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A review of the literature published since 2004 with potential relevance in the diagnosis of HAVS

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Research Report

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A review of the literature published since 2004 with potential relevance in the diagnosis of HAVS

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Health surveillance for those exposed to hand-arm vibration, and the diagnosis of hand-arm vibration syndrome (HAVS) is heavily dependent upon self-reporting of symptoms. However, this self-reporting may not be accurate for a number of reasons including the ability of individuals to recall symptoms, misunderstanding or misidentification of symptoms and fears regarding an individual's job, or ongoing litigation. Therefore techniques that could be used to obtain better information, or tests that could be applied to obtain a more accurate diagnosis may be useful in this area. In 2004 the Faculty of Occupational Medicine published an evidence based review of clinical testing and management of individuals exposed to hand transmitted vibration. More recent work, which is the subject of this report, is a short update review of the literature published in this area since 2004. It is the intention that this review is used to inform future research work in the area of assessment for HAVS.

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EXECUTIVE SUMMARY

Health surveillance for those exposed to hand-arm vibration, and the diagnosis of hand-arm vibration syndrome (HAVS) is heavily dependent upon self-reporting of symptoms. However, this self-reporting may not be accurate for a number of reasons including the ability of individuals to recall symptoms, misunderstanding or misidentification of symptoms and fears regarding an individual's job, or ongoing litigation. Therefore techniques that could be used to obtain better information, or tests that could be applied to obtain a more accurate diagnosis may be useful in this area. In 2004 the Faculty of Occupational Medicine published an evidence based review of clinical testing and management of individuals exposed to hand transmitted vibration. More recent work, which is the subject of this report, is a short update review of the literature published in this area since 2004. It is the intention that this review is used to inform future research work in the area of assessment for HAVS.

Objectives

1. To review simple tools which have been applied in individuals with HAVS, or other diseases of the circulatory or nervous systems (e.g. diabetic neuropathy).

2. To review complex laboratory based tests which have been applied in individuals with HAVS or other diseases of the circulatory or nervous systems.

3. To investigate whether there are any simple or complex tests that are useful in identifying other disorders that could be confused with HAVS and aid in exclusory and differential diagnosis.

Main Findings and Recommendations

1. The DASH questionnaire consists of 30 individual questions. However, the relative diagnostic value of each question has not been evaluated in HAVS. Identification of questions that could be incorporated in standard HAVS screening or diagnostic questionnaires to assess problems with manual dexterity would be useful.

2. The EDAQ questionnaire has not been used as widely as DASH, but does seem to have some value. It may be useful to investigate the usefulness of this questionnaire further for use in HAVS.

3. Questionnaires are available that are specific for Carpal Tunnel Syndrome (CTS). One problem in the HAVS area is the differential diagnosis of HAVS and CTS. Whilst there is no evidence at present that these questionnaires could help with this, it may be worth investigating whether they may help with this purpose.

4. The musculoskeletal component of HAVS is the most poorly defined and studied area of this disease. This component appears to be a strong determinant of upper limb disability in HAVS cases and warrants further investigation.

5. Maximal handgrip may be of some use in HAVS, but the simple measurement of strength in key intrinsic muscles of the hand may result in more sensitive measures to detect changes in disease and requires further investigation.

6. Simple techniques such as the Neuropen (based on monofilaments) and the NeuroQuick (cold perception) have been established in the diabetic literature and show some

promise, but have not been evaluated for sensory HAVS to date. This may be useful as these techniques are simple to use and portable.

7. There is still limited information regarding the usefulness of nerve conduction studies in HAVS. However, they have been used to detect nerve conduction problems at multiple sites (i.e. median, radial and ulnar nerves) in individuals with HAVS. Diagnosis of CTS on a background of HAVS is difficult, but it has been suggested that this may be possible using nerve conduction measurements and new techniques of analysis. Nerve conduction studies may also play a role in the diagnosis of Thoracic Outlet Syndrome, which can be confused with HAVS. A new hand-held device has been reported in the literature.

