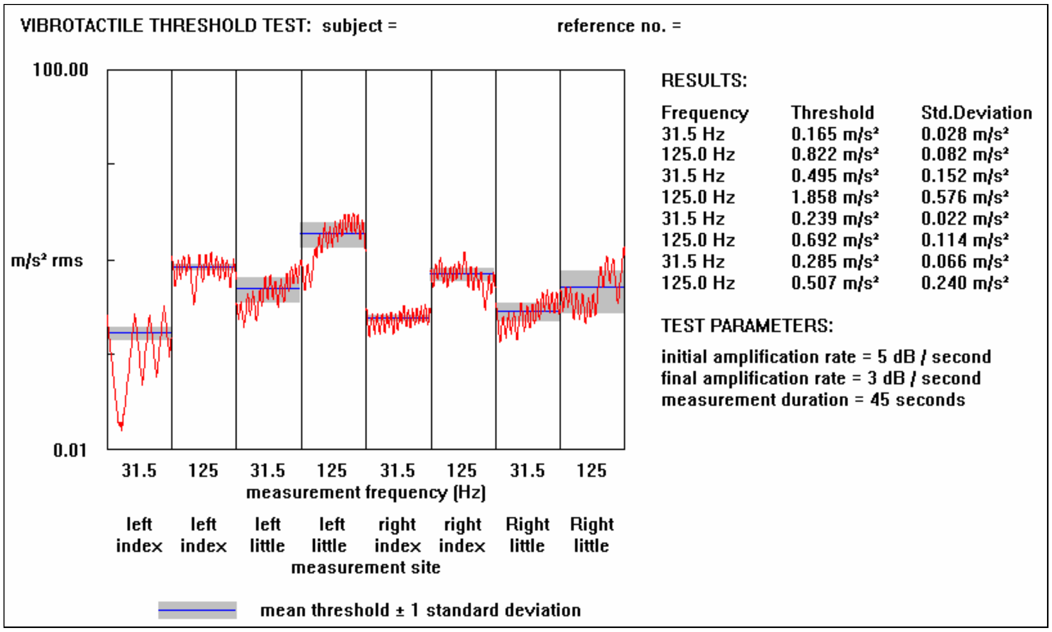

Figure 5-3 Test results example for the vibrotactile threshold test

5.2.1.2 Vascular functions

Fingertip re-warming time is measured after the hands have been soaked in a cold water bath at 15 °C. The rate at which the fingers re-warm gives an indication of the vascular dysfunction of the measured fingers.

This test was done after all the other examinations and tests to exclude interference with other test results due to the slow re-warming of the fingers caused by possible vascular damage.

5.2.1.2.1 Cold provocation test

Thermocouples are attached to all the fingers, excluding the thumbs, of both hands. The hands are gloved to protect the thermocouples and keep the hands dry. A period of 5 minutes for finger temperature stabilisation is taken after which the hands are placed in cold water at 15 °C for 5 minutes. After 5 minutes the hands are taken out of the bath and the gloves are removed. The time taken for the hands to re-warm by 4 °C is recorded. The scores for this test are given in Table 5-6.

Table 5-6 Scores for cold provocation test

Time for re-warming	≤ 300 sec	> 300 and ≤ 600 sec	> 600 sec
Scores	0	1	2

A score of 0 is normal and an abnormal test score is between >0 and ≤8.
The technician's report for this test can be seen in Appendix G. Figure 5-4 is an example of a test from the computer program that runs the procedure for the CPT test.

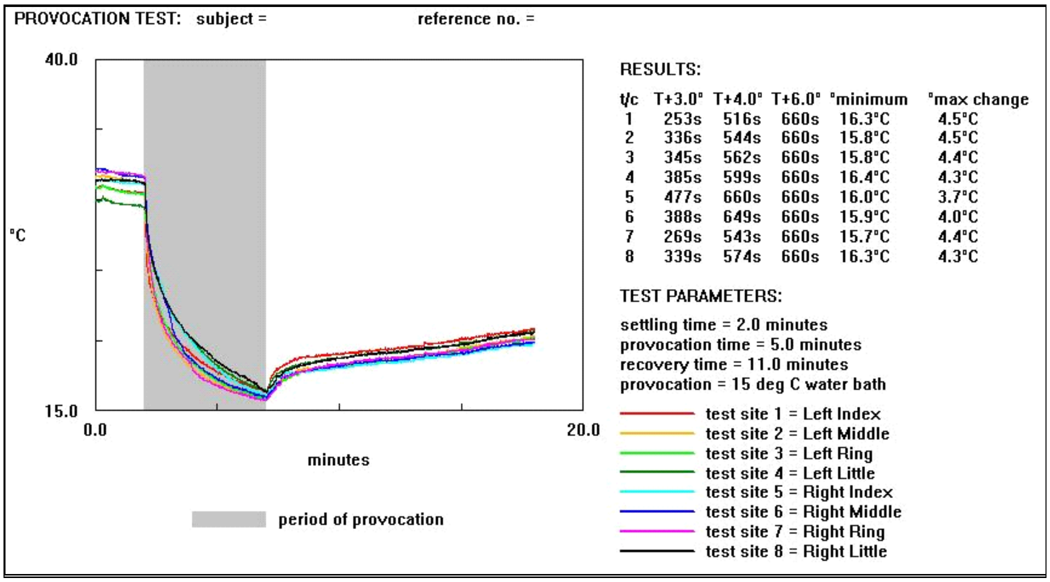

Figure 5-4 Test results example for a cold provocation test

5.2.2 Medical examination

The medical examination question paper used in the current study can be found in Appendix D, followed by summary pages of the standardised objective tests (Appendix F) and a summary of all other test results, (Appendix E).

5.2.2.1 Physical examination

An examination of the hands, fingers and upper body were carried out by an occupational medical specialist. This was to determine whether any callosities, scars, trophic changes or skeletal abnormalities were present. Blood pressure was measured in both arms.

5.2.2.2 Allen test

This is a test for the integrity of the radial and ulnar artery supply to the arm. The examiner compresses the patient's radial and ulnar arteries at the wrist. The patient is then asked to open and close the hand rapidly until the blood is emptied out of the vessels of the hand. The examiner releases either the radial or the ulnar artery. A prompt flushing of blood to the fingers (within 60 seconds) indicates a normal contribution from the tested artery. The test is then repeated, releasing the other artery.

5.2.2.3 Phalen test

In the Phalen test both hands are held tightly, palmar flexed (opposite to a prayer position) with the arms held horizontally. This creates an angle of at least 90 degrees between the forearm and the hand. The test is positive if a subject experiences a tingling sensation in the first three fingers.

5.2.2.4 Tinel test

This test is used to determine symptoms of carpal tunnel compression. The subject's hand and forearm are placed horizontally on a flat, hard surface with the hand supine. A tendon hammer is used to tap the median nerve at the carpal tunnel. A response of tingling in the first three fingers indicates median nerve compression at the wrist.

5.2.2.5 Adson test

This test is used to detect any obstruction of the arterial flow to the arm at the level of the neck. The subject is asked to stand with the arm extended laterally at the level of the shoulder. While the arm is extended, the head is rotated to the side being examined. The subject is instructed to take a deep breath and hold it in while the radial artery at the wrist is palpated. The test is normal if the radial pulse is present and abnormal if it is absent or reduced.

5.2.2.6 Purdue Pegboard

This test assesses the dexterity and speed of the fingers and hands. The right and left hands are tested separately and then simultaneously. The participant picks up pins out of a bowl and assembles them on a board into specified holes. 30 seconds are allowed per test. The number of pins assembled on the board is counted. A normal score for each hand is ≥ 13 pins and for both hands ≥ 9 pins, Figure 5-5.

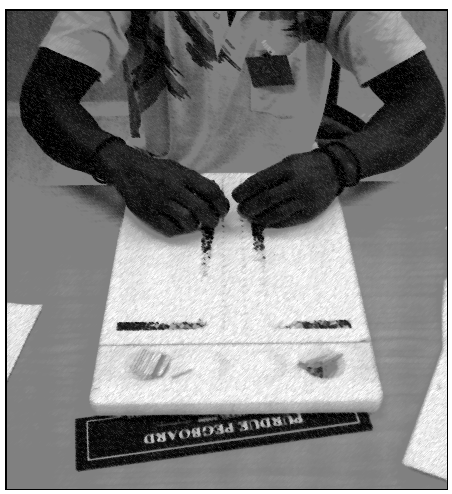

Figure 5-5 Purdue Pegboard test

5.2.2.7 Maximum grip strength

This test assesses the muscle strength of the hands and forearms. The participant sits in a comfortable position with the elbow flexed at 90°. The participant holds a dynamometer in one hand and squeezes the handle of the dynamometer as hard as possible. The instrument records the force exerted on the handle in kilograms. In this study the test was repeated three times, and an average reading was taken. An average reading of ≥ 33 kg is taken as normal and < 33 kg as abnormal.

Factors that can affect the grip strength are height, weight, age, sex, hand dominance, occupation and hobbies. This instrument measures the maximum momentary force in the hand.

5.2.3 Occupational history

The occupational history was obtained from all the study participants. Exposure to a rock drill was specifically asked about and the number of years of hand vibration transmitted from the rock drill, at the current mine and at other mines, was recorded. The question paper used in this study can be found in Appendix C.

5.3 Screening tool protocol

An explanation of the screening-tool tests was given to the participants in their own language, and they were asked if the test procedure was understood. The screening tests were performed on the thumb, middle and ring fingers of both hands. Three tests per finger, to determine an average, per tool were administered, and the average of these tests was used to obtain the final results for a specific finger and test.

The tests were conducted in a quiet room with subjects seated comfortably. They were provided with ear muffs to ensure that the vibrations of the tuning fork and tuning box were felt and not heard. The two-point discriminator test did not need ear protection as no sound is emitted. Subjects were asked to keep their eyes closed during all tests.

A test run for each screening tool was done on mainly the middle finger. If this finger had been amputated the little finger was used. Grunert (et al., 1990) found that an initial trial allowed patients to sensitise themselves to the nature of the stimuli, which resulted in more consistent reporting of the vibratory sensation. This is particularly important if the tool is to be used for clinical evaluation of patients with possible HAVS.

Each test lasted proximally four seconds per finger, and if no response was given within this time the subjects were asked if they had felt anything.

In the tuning fork and tuning box tests the participants were asked to indicate with a nod of the head if any vibration was felt. In the two-point discriminator test the participants were asked to say “two” if they felt two pin pricks on their finger or “one” when only one was felt. The two-point discriminator had three different distances to be tested on a finger. The sequence of the tests was varied to ensure that the participants indicated what they felt and not what they thought would come next.

The tuning fork was applied perpendicularly with the foot touching and resting on its own weight against the fleshiest part of the finger (see Figure 5-6) for the test position on the fingers. The participants were seated with palms facing upwards. The same test sites and hand position was used in the two-point discrimination tests.

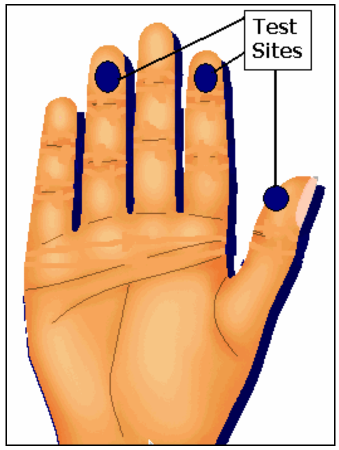

Figure 5-6 Test sites for the tuning fork and two-point discriminator

The test position was changed for the tuning box, with the front part of the fingertip being tested on the same three fingers (see Figure 5-7). The participant was seated in the same position as for the tuning fork test except that the palms of the hands faced down.

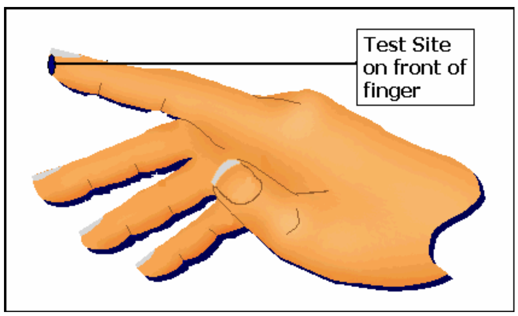

Figure 5-7 Test sites for tuning box

5.4 Possible biases

Factors that might influence the results of the data retrieved from the study are described in the following section.

5.4.1 Skin temperature

The vibration threshold in the fingertips is influenced by the skin temperature of the fingers. Green (1977) examined the effect of skin temperature on the detection of vibrotactile stimuli at frequencies of 30 and 250 Hz. It was found that temperature had a negligible effect on sensitivity at the lower frequencies of 30 Hz. The sensitivity at the higher frequency had a U-shape as a function of skin temperature.

Figure 5-8 illustrates the relation between the skin temperature of the fingers and the threshold level at 30 and 250 Hz.

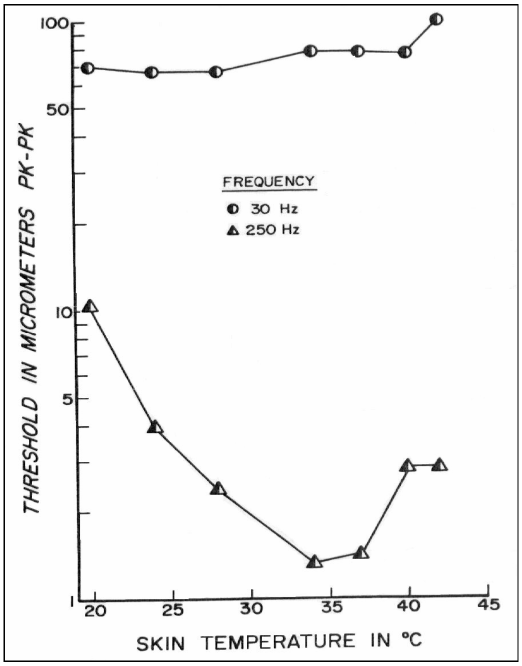

Figure 5-8 Vibration threshold at skin temperatures for two vibration frequencies (Green, 1977)

Hilz (et al., 1998) concluded that initial warming of the skin to a standardised temperature of 34 °C or 35 °C is not required. He recommended that the tested areas only need warming when the pre-test skin temperature is lower that 25 °C.

5.4.2 Vibration exposure

Participants should have a vibration-free period of at least 16 hours (Nyantumbu et al., 2002) before the assessments are done. If not, this may lead to a temporary vibration threshold shift that could influence the results of the evaluation.

The participants who were assessed after their shift appeared tired and were not fully concentrating. This might have had an influence on the test results, as the participants wanted to complete the tests as quickly as possible.

5.4.2.1 Participants exposure history

The exposure history to only rock-drill vibration did not only include exposure at the current mine but also included previous work at other mines. The average, standard deviation and range of vibration exposure can be seen in Table 5-7.

Table 5-7 Average, standard deviation and range of years exposed to vibration

Years	Vibration exposed group
Mean	13.7
±SD	8.7
Range	0 - 31

One participant only had a week exposure to rock drill vibration. This was taken as no vibration exposure. A breakdown of the participant group percentages in a certain vibration exposure range are given in Table 5-8.

Table 5-8 Percentage of participants in certain exposure ranges

Exposure Group (years)	Subjects	
	N	%
0	1	2.4
<5	5	11.9
5-9	10	23.8
10-14	10	23.8
15-19	4	9.5
20+	12	28.6

5.5 Analysis of data

The analysis of the data for the study were performed by the Statistical Consultation Service at the University of Johannesburg, using the software Statistical Package for Social Sciences (SPSS). Tests used during the statistical evaluation were decided on by the consultation service.

The Independent-Samples T Test which is a parametric test compares means for two groups of cases. Ideally for this test, the subjects should be randomly assigned to two groups, so that any difference in response would be due to the treatment (or lack of treatment) and not to other factors.

Phi is a chi-square-based measure of association that involves dividing the chi-square statistic by the sample size and taking the square root of the result. **Cramer's V** is a measure of association based on chi-square.

Chi-square tests the hypothesis that the row and column variables are independent, without indicating strength or direction of the relationship. **Pearson chi-square**, likelihood-ratio chi-square, and linear-by-linear association chi-square are displayed. **Fisher's exact test** and Yates' corrected chi-square are computed for 2 x 2 tables.

McNemar is a nonparametric test for two related dichotomous variables. It tests for changes in responses using the chi-square distribution and is useful for detecting changes in responses due to experimental intervention in "before-and-after" designs. For larger square tables, the McNemar-Bowker test of symmetry is reported.

The Mann-Whitney U test is the most popular of the two-independent-samples tests. And is a non-parametric equivalent of the T-test. It is equivalent to the Wilcoxon rank sum test and the Kruskal-Wallis test for two groups. Mann-Whitney tests whether two sampled populations are equivalent in location. The observations from both groups are combined and ranked, with the average rank assigned in the case of ties. The number of ties should be small relative to the total number of observations. If the populations are identical in location, the ranks should be randomly mixed between the two samples. The number of times a score from group 1 precedes a score from group 2 and the number of times a score from group 2 precedes a score from group 1 are calculated.

The Crosstabs procedure forms two-way and multi-way tables and provides a variety of tests and measures of association for two-way tables. The structure of the table and whether categories are ordered determine what test or measure to use.

Linear Regression estimates the coefficients of the linear equation, involving one or more independent variables that best predict the value of the dependent variable.

The Paired-Samples T test procedure compares the means of two variables for a single group. It computes the differences between values of the two variables for each case and tests whether the average differs from 0.

Wilcoxon Signed-Rank test procedure compares the distributions of two variables.

The Bivariate Correlations procedure computes Pearson's correlation coefficient, Spearman's rho, and Kendall's tau-b with their significance levels. Correlations measure how variables or rank orders are related.

5.6 Screening tool decision matrix

In the search for a screening tool for HAVS, few reports were found that specified tool sensitivity and specificity. These exclusions made it difficult to decide on what tool would be suitable for screening for HAVS. In the end, a multi criteria decision matrix was used to evaluate the different tools. The criteria used for comparison was that mentioned in Section 3.1. For each criteria used in the decision matrix a weighting values was given to the outcomes in a criteria for each tool. The criteria used and the outcome of each criteria were:

- Tool size, the tool was considered small when it was the size of a female hand, a medium-sized tool was bigger than this, and a large tool was considered to be a tool that needed a table surface to support it;
- Test time was regarded as short if it took less than five minutes per test, medium from five to ten minutes and long when it took more than ten minutes;
- Patient understanding was labelled as easy if the patient did not need instructions to understand the gist of the test, medium if some instruction was needed and difficult when the patient was unable to understand the test without an initial trial;
- The cost was seen as low if a tool cost less than R500, medium if it cost from R500 to about R5 000 and high when the cost exceeded R5 000. Costs were calculated according to pricing for 2004;
- The ease of reporting was considered easy if no data translation had to be done, e.g. reporting only “Yes” or “No”. Medium was considered to include some translation of data, e.g. an average of three tests is required. Difficult reporting was seen as a test needing data translation and manipulation;
- Consistency in testing was constant if the test produced the same result for two different tests, average if inconsistency could be controlled by training and inconsistent if training was insufficient but more experience was needed to apply the test;
- The ease of administering the test was considered easy if no extensive training was needed to administer the tests, medium if some training was necessary and difficult if extensive training was necessary;

- An indication if any interaction between the administrator and the test was necessary that could skew the test results;
- An indication if tests could be repeated if any abnormalities occurred in the previous test.

Table 5-9 Weight values for outcomes of each criteria

Criteria	Outcome	Weight	Outcome	Weight	Outcome	Weight
Tool size	Small	2	Medium	1	Large	0
Test time	Short	2	Medium	1	Long	0
Patient understanding	Easy	2	Medium	1	Difficult	0
Tool cost	<R500	2	R500-R5000	1	>R5000	0
Ease of reporting	Easy	2	Medium	1	Difficult	0
Consistency of testing	Consistent	2	Inconsistent	1	Inconsistent	0
Ease of administering	Easy	2	Medium	1	Difficult	0
Administrator interaction	Yes	2	No	1		
Test repeatability	Yes	2	No	1		

Table 5-9 list the weighting values for outcomes of each criteria and Table 5-10 is the multi criteria decision matrix using all weighting values. The last column in the decision matrix is a sum of all the criteria weighting values for one screening tool. The nail compression test is a test performed with out a tool, and under the size of tool criteria the nail compression test received the highest weighting value.

From the decision matrix it is evident that the two-point discriminator, traditional tuning fork and the tuning box had the best results according to the matrix. This was supported by consultation with industry specialist Lars Berregard, who was of the opinion that the two-point discriminator should be more reliable and specific for HAVS than a tuning fork. It was therefore decided to evaluate the two-point discriminator, traditional tuning fork and the tuning box for a possible screening tool for screening of workers most likely to have HAVS.