8. New novel techniques that involve the delivery of substances through the skin to provoke changes in blood flow have been shown to be useful in diabetic neuropathy and may be useful in HAVS diagnosis. They may also have a role to play in differential diagnosis between conditions that may be confused with HAVS (primary Raynaud's) and HAVS itself.

9. The addition of simple techniques such as colour charts or photographs of attacks to the medical examination can improve the reliability of detection of true Raynaud's attacks and thus may help in accurate diagnosis.

10. Measures using laser Doppler technology may be promising in the area of diagnosis of the vascular component of HAVS and novel ways of establishing vascular function (e.g. venoarteriolar reflex) may also be useful. Doppler techniques may also be useful in discriminating between conditions that can be confused with HAVS (primary Raynaud's, hypothenar hammer) and HAVS itself.

11. New novel techniques such as measuring changes in gene expression are being developed for use in HAVS and may prove to be useful in the future.

1 INTRODUCTION

Adequate health surveillance is important in controlling and preventing disabling disease in occupations where there is some risk associated with vibration exposure. However, this health surveillance must be cost-effective in order to reduce unnecessary economic burdens to industry. The tiered approach to health surveillance that has been recommended by HSE (L140) suggests a way in which health surveillance may be managed with the earliest tiers involving the use of simple screening questionnaires, moving to the use of more detailed questionnaires with clinical examination and formal diagnosis by a physician [1].

The diagnosis of hand-arm vibration syndrome (HAVS) is largely dependent upon self-reporting of symptoms related to the extent and frequency of attacks of whiteness in the fingers, the frequency of tingling or numbness in the fingers, pain in the hands/wrists and problems with sensory perception or manual dexterity. In order that a diagnosis of HAVS can be made all other potential causes of these symptoms must be excluded and the individual must have a history of occupational vibration exposure. Self-reporting of symptoms may be unreliable for a variety of reasons including recall bias, misunderstanding or misidentification of symptoms and fears regarding an individual's job, or ongoing litigation. Consequently, complete reliance upon self-reporting of symptoms could lead to misdiagnosis or inaccurate grading of severity of disease.

Quantitative investigative tests have been used in HAVS medico-legal assessments, health surveillance and research studies [2]. Many authors have argued that because of the subjectivity of diagnosis and staging of HAVS some form of quantitative testing may be valuable [3-8]. In 2004 an evidence based review of clinical testing and management of individuals exposed to hand arm vibration was published by our team at HSL for the Faculty of Occupational Medicine (FOM) [2]. In this work the area of quantitative testing in HAVS and the tests that should be used was reviewed in great detail. Overall, this work reported that the sensitivity and specificity of individual tests used in this area had not been shown to be sufficiently high enough to warrant their use alone, and that no single test had been shown to accurately diagnose and stage the severity of HAVS.

The use of quantitative tests, namely vibration and thermal perception threshold testing, in HAVS health surveillance is optional within HSE's guidance. However, given the difficulty in relying upon self-reported symptoms some form of testing may yield more accurate diagnosis and staging. There is a need for simple assessment tools and techniques that will help physicians diagnose and stage this condition and stop a drift upwards in the tiered approach to health surveillance. Furthermore, HAVS is an exclusory diagnosis, such that all other possible causes of the problem must be excluded before a diagnosis of HAVS can be given. Consequently, some individuals may be miss-diagnosed as having HAVS when in fact they are suffering from other upper limb musculoskeletal disorders that require different treatment or management. This differential or exclusory diagnosis can be difficult and thus any techniques that could be used to aid in this would be of value.