Table 5-10 Multi criteria decision matrix for the choosing of screening tools for evaluation

Screening Tools	Tool Size	Test Time	Patient Understanding	Tool Cost	Ease of Reporting	Consistency of Test	Easy of Administering	Administrator Interaction	Test Repeatability	Screening Tool Score
Nail Compression	2	2	2	2	2	0	2	1	1	**14**
Finger Temperature	0	2	2	0	1	2	2	2	2	**13**
Light Touch	2	2	2	2	2	1	2	1	2	**16**
Pain Sense	2	2	2	2	1	0	0	1	1	**11**
Two Point Discriminator	2	2	2	2	2	1	2	2	2	**17**
Monofilaments	2	1	2	1	2	2	2	2	2	**16**
Traditional Tuning Fork	2	2	2	2	2	1	2	2	2	**17**
Tuning Box	2	2	2	2	2	1	2	2	2	**17**
Graduated Tuning Fork	2	2	2	1	2	1	2	2	2	**16**
Vibration Sensimeter	0	0	0	0	0	2	1	2	2	**7**
Grip Force	1	1	2	2	1	2	2	2	2	**15**
Pinch Force	2	1	2	2	1	2	2	2	2	**16**
Finger Tapping Test	1	1	1	1	1	2	2	2	2	**13**
Pick Up Test	2	1	1	2	1	2	2	2	2	**14**

6 Results

6.1 HAVS diagnosis

6.1.1 Introduction

This study was concerned with whether participants were diagnosed with HAVS or not, and not the severity of HAVS. The screening tools are only to identify workers with possible HAVS, and not as an assessment tool. in the vibration-exposed group, 28 participants were diagnosed with HAVS, while 14 did not have HAVS.

None of the medical aspects will be discussed in this study. A detailed breakdown can be found in SIMRAC HEALTH 806. Only tools used in the diagnosis will be discussed. The medical examination tools, which consisted of the grip strength and the Purdue Pegboard, were also studied as possible screening tools. The finger skin temperature and standardised objective tests were also included in this comparison.

6.1.2 Results for medical examination tools, finger skin temperature and standardised objective test

The abnormal grip strength and Purdue Pegboard results for the vibration-exposed group can be found in Table 6-1.

Table 6-1 Abnormal grip strength and Purdue Pegboard in the diagnosed HAVS population

	HAVS Diagnosed Participants	
	N	%
Right Grip Strength	2	4.8
Left Grip Strength	4	9.5
Right Purdue Pegboard	30	71.4
Left Purdue Pegboard	36	85.7
Both Purdue Pegboard	30	71.4

The mean (±SD) and range of the finger skin temperature measurements, for the right and left hands, are given in Table 6-2. One participant had extremely low finger skin temperatures, and it was decided to continue and perform all the tests terminating any test the moment the participants felt any discomfort. This decision was made due to the already limited sample size. The results of this participant would not influence the outcome of any results, owing to the low frequencies of the VTT. These frequencies are in the lower ranges that are not influenced by finger skin temperature. Four participants had finger skin temperatures below 25°C in the right hand with only one of these not with HAVS. On the left hand, only three participants had low finger skin temperatures, again with only one not having HAVS.

Table 6-2 Finger skin temperature average, standard deviation and range for the right and left hands

Temperature (°C)	Temperature of right hand	Temperature of left hand
Mean	30.5	30.4
±SD	3.9	3.7
Range	20.8 - 36	20.9 – 35.8

The pilot group did not perform the standardised objective test, as the test can only be performed on persons exposed to vibration. Five participants of the vibration exposed group did not perform the standardised objective CP test because of medical reasons (high blood pressure). One participant had an amputated right middle finger and two other participants had amputated right little fingers for religious reasons. For this reason VTT and TA tests were done on the right ring fingers and these fingers were disregarded in the CPT. Test results for the different standardised objective test, are given in Table 6-3.

Table 6-3 Standardised objective test results

Standardise Objective Test		Progression Group N	%	Cool Mine Group N	%	Vibration Exposed Group N	%
Thermal Aestesiometry							
R Index Finger	Abnormal	12	57.1	10	47.6	22	52.4
	Normal	9	42.9	11	52.4	20	47.6
R Little Finger	Abnormal	16	76.2	16	76.2	32	76.2
	Normal	5	23.8	5	23.8	10	23.8
L Index Finger	Abnormal	9	42.9	11	52.4	20	47.6
	Normal	12	57.1	10	47.6	22	52.4
L Little Finger	Abnormal	12	57.1	11	52.4	23	54.8
	Normal	9	42.9	10	47.6	19	45.2
Vibrotactile Threshold (31.5Hz)							
R Index Finger	Abnormal	16	76.2	12	57.1	28	66.7
	Normal	5	23.8	9	42.9	14	33.3
R Little Finger	Abnormal	14	66.7	12	57.1	26	61.9
	Normal	7	33.3	9	42.9	16	38.1
L Index Finger	Abnormal	15	71.4	10	47.6	25	59.5
	Normal	6	28.6	11	52.4	17	40.5
L Little Finger	Abnormal	14	66.7	12	57.1	26	61.9
	Normal	7	33.3	9	42.9	16	38.1
Vibrotactile Threshold (125Hz)							
R Index Finger	Abnormal	16	76.2	14	66.7	30	71.4
	Normal	5	23.8	7	33.3	12	28.6
R Little Finger	Abnormal	18	85.7	15	71.4	33	78.6
	Normal	3	14.3	6	28.6	9	21.4
L Index Finger	Abnormal	14	66.7	12	57.1	26	61.9
	Normal	7	33.3	9	42.9	16	38.1
L Little Finger	Abnormal	16	76.2	15	71.4	31	73.8
	Normal	5	23.8	6	28.6	11	26.2
Cold Provocation							
R Index Finger	Abnormal	11	52.4	7	33.3	18	42.9
	Normal	7 (3)	33.3	12 (2)	57.1	19 (5)	45.2
R Middle Finger	Abnormal	11	52.4	11	52.4	22	52.4
	Normal	6 (4)	28.6	9 (1)	42.9	15 (5)	35.7
R Ring Finger	Abnormal	13	61.9	10	47.6	23	54.8
	Normal	5 (3)	23.8	10 (1)	47.6	15 (4)	35.7
R Little Finger	Abnormal	11	52.4	11	52.4	11	26.2
	Normal	7 (3)	33.3	8 (2)	38.1	15 (5)	35.7
L Index Finger	Abnormal	10	47.6	8	38.1	18	42.9
	Normal	8 (3)	38.1	12 (1)	57.1	20 (4)	47.6
L Middle Finger	Abnormal	11	52.4	12	57.1	23	54.8
	Normal	7 (3)	33.3	8 (1)	38.1	15 (4)	35.7
L Ring Finger	Abnormal	12	57.1	12	57.1	24	57.1
	Normal	6 (3)	28.6	8 (1)	38.1	14 (4)	33.3
L Little Finger	Abnormal	11	52.4	9	42.9	20	47.6
	Normal	7 (3)	33.3	11 (1)	52.4	18 (4)	42.9

* Amount in brackets is fingers excluded from test

6.2 Screening tool results

From discussions held with the Statistical Consultation Services form the University of Johannesburg, it was decided that a any results with a difference of 5% and more were considered significant. A tabular format of the results for the screening tools can be found in Appendix I.

6.2.1 Tuning fork

In the comparison between the right and left hands for the HAVS group, no difference was found for the thumb and index fingers. A difference of around 10% was detected between the two hands for the ring finger. The non-HAVS group had about a 3% difference between left and right hand for all fingers.

A comparison between the fingers showed that the thumb and index fingers were similar, with around a 3% difference in the HAVS group and no difference in the non-HAVS group. The difference between the ring finger and the other fingers was around 10% in the HAVS group and 3% in the non-HAVS group.

In comparison between HAVS and non-HAVS for the positively identification of vibration of the tuning fork, a small difference between the thumb and the index fingers in both hands, for the HAVS group. Only the results for the thumb with results for both right and left hand in the ring finger stated. The HAVS group positively identified the vibration of the tuning fork in 92,9% of the cases, with the non-HAVS identifying 100% ($p = 0,188$) of the time. The right hand ring finger had a positive identification of 78,6% for HAVS and 97,2% ($p = 0,037$) non-HAVS groups. For the left hand ring finger this was 89,3% for HAVS and 100% ($p = 0,079$) non-HAVS.

6.2.2 Tuning box

The tuning box test showed no significant differences in the HAVS group between the index fingers of the right and left hands, when comparing the left and right hands. There was around a 5% difference for the thumb and a 25% (significant) difference for the ring finger between the right and left hands. In the non-HAVS group there was no difference for the thumb, an 11,1% difference for the index finger, and a 19,5% difference for the ring finger, between the two hands.

A comparison between the fingers the, thumb and ring finger showed a 7,2% difference for the HAVS group and a 5,5% difference for the non-HAVS group. When the index finger was compared to the ring finger differences of 14,3% for the HAVS and 11,2% for the non-HAVS groups were found.

In comparison between HAVS and non-HAVS group positively identifying the vibration of the tuning box, variances in most fingers were seen and results for all fingers and hands were considered, Table 6-4 list these percentages of correctly identified vibration from the tuning fork. From the table it is clear that the for the non-HAVS group large percentages correctly identified the vibration of the tuning box, and the lowest level was for the right hand ring finger, a similar result was seen in the HAVS group with the same finger having the lowest percentage. Over all the highest percentages were seen in the left hand for the non-HAVS group with again the HAVS group having similar results.

Table 6-4 Percentages of positive identification of tuning box vibration by the different groups in right and left hands

Finger Tested		Right (%)	Left (%)
Thumb	HAVS	53.6	57.1
	Non HAVS	86.1	86.1
		p=0.005	p=0.012
Index	HAVS	46.4	46.4
	Non HAVS	80.6	91.7
		p=0.007	p=0.000
Ring	HAVS	32.1	57.1
	Non HAVS	69.4	88.9
		p=0.005	p=0.008

6.2.3 Two-point discriminator

In the 3mm test for the thumb and index fingers, a 10.7% (significant) difference between the left and the right hands was found in the HAVS group. The difference between the right and left hand for the ring finger was 3.6%. The non-HAVS group had 2,8%, 0% and 8,3% (significant) differences between the right and left hand for the thumb, index and ring fingers, respectively.