The current work reviews the literature published since 2004 and updates the evidence base following the publication of the FOM review [2]. The current review was not restricted to the area of HAVS alone and covered other clinical areas, which may yield techniques that could be used in HAVS (e.g. diabetic neuropathy). The main objectives of this work were:

1. To review simple tools which have been applied in individuals with HAVS, or other diseases of the circulatory or nervous systems (e.g. diabetic neuropathy). These tools

may include questionnaires used for assessing upper limb disorders, measures of hand function and strength, and measures of sensory or vascular function.

2. To review complex laboratory based tests which have been applied in individuals with HAVS or other diseases of the circulatory or nervous systems.

3. To investigate whether there are any simple or complex tests that are useful in identifying other disorders that could be confused with HAVS and aid in exclusory and differential diagnosis.

It is envisaged that the results of this work will help to inform future research work related to the assessment and diagnosis of HAVS.

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2 METHODS

The literature review was conducted on literature published from 2004 using the PubMed database from the National Library of Medicine. A large number of search terms were used to cover all the areas for this review and these are detailed in Appendix 1. The searches produced 685 references that were imported into a reference management system (Endnote version 9.0). These were reviewed to establish their relevance for the current review and key words were allocated to enable a search of the database for relevant articles for each topic. Paper copies of all the relevant articles were obtained and reviewed. The database and paper library have been retained as an available resource for any future work in this field.

In the summary tables that follow key information regarding each paper is detailed and, where necessary, comments by the author of this report are included in italics.

3 QUESTIONNAIRES USED IN UPPER LIMB DISORDERS

The use of questionnaires is widespread in clinical practice and can be a simple, easy way to obtain and standardise information. In diseases that rely heavily upon self-reporting of symptoms to make a diagnosis (e.g. HAVS) questionnaires are key in obtaining accurate and standardised information. The majority of questionnaires have been developed for a specific purpose or use. Some have published scoring systems available to enable a quantitative measure to be obtained, and some have normal values associated with them.

The original FOM review covered the use of questionnaires designed to diagnose HAVS but did not extensively cover all questionnaires that have been used in upper limb disorders [2]. The current work gives up to date information regarding questionnaires used for the diagnosis of HAVS and also focuses upon questionnaires that have been used in upper limb disorders (including HAVS) to assess disability/lack of function, and questionnaires that may be useful in differential diagnosis. An overview of the papers published can be found in Table 1.

3.1 Questionnaires for HAVS diagnosis

There has been little information published in this area since 2004. However, one study has identified four key questions related to signs and symptoms of sensory HAVS that have a high sensitivity, and could be used in a screening questionnaire for HAVS [9]. These questions were: 1. Do you suffer from numbness in response to the cold?; 2. Do you suffer from tingling in response to the cold?; 3. Do you suffer from tingling (for longer than 20 minutes) after using vibratory tools? and 4. Do you suffer from numbness (for longer than 20 minutes) after using vibratory tools?. These questions had a sensitivity of 94%, specificity of 52%, with 86% of the cohort correctly assigned.

It was proposed that such a screening questionnaire could be used to identify those individuals who would be required to undergo further clinical examination and testing, as suggested in HSE guidance [1].

A further study has also suggested that it may be possible to stage the severity of HAVS according to the answers of three main signs or symptoms: 1. Numbness in the hands or fingers at night; 2. Drop things easily? and 3. Difficulty with buttoning [10]. The same individuals were also staged according to the results of quantitative tests. It was found that in 60% of the cases the two ways of staging agreed, but the authors recommended that this should be applied in a more severely affected population to ensure its validity.