Table 6-5 Percentages of positive identification of two points for two point discriminator by the different groups in right and left hands

Finger Tested		3mm		6mm		10mm	
		Right (%)	Left (%)	Right (%)	Left (%)	Right (%)	Left (%)
Thumb	HAVS	10.7	0.0	82.1	75.0	92.9	92.9
	Non HAVS	22.2	25.0	91.7	86.1	100	100
		p= 0.322	p=0.004	p=0.282	p=0.338	p=0.188	p=0.188
Index	HAVS	25.0	14.3	71.4	60.7	85.7	92.9
	Non HAVS	27.8	27.8	91.7	94.4	100	100
		p=1.000	p=0.235	p=0.047	p=0.001	p=0.032	p=0.188
Ring	HAVS	3.6	0.0	53.6	46.4	96.4	89.3
	Non HAVS	16.7	25.0	80.6	86.1	100	100
		p=0.125	p=0.004	p=0.030	p=0.001	p=0.438	p=0.079

Table 6-5 list the percentages for the HAVS and non-HAVS groups for positively identifying two points for the two-point discriminator test, on the different fingers.

From the table it is clear that none of the HAVS group could feel the two points in the thumb and the ring fingers for the left hand, for the 3mm test. The index finger for the left hand for the HAVS group was very low, (14,4%). Also, the right hand had low results again with the highest for the index with 25%, positively identifying two points.

Low percentages were also seen in the non-HAVS group for the 3mm test, for the left hand ranging from 25 to 27,8%, and the right hand from 16,7 to 27,8%. Again, the highest results were for the index finger.

The only significant difference between the HAVS and non-HAVS groups was seen for the right index finger, in the 3mm test (p = 1).

The 6mm test for the HAVS group had percentages for correctly identifying two points from 46,4 to 75% for the left hand and 53,6 to 82% for the right hand. The highest percentage was seen in the thumbs for both left and right hand.

The non-HAVS group had overall higher percentages than the HAVS group. The highest was seen in the left index with 94,4%, followed by the right thumb and right index both with 91,2%. No significant difference was seen in any of the fingers for the 6mm test. The results for the 6mm test were the opposite of those for the 3mm test in that more non-HAVS were picked up correctly compared to the more HAVS in the 3mm test.

No difference was found in the right and left hands for the non HAVS group in the 10mm test. The HAVS group had about a 7% difference in only the index and ring fingers, with the thumb having no difference. The HAVS group had percentage of correctly identified to points ranging from 89,3 to 92,9% for the left hand. The right hand had slightly higher results ranging from 85,7 to 96,4%. From the 10mm test the highest percentages where seen in the thumb and index for the left hand with the ring finger having the highest for the right hand.

The non-HAVS group had 100 per cent correctly identified two points in all fingers, in both hands. No significant difference was seen between the HAVS and non-HAVS groups.

6.3 Comparison between screening tools

Figure 6-1 and Figure 6-2 show the results of the screening tools that correctly identified the HAVS and the non-HAVS groups.

Both the tuning fork and the two-point discriminator set at 10mm had 100% identification of the non-HAVS group, but with a very low HAVS identification. The sensitivity and specificity of these tools are discussed further in Section 7.2. The tuning box had all-round average results for both non-HAVS and HAVS. The 3mm and 6mm two-point discriminator results are inverted. When comparing results for the 3mm and 6mm two-point discriminator results, an inverse is seen. The 3mm test had a high percentage of correctly identifying the HAVS group, where as, the 6mm test had a high percentage correctly identifying the non-HAVS group.

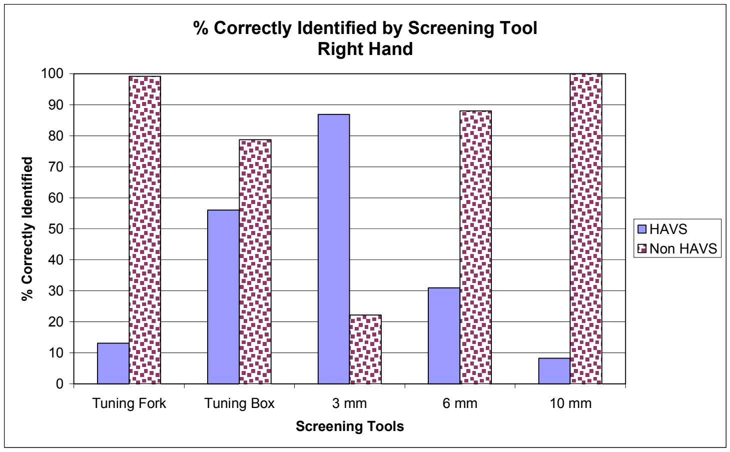

Figure 6-1 HAVS and Non HAVS correctly identified by screening tools for the right hand

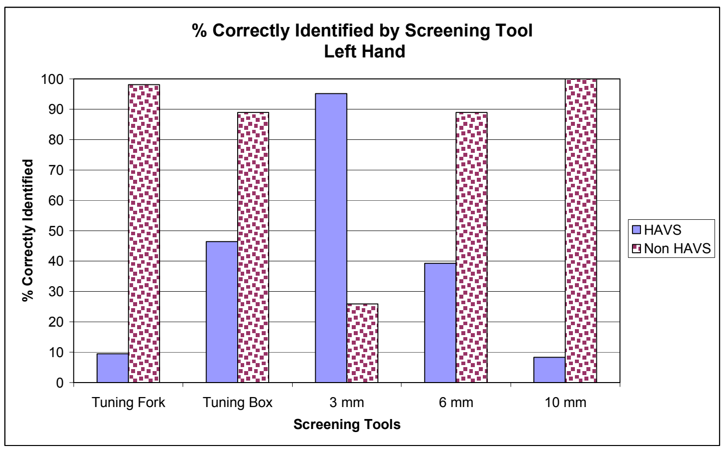

Figure 6-2 HAVS and Non HAVS correctly identified by screening tools for the left hand

Similar results can be seen for the left and the right hands. The tuning fork and 3mm and 6mm two-point discriminator tests show small differences in the HAVS group, but no significant differences. The tuning box test was the only test with a difference in the non-HAVS group and showed with better results when using the left hand.

6.4 Screening questionnaire results

The mean age (SD) obtained from the questionnaire was 42.26 years (±7.97), and the maximum and minimum ages were 60 and 23 (p = 0,107), respectively.

In the group diagnosed with HAVS, the mean years (SD) worked with a rock drill were 12,36 (±7,94) compared to the 5,42 (±8,85) years in the non-HAVS group (p = 0.911). The number of hours worked per day were 5,46 (±3,3) for the HAVS and 2,19 (±3,45) for the non-HAVS groups (p = 0.63).

Table 6-6 Percentage HAVS- and non-HAVS indicating symptoms on screening questionnaire

Symptoms		Yes (%)	No (%)	p-value
Tingling in fingers	HAVS	78.6	21.4	0.019
	Non-HAVS	47.2	52.8	
Problem with movement of fingers	HAVS	42.9	57.1	0.001
	Non-HAVS	5.6	94.4	
Pain in hands	HAVS	39.3	60.7	0.016
	Non-HAVS	11.1	88.9	
Swelling of hands	HAVS	25	75	0.035
	Non-HAVS	5.6	94.4	
White fingers	HAVS	67.9	32.1	0.00
	Non-HAVS	13.9	86.1	

Table 6-6 shows the percentage of the diagnosed HAVS and non-HAVS groups with specific symptoms. In all cases, the percentage with symptoms was higher in the HAVS group, and the prevalence's of all symptoms were significantly different between the two groups. Tingling and white fingers were the symptoms with the highest prevalence's in the HAVS group (78.6% and 67.9%, respectively).

There were no differences in injury to the upper body between the HAVS and non-HAVS group (64,3% and 58,3% respectively). Medication intake again showed no difference, with 78,6% of the HAVS and 69,4% of the non-HAVS group not taking any medication.

Two symptoms (problem with movement of fingers and swelling of hands) had very interesting results when considering the non-HAVS group results. In both symptoms 94,4% of non-HAVS participants indicated to never having these symptoms. This is a valuable result and indicates that any person with either one of these symptoms most likely has HAVS.

7 Discussion

7.1 Medical examination tools, finger skin temperature and standardised objective tests

Tools used in the medical examination, grip strength and Purdue pegboard test and the finger skin temperature, have been compared using the tool sensitivity, specificity and positive predictive values. The results of this comparison can be seen in Table 7-1. A similar exercise was completed for the standardised objective tests. These results are in Table 7-2.

Table 7-1 Sensitivity, specificity and positive predictive values for the medical examination tools

Medical Examination Tools	Sensitivity	Specificity	PPV
Purdue pegboard - Right	67.9	14.3	61.3
Purdue pegboard - Left	89.3	21.4	69.4
Purdue pegboard - Both	75	35.7	70
Grip strength – Right	0	100	0
Grip Strength – Left	10.7	92.9	75
Finger skin temperature – Right	14.3	92.9	80
Finger skin temperature - Left	10.7	92.9	75

PPV – positive predictive values

Table 7-2 Sensitivity, specificity and positive predictive values for the standardised objective tests

Standardised Objective Tests	Sensitivity	Specificity	PPV
TA - Right	78.6	21.4	66.7
TA - Left	64.3	57.1	81.8
VTT 31.5 Hz - Right	71.4	28.6	66.7
VTT 31.5 Hz – Left	78.6	42.9	73.3
VTT 125 Hz – Right	67.9	21.4	63.3
VTT 125 Hz – Left	82.1	42.9	74.2
CPT – Right	71.4	35.7	69
CPT - Left	71.4	14.3	62.5

PPV –positive predictive value
TA – Thermal Aesthesiometry
VTT – Vibration Threshold Test
CPT - Cold

From the above tables it is clear that the grip strength test did not show good results in the identification of HAVS cases. The participants that performed these tests do physical labour. Owing to their strength the grip strength test was not very sensitive on this population. The Purdue pegboard had better results when compared to the grip strength. The specificity of this test, however, was below 36% in all cases. The finger skin temperature had good specificity and positive predictive values. but the sensitivity of the tool is extremely low.

In the standardised objective tests, the overall test results were higher than those of the medical examination tools and skin temperature, with only the TA test in the left hand with a high specificity. The left hand results for the VTT were good in all tests. This can be an indication of the dominant hand having more symptoms that that of the other hand. The highest sensitivity was seen in the VTT for 125 Hz in the left hand. Only one specificity was above 50% and that was for the TA, in the left hand. The positive predictive values were very high overall, with not one test falling under 62%. The highest predictive value was for the left TA test.

7.2 Screening tools

The tuning fork detected between 97,2% and 100% of non-HAVS cases in the three fingers tested, but the tool was not successful in detecting cases of HAVS. The highest percentage of HAVS cases correctly identified was 10,7%. No difference was found between the left and the right hand results. This tool could be of use in eliminating workers with no vibration perception loss, but could not be used to screen possible HAVS patients, even with a high sensitivity (71,7%) the specificity (36,9%) and positive predictive value (12,9%) where very low. This tool would me more suited for eliminating workers with no vibration perception loss than for identifying possible HAVS cases.

The tuning box detected between 69,4 % and 91,7% of the non-HAVS cases in the different fingers tested. The detection of HAVS cases ranged from 42,9% to 67,9% for the three fingers tested. This test showed better results, than the tuning fork, when comparing specificity (68,6%) and positive predictive value (51,2%). This test again could be more useful as a test excluding worker with no vibration perception loss, than for including workers.

The two-point discriminator, set at a distance of 3mm, showed better detection rates for the HAVS group, ranging from 75% to 96,4%, compared to the detection rate of 16,7% to 27,8% for the non-HAVS group, in the right hand. The opposite occurred for the 6mm distance, where the correct detection of the HAVS group ranged from 17,9% to 46,4% compared to 80,6% to 91,7% of the non-HAVS. These three tools could be used in conjunction to exclude or include a worker in a full HAVS evaluation. The same results were seen with the left hand, except that the correct identification of the HAVS group for the 3mm test was 100%, compared to 25% for the non-HAVS group.

Table 7-3 shows the sensitivity, specificity and positive predictive values of the different tools used. The two-point discriminator set at 10mm showed a high sensitivity when compared to the PPV, however the very low PPV shows that the tool will not be a successful screening tool. The tool with the best results for HAVS discrimination was the 3mm TPD, and although its sensitivity was low the PPV had the best results when compared to the other tools. The ideal screening tool is a tool with high sensitivity and high specificity with a high PPV also. However this is not always the case as can be seen above and a tool should be chosen on the overall best results.

Table 7-3 Sensitivity, specificity and positive predictive values for the screening tools

Screening Tools	Sensitivity	Specificity	PPV
Tuning fork	71.1	36.9	12.9
Tuning box	71.1	68.8	51.2
TPD 3mm	48.3	77.6	91.1
TPD 6mm	70.2	63.7	35.1
TPD 10mm	100	58.4	8.3

PPV – positive predictive value
TPD – Two point discriminator

7.3 Problems encountered with the screening tools

7.3.1 Tuning fork

The vibration of the tuning fork is difficult to regulate. In some instances the fork was excited with a larger force than at other times. The fork was hit against the palm of the hand to ensure that the amplitude of the fork was lower than when hit against a hard object.

7.3.2 Tuning box

The participants used hearing protection (ear muffs) to ensure that they did not hear when the fork was excited, but unfortunately this was not sufficient to block out all the sound. It has been suggested that small hearing protection placed inside the ear should be used in conjunction with the larger external hearing protection.

It was difficult to place the participants' fingers on the right spot on the back of the tuning fork. Most of the time the front part of their fingers just below the nail was used to feel the vibration. However, this did not cause any problems with feeling the vibration.

7.3.3 Two point discriminator

One of the problems encountered with the discriminator test was that the participants were shown the three verniers, none of which had only one point, and this could lead the participants to answer falsely after seeing that all the tools had two points. This was overcome by explaining to the participants that the 10mm distance was used to show that only one or both sides could be used. This was done to make them uncertain of what to expect in the tests.

Another problem occurred when applying the discriminator to the participant's finger. If the discriminator was held at an angle the participant would only feel one prick even though two were applied. The technicians had to take care to place the tool horizontally on the finger.

7.4 Screening questionnaire

Table 7-4 shows the sensitivity, specificity and positive predictive values for the symptoms used in the questionnaire. It is clear that all the symptoms had a high sensitivity, with tingling having the lowest value at just below 60%. Specificity was exceptionally high in all symptoms. The positive predictive value was lowest in swelling of hands, followed by pain in the hands. The best overall results were in problems of movement of the hands. This question showed high sensitivity, relative high specificity and a high positive predictive value. It is clear from these results that if any symptom is acknowledged by a patient, that patient is a candidate for HAVS diagnosis and should be sent for further evaluation.

Table 7-4 Sensitivity, specificity and positive predictive value for the screening questionnaire

Screening Question	Sensitivity	Specificity	PPV
Tingling in fingers	56.4	76.0	78.6
Problem with movement of fingers	85.7	68.0	78.6
Pain in hands	73.3	65.3	36.3
Swelling of hands	77.8	61.8	25.0
White fingers	79.2	77.5	67.9

PPV – positive predictive value

7.5 Comparison between medical examination tools, standardised objective tests, and screening tools

Figure 7-1 to Figure 7-3 all compare the medical examinations tools, the standardised objective tests and the screening tools either with sensitivity, specificity or positive predictive values.

Sensitivities above 80% were seen in the TPD test set at 10mm, the Purdue pegboard test in the left hand, the screening question on problems with movement of the hands and the VT test at 125 Hz for the left hand.

Specificities above 80% were seen in the grip strength for both the left and right hands, and the finger skin temperature for both hands.

The TPD test at 3mm and the TA test in the left hand were the only tests with a PPV of above 80%, with the finger skin temperature test just falling below this mark.

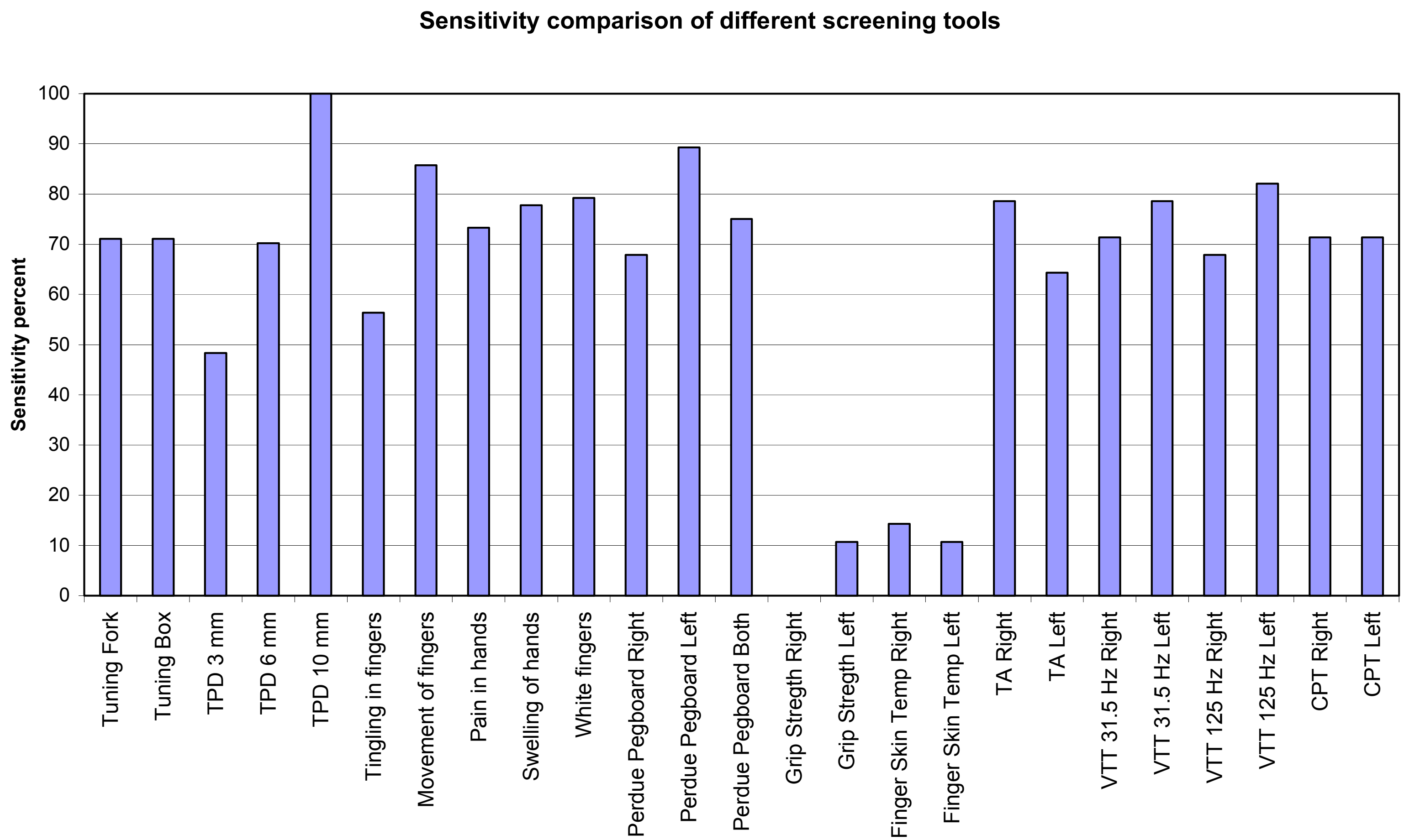

Figure 7-1 Sensitivity comparison between screening tools, medical examination tools and standardised objective tests

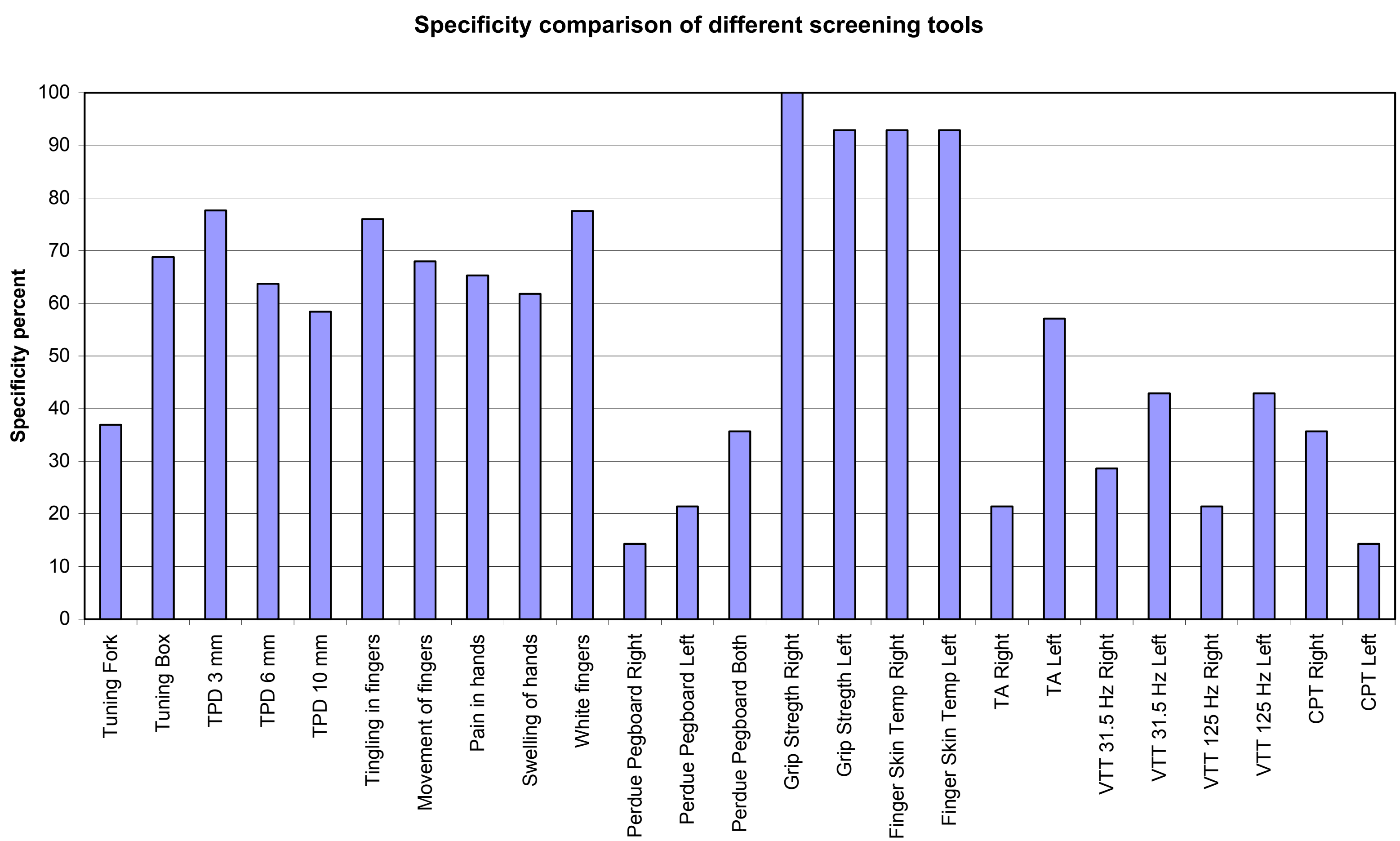

Figure 7-2 Specificity comparison between screening tools, medical examination tools and standardised objective tests

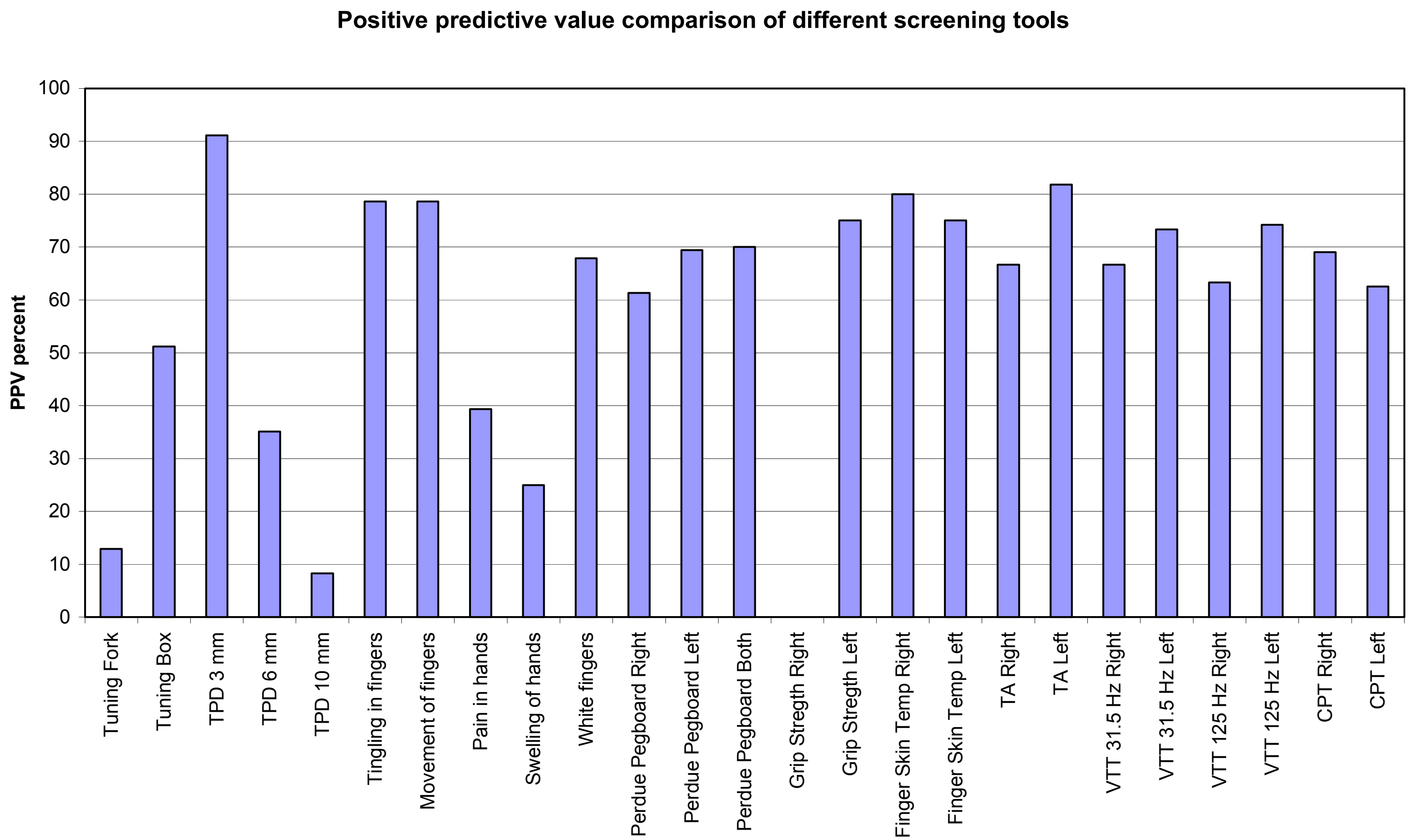

Figure 7-3 Specificity comparison between screening tools, medical examination tools and standardised objective tests

8 Conclusions

The screening tool that showed the best results was the screening questionnaire which specifically focused on the symptoms of HAVS. This questionnaire alone is able to pick up more cases of HAVS than the other screening tools used in the study. An interesting result from the signs showed that more cases of HAVS were picked up through problems with movements of the hands and dexterity, but the symptoms mainly mentioned in the literature in relation to HAVS, is white fingers, tingling and numbness.

The other tools that showed good results were the 3mm and 6mm TPD. These tools could be used together, the one to include workers for further evaluation and the other to exclude them.

The Purdue pegboard test from the medical examination had good results. Even thought the specificity was low, the sensitivity and positive predictive values for all the tests were above 62%, making it possible to use this tool as a screening tool.

The standardised objective test had overall good results. These tools are expensive, however, and trained personnel are needed to operate the tests successfully, making these not suitable for screening purposes.

9 Recommendations

The screening questionnaire showed the best results in identifying HAVS cases. This tool is also inexpensive and easily performed by personnel at the mine. HAVS, however, is still an unknown disease, and none of the participants were aware of any symptoms related to HAVS. With an increase in knowledge about HAVS, especially about the compensation aspect of the disease, the bias in relation to the questionnaire is likely to increase. For this reason it is recommended that other screening tools be evaluated for screening at a later stage when more people are aware of the disease.

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Appendix B – Client Information Sheet and Consent Form

Hand Arm Vibration Syndrome

We are currently running a project to determine how many workers working with vibrating machinery have problems with their hands.

We will be asking you a few questions on your previous work history, and some questions regarding your hands. A screening tool will be used on each finger to determine if there are any abnormalities in that finger.

Taking part in the study is voluntary and you may withdraw from this study at any time without giving a reason and this will not affect the medical care you receive or your job. We are not asking you to give us any samples for testing.

The answers will be seen by a small group of researchers and will be used to determine how many workers exposed to vibration has hand problems.

If you agree to take part in this study, I will ask you some questions and examine both hands. It will take about 20 minutes.

If you have any questions about this study, please ask us.

Consent form Hand Arm Vibration Syndrome

The information sheet about this study has been read to me, and I understand what will be required of me if I take part in the study. My questions concerning this study have been answered by……………………..(name of study staff member)
My participation in the study is voluntary and I understand that I may withdraw from this study at any time without giving a reason and without affecting my normal care and management.

I agree to take part in this study YES/NO

Participant's name: ……………………………….……………………………….

Participant's signature: ....Date…………………

If the information sheet and consent form were translated or explained to the participant, please enter the name of the translator here, and their signature:

Translator's name: ……………………………….……………………………….

Translator's signature: …………………………………..Date…………………

If the participant gave verbal consent, please enter the name of person who witnessed the consent here, and their signature:

Witness' name: ……………………………….……………………………….

Witness' signature: …………………………………..Date…………………

Appendix C – HAVS Question Paper

HAVS INTERVIEW FORM

A. General Information

Study number _______
Date of interview ___/___/___
Interviewer ____________________
Date of birth/age ________________

B. Occupational History

How many years have you been working at this mine? _____yrs
What job do you do? ______________________________________
How long have you been doing this job? ______yrs
(a) Are you presently using a vibrating tool? **YES / NO**
If YES, (ii) Which tools? ___________
(iii) For how long? _________yrs
Do you use any vibrating tool outside the working environment? **YES / NO**
(i) Have you worked at other companies/mines before this one? **YES / NO**
If NO, go to 10
If YES, (ii) where you using vibrating tools? **YES / NO**
If YES, (iii) Which tools? _______________________
(iv) For how long? ______

Total exposure to vibration = __________

C. Smoking / Alcohol Habits

(i) Are you a smoker? **YES / NO**
If NO, (ii) Are you an ex-smoker? **YES / NO**
If NO, go to 12
If YES **<u>for ex-smokers</u>**, (iii)How many years did you smoke for? ______yrs
(iv)How much do you smoke?________.
(v)When did you stop?___/___/___
If YES, **<u>for smokers</u>** (vi) How many years have you been smoking for? __yrs
(vii)How much do you smoke? _________

Do you drink alcohol? **YES / NO**
If YES, How much do you drink? __________

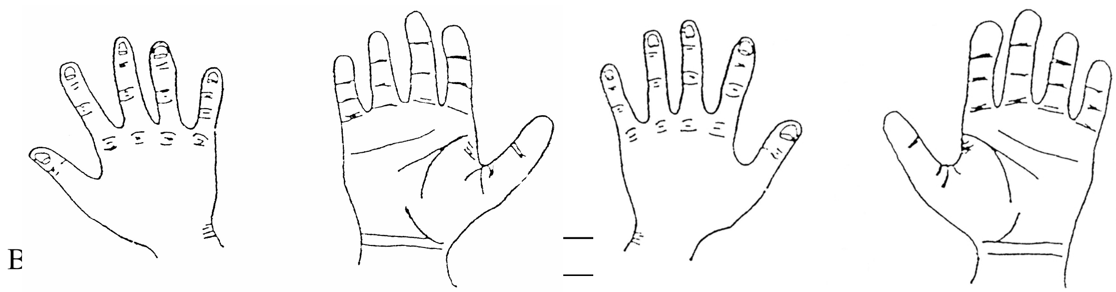
D. HAVS SYMPTOMS

I. GENERAL

Which hand is dominant? RIGHT / LEFT / BOTH
How do your hands trouble you? ____
____

II.VASCULAR SYMPTOMS

Have you ever suffered from your fingers going white? **YES / NO**
If NO, go to 17
If YES:-
When did you first notice it? _______________
Was it before you started working with vibrating tools? **YES / NO**
When do the attacks happen? ______________________________
____
How many attacks/week in winter? __________________
How many attacks/week in summer? ________________
Is it always brought on by cold? **YES / NO**
Which fingers are affected?



Does these attacks affect your job, hobbies or sports? **YES / NO**
Are the attacks getting: less / the same / more frequent?
Do the attacks affect your feet, ears or nose? **YES / NO**
Do/does your family member/s have similar attacks? **YES / NO**

III. SENSORINEURAL SYMPTOMS
Do you suffer from tingling in your fingers? **YES / NO**
If NO, go to 19

If YES:-
During an attack of whiteness? **YES / NO**
Is it in response to cold? **YES / NO**
At other times? **YES / NO**
Is it persistent (> 2 hrs)? **YES / NO**
Comments on tingling:- ____________________________________
____
When did you first notice the tingling? ________________
Does the tingling affect your job? **YES / NO**
Does these attacks affect your job, hobbies or sports? **YES / NO**
Does the tingling waken you at night? **YES / NO**
If YES, how often per week? ________
Do you suffer from numbness in your fingers? **YES / NO**
If NO, go to 21
If YES:-
During an attack of whiteness? **YES / NO**
Is it in response to cold? **YES / NO**
At other times? **YES / NO**
Is it persistent (> 2 hrs)? **YES / NO**

When did you first notice the tingling? ____________________
Does the numbness affect your job? **YES / NO**
Does these attacks affect your job, hobbies or sports? **YES / NO**
Does the numbness waken you at night? **YES / NO**
If YES, how often per week?_________
Do you have:
Intermittent numbness with or without tingling? **YES / NO**
Intermittent or persistent numbness/or tingling AND reduced sensory perception? **YES / NO**

IV MUSKULOSKELETAL

Do you have any problems with the muscle/joints of your hands or arms? **YES / NO**
If NO, go to 23
If YES:-
Do you have swelling? **YES / NO**
Do you have pain? **YES / NO**
Do you have weakness of your grip? **YES / NO**
Do you have stiffness? **YES / NO**
(i) Do you have any problems with fine movements and dexterity of your fingers? YES / NO
If YES, (ii) give details:- ____
____
____

E MEDICAL HISTORY

I. PAST MEDICAL HISTORY

Have you ever had injuries/accidents to fingers/palms/wrists or forearms? **YES / NO**
Give details of cuts, lacerations to fingers:- _______________________________
____
Give details of fractures to fingers/wrist/forearm:- ___________________________
____
(i) Have you had any injuries to neck/shoulder/chest or upper arms? **YES / NO**
If YES, (ii) has it left any after effects? **YES / NO**

II. OTHER CONDITIONS

Do you suffer from any of these conditions?
Angina YES / NO
Coronary thrombosis **YES / NO**
High blood pressure **YES / NO**
Diabetes YES / NO
If YES, give details:-____
____
Do you suffer from any conditions of the nerves?
Carpal tunnel syndrome? **YES / NO**
Poliomyelitis **YES / NO**
Multiple Sclerosis? **YES / NO**
Stroke? YES / NO
Have you ever suffered from the disease of the joints (arthritis, rheumatoid, CTD)? **YES / NO**

If YES, give details:-____

____

Have you had any serious disease? **YES / NO**
If YES, give details:-____

____

Are you taking any medication or tablets? **YES / NO**
If YES, list medication:-____

____

Are you attending a hospital or your GP? **YES / NO**
Are you presently taking treatment for TB? **YES / NO**

Appendix D – Medical Examination

EXAMINATION BY DOCTOR **STUDY NO ________**

1. Blood pressure: Right: ☐☐☐ / ☐☐☐
Left: ☐☐☐ / ☐☐☐
2. Radial Pulse normal: Right YES / NO
Left YES / NO
3. Ulnar Pulses normal: Right YES / NO
Left YES / NO
4. Colour of fingers:
…………………………………………………………………………………..
5. Scars or Callosites:
…………………………………………………………………………………..
…………………………………………………………………………………...
6. Normal range of movement of:
Cervical spine YES / NO
Shoulder YES / NO
Elbow YES / NO
Wrist YES / NO
fingers YES / NO
7. Purdue Pegboard Test: Dominant hand score: ________
Other hand score: ________
Both hands score: ________
8. Grip Strength: Right: ________
Left: ________
9. Clinical findings of hands: (Please indicate yes or no in the appropriate box)

	RIGHT	LEFT	BOTH
Dupuytrens disease			
Allen test - normal?			
Tinel test -normal?			
Phalen test -normal?			
Adson test – normal?			
Purdue Pegboard Test – normal?			
Grip Strength – normal?			

Appendix E – Standardised Test Scores

STANDARDISED TESTS STUDY NO. __________

Room temperature: ______

FST Left: _____

FST Right: ______

I Thermal Aesthesiometry

	Left Little	Left Index	Right Little	Right Index
Mean Hot				
Mean Cold				
Neutral Zone				

Total TA Left = ________

Total TA Right = _________

II Vibrotactile Threshold index and little finger

	Left Little	Left Index	Right Little	Right Index
Mean 31.5 Hz				
Mean 125 Hz				
Finger scores				

Total VTT Left = ________

Total VTT Right = ________

III Cold Provocation Test

	Ltl	LtM	LtR	LtL	Rtl	RtM	RtR	RtL
Time in seconds								
Score								

Total Left CPT = _______

Total Right CPT = _______

NAME OF TECHNICIAN _______________________

SIGNATURE OF TECHNICIAN ______________________

DATE _____/_____/______

Appendix F – HAVS Test Score Summary

HAVS TEST SCORE SUMMARY **STUDY NO._______**

I. SENSORINEURAL SCORE

	RIGHT	LEFT
Thermal Neutral Zones (TA)		
Vibrotactile Thresholds (VTT)		
TA + VTT		
Dexterity Test		
FINAL SENSORINEURAL SCORE		

II. VASCULAR SCORING

	RIGHT	LEFT
Cold Provocation Test (CPT)		
Blanching Score		

III. STAGING BY STOCKHOLM WORKSHOP SCALES

	RIGHT	LEFT
Vascular staging		
Sensorineural Staging		

IV. ASSEMENT

Examining Doctor _____________
Signature ___________________
Date _____/____/_____

Appendix G– Standardised Objective Test Forms

Thermal Aesthesiometry Test

Study Number: _________________ Operators Name: _________________
Date: __________________

Finger 2 = Fore finger (index)
Finger 3 = Middle finger
Finger 4 = Ring finger
Finger 5 = Little finger

Temperatures to be taken	
Room (°C)	
FST Left (°C)	
FST Right (°C)	

<u>Thermal Aesthesiometry (1°C/sec Index and Little Fingers)</u>

Neutral Z: < 21°C = 0 ≥ 21°C < 27°C = 2 ≥ 27°C = 4

Hot Threshold

	Left Index	Score	Left Little	Score	Right Index	Score	Right Little	Score	Messages
Mean									
St.dev									
Mean									
St.dev									
Mean									
St.dev									

Cold Threshold

	Left Index	Score	Left Little	Score	Right Index	Score	Right Little	Score	Messages
Mean									
St.dev									
Mean									
St.dev									
Mean									
St.dev									
Neutral Z									
	Total TA Left				Total TA Right				

Cold Provocation Test

Study Number: _________________ Operators Name: _________________
Date: __________________

Temperatures to be taken	
Room (°C)	
FST Left (°C)	
FST Right (°C)	

Cold Provocation Test (15°C for 5 min, 10 min Recovery)

Scores:
T(+4°C) ≤ 300sec = 0 > 300sec ≤ 600sec = 1 > 600sec = 2

Fingers	1 Left Index	2 Left Middle	3 Left Ring	4 Left Little	5 Right Index	6 Right Middle	7 Right Ring	8 Right Little
Rewarming Times								
Finger Scores								
	Total Left CPT				Total Right CPT			

Vibrotactile Threshold Test

Study Number: _________________ Operators Name: _________________

Date: __________________

Finger 2 = Fore finger (index)
Finger 3 = Middle finger
Finger 4 = Ring finger
Finger 5 = Little finger

Temperatures to be taken	
Room (°C)	
FST Left (°C)	
FST Right (°C)	

Vibrotactile Threshold Index and Little Finger

Scores: 31.5Hz: $< 0.3 m/s^2 = 0$ $\geq 0.3 m/s^2 < 0.4 m/s^2 = 1$ $\geq 0.4 m/s^2 = 2$

125Hz: $< 0.7 m/s^2 = 0$ $\geq 0.7 m/s^2 < 1.0 m/s^2 = 1$ $\geq 1.0 m/s^2 = 2$

31.5Hz	Left Index	Score	Left Little	Score	Right Index	Score	Right Little	Score	Messages
Mean									
St.dev									
Mean									
St.dev									
Mean									
St.dev									
125 Hz	**Left Index**	**Score**	**Left Little**	**Score**	**Right Index**	**Score**	**Right Little**	**Score**	**Messages**
Mean									
St.dev									
Mean									
St.dev									
Mean									
St.dev									
TotalScores	L.Index		L.Little		R.Index		R.Little		
	Total VT Left				Total VT Right				

Appendix H– Screening Questionnaire

General Information

Name: ______________________________

Industry Number: ______________________________

ID Number/Age: ______________________________

Mine: ______________________________

Date: ______________________________

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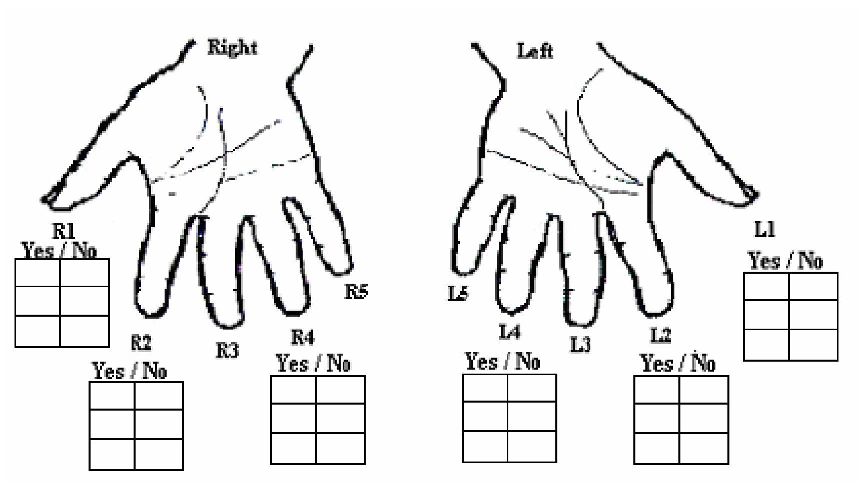
1. Tuning Fork Tests

Explain tuning fork test to patient and make sure he/she understands what is expected from them.

Conduct explanation test.

Indicate whether vibration is felt

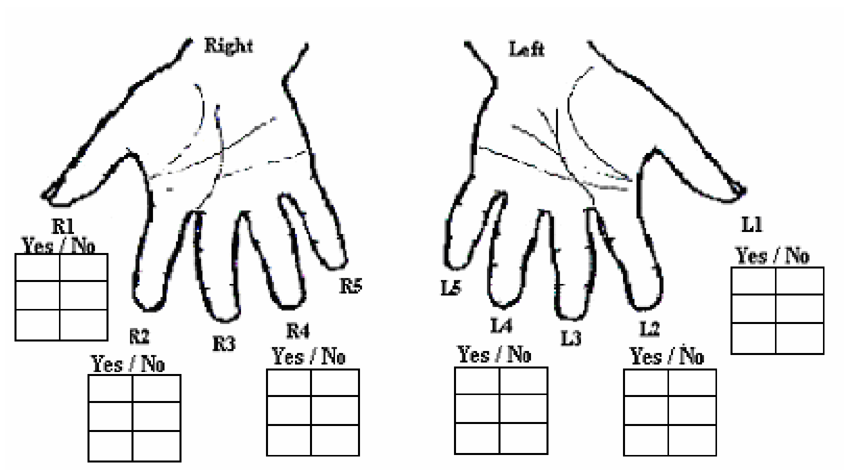


2. Two Point Discriminator

Finger Tested RIGHT	Distance Tested	Perception (One/Two)		
R 1	10mm			
	6mm			
	3mm			
R 2	10mm			
	6mm			
	3mm			
R 4	10mm			
	6mm			
	3mm			

Finger Tested LEFT	Distance Tested	Perception (One/Two)		
R 1	10mm			
	6mm			
	3mm			
R 2	10mm			
	6mm			
	3mm			
R 4	10mm			
	6mm			
	3mm			

3. Tuning Fork Box



Appendix I– Screening Tool Results

Tuning Fork

Thumb		Right Yes	Right No	Right p - value	Left Yes	Left No	Left p - value
HAVS	Count	26	2	0.188	26	2	0.577
	%	92.9	7.1		92.9	7.1	
Non HAVS	Count	36	0		35	1	
	%	100	0		97.2	2.8	
Total	Count	62	2	64	61	3	64
	%	96.9	3.1	100	95.3	4.7	100

Index Finger		Right Yes	Right No	Right p - value	Left Yes	Left No	Left p - value
HAVS	Count	25	3	0.079	25	3	0.311
	%	89.3	10.7		89.3	10.7	
Non HAVS	Count	36	0		35	1	
	%	100	0		97.2	2.8	
Total	Count	61	3	64	60	4	64
	%	95.3	4.7	100	93.8	6.3	100

Ring Finger		Right Yes	Right No	Right p - value	Left Yes	Left No	Left p - value
HAVS	Count	22	6	0.037*	25	3	0.079
	%	78.6	21.4		89.3	10.7	
Non HAVS	Count	35	1		36	0	
	%	97.2	2.8		100	0	
Total	Count	57	7	64	61	3	64
	%	89.1	10.9	100	95.3	4.7	100

* Dependence in this case with Effective size of 0.296 (small dependence)

Tuning Box

Thumb		Right Yes	Right No	Right p - value	Left Yes	Left No	Left p - value
HAVS	Count	15	13	0.005*	16	12	0.012**
	%	53.6	46.4		57.1	42.9	
Non HAVS	Count	31	5		31	5	
	%	86.1	13.9		86.1	13.9	
Total	Count	46	18	64	47	17	64
	%	71.9	28.1	100	73.4	26.6	100

* Dependence in this case with Effective size of 0.359 (medium dependence)
** Dependence in this case with Effective size of 0.325 (medium dependence)

Index Finger		Right			Left		
		Yes	No	p - value	Yes	No	p - value
HAVS	Count	13	15	0.007*	13	15	0.00**
	%	46.4	53.6		46.4	53.6	
Non HAVS	Count	29	7		33	3	
	%	80.6	19.4		91.7	8.3	
Total	Count	42	22	64	46	18	64
	%	65.6	34.4	100	71.9	28.1	100

* Dependence in this case with Effective size of 0.356 (medium dependence)
** Dependence in this case with Effective size of 0.499 (medium dependence)

Ring Finger		Right			Left		
		Yes	No	p - value	Yes	No	p - value
HAVS	Count	9	19	0.005*	16	12	0.008**
	%	32.1	67.9		57.1	42.9	
Non HAVS	Count	25	11		32	4	
	%	69.4	30.6		88.9	11.1	
Total	Count	34	30	64	48	16	64
	%	53.1	46.9	100	75	25	100

* Dependence in this case with Effective size of 0.371 (medium dependence)
** Dependence in this case with Effective size of 0.364 (medium dependence)

Two point Discriminator

Right Thumb		3 mm			6 mm			10 mm		
		2	1	p - value	2	1	p - value	2	1	p - value
HAVS	Count	3	25	0.322	23	5	0.282	26	2	0.188
	%	10.7	89.3		82.1	17.9		92.9	7.1	
Non HAVS	Count	8	28		33	3		36	0	
	%	22.2	77.8		91.7	8.3		100	0	
Total	Count	11	53	64	56	8	64	62	2	64
	%	17.2	82.8	100	87.5	12.5	100	96.9	3.1	100

Right Index		3 mm			6 mm			10 mm		
		2	1	p - value	2	1	p - value	2	1	p - value
HAVS	Count	7	21	1.00	20	8	0.47*	24	4	0.32
	%	25	75		71.4	28.6		85.7	14.3	
Non HAVS	Count	10	26		33	3		36	0	
	%	27.8	72.2		91.7	8.3		100	0	
Total	Count	17	47	64	53	11	64	60	4	64
	%	26.6	73.4	100	82.8	17.2	100	93.8	6.3	100

Right Ring		3 mm			6 mm			10 mm		
		2	1	p - value	2	1	p - value	2	1	p - value
HAVS	Count	1	27	0.125	15	13	0.03**	27	1	0.438
	%	3.6	96.4		53.6	46.4		96.4	3.6	
Non HAVS	Count	6	30		29	7		36	0	
	%	16.7	83.3		80.6	19.4		100	0	
Total	Count	7	57	64	44	20	64	63	1	64
	%	10.9	89.1	100	68.8	31.3	100	98.4	1.6	100

* Dependence in this case with Effective size of 0.266 (small dependence)
** Dependence in this case with Effective size of 0.289 (small dependence)

Left Thumb		3 mm			6 mm			10 mm		
		2	1	p - value	2	1	p - value	2	1	p - value
HAVS	Count	0	28	0.004*	21	7	0.338	26	2	0.188
	%	0	100		75	25		92.9	7.1	
Non HAVS	Count	9	27		31	5		36	0	
	%	25	75		86.1	13.9		100	0	
Total	Count	9	55	64	52	12	64	62	2	64
	%	14.1	85.9	100	81.3	18.8	100	96.9	3.1	100

* Dependence in this case with Effective size of 0.357 (medium dependence)

Left Index		3 mm			6 mm			10 mm		
		2	1	p - value	2	1	p - value	2	1	p - value
HAVS	Count	4	24	0.24	17	11	0.001*	26	2	0.188
	%	14.3	85.7		60.7	39.3		92.9	7.1	
Non HAVS	Count	10	26		34	2		36	0	
	%	27.8	72.2		94.4	5.6		100	0	
Total	Count	14	50	64	51	13	64	62	2	64
	%	21.9	78.1	100	79.7	20.3	100	96.9	3.1	100

* Dependence in this case with Effective size of 0.416 (medium dependence)

Left Ring		3 mm			6 mm			10 mm		
		2	1	p - value	2	1	p - value	2	1	p - value
HAVS	Count	0	28	0.004*	13	15	0.001*	25	3	0.079
	%	0	100		46.4	53.6		89.3	10.7	
Non HAVS	Count	9	27		31	5		36	0	
	%	25	75		86.1	13.9		100	0	
Total	Count	9	55	64	44	20	64	61	3	64
	%	14.1	85.9	100	68.8	31.3	100	95.3	4.7	100

* Dependence in this case with Effective size of 0.357 (medium dependence)
** Dependence in this case with Effective size of 0.425 (medium dependence)