3.2 Questionnaires used for the assessment of disability

The questionnaire that has been used most extensively in the area of upper limb disability since 2004 is the Disability of the Arm, Shoulder and Hand (DASH) questionnaire (Table 1). This questionnaire involves a series of 30 questionnaires related to the ability to perform everyday tasks and symptoms. Each question is scored and an overall score is obtained on a scale of 0-100. Consequently, the outcome of this questionnaire can be used in a quantitative way and normal values are available from a population from the United States. The DASH questionnaire has been shown to be responsive to upper extremity problems, and changes in disease following surgery or treatment, in a wide range of problems including Carpal Tunnel Syndrome, Dupuytren's contracture, median nerve repair, osteoarthritis and HAVS (Table 1). It

has been compared with other questionnaires in a variety of upper limb problems and found to be a reliable and responsive measure. The outcome of the DASH questionnaire has also been compared to quantitative test measures, such as handgrip strength and manual dexterity. In general, the DASH score has been shown to be related to handgrip strength in HAVS, in individuals who have undergone replantation of the thumb, individuals with rheumatoid arthritis and other upper extremity problems [11-14]. It also appears to be related to the Purdue pegboard measurement (manual dexterity) in HAVS [11], hand function as measured by the Moberg pick-up test in rheumatoid arthritis [15] and cutaneous sensation in individuals who have undergone replantation of the thumb [12].

The Evaluation of Activities of Daily Living (EDAQ) questionnaire has also been used in the HAVS area [16, 17]. This is a self-administered questionnaire measuring difficulty in performing activities of daily living. It has been shown that individuals with HAVS had more difficulties in performing daily activities, and that measurement of manual dexterity (using the bean transfer test) was associated with difficulties in performing activities (picking up coins, turning the pages of a newspaper, buttoning clothes and pouring from a teapot).

Other questionnaires have been used in the assessment of disability including the ABILHAND, the Michigan hand outcomes (MHQ), and the Patient Evaluation Measure (PEM) questionnaires. To my knowledge these have not been used in the HAVS area, but have been applied in such conditions as Carpal Tunnel Syndrome, Distal radius fracture and rheumatoid arthritis [18-22].

3.3 Questionnaires specifically designed for use in carpal tunnel syndrome

Since 2004 papers on two questionnaires designed to specifically assess Carpal Tunnel Syndrome have been published [22-25]. These questionnaires are termed the Boston questionnaire and the Levine-Katz questionnaire. These publications have shown that the results of the Boston questionnaire have been shown to correlate with other measures including the DASH and PEM questionnaires [22] and measures of pinch/grip strength and quality of life [23]. The Levine-Katz questionnaire has been shown to be sensitive to changes in symptoms following carpal tunnel release surgery [24-26].

Main findings related to questionnaires used in upper limb disorders

- Questionnaires are simple, easy to use tools that can be used to obtain medical symptom information in a standardised way, to assess disability in the upper limbs and assess the impact of specific diseases (e.g. Carpal Tunnel Syndrome).

- Since 2004 the DASH questionnaire has been most widely used for assessing disability in a variety of disease conditions and its outcome is related to measures of manual dexterity and handgrip.

- The DASH questionnaire consists of 30 individual questions. However, the relative diagnostic value of each question has not been evaluated in HAVS. It has been used to support loss of functionality related to vibration exposure. It may be useful to investigate if any particular questions may have value in being incorporated in standard HAVS screening or diagnostic questionnaires.

- The EDAQ questionnaire has not been used as widely as DASH, but does seem to have some value. It may be useful to investigate the usefulness of this questionnaire further for use in HAVS.

- Questionnaires are available that are specific for Carpal Tunnel Syndrome. One problem in the HAVS area is the differential diagnosis of HAVS and CTS. Whilst there is no evidence at present that these questionnaires could help with this, it may be worth investigating whether they may help with this purpose.

Table 1 Summary of papers published since 2004 using questionnaires in upper limb disorders

Name	Purpose	Diagnostic group(s)	Comments
Disability of the Arm, Shoulder and Hand questionnaire (DASH) Self-administered questionnaire that obtains information regarding difficulty in performing simple everyday tasks. Series of 30 questions that can be scored to give an overall total score on a scale from 0-100, with 100 being the worst disability. It also has additional optional work and sports modules.	Sensitivity to particular diseases or changes following injury/surgery/treatment. Response specific to upper limb problems but not joint or disease specific. Available in several languages and has normal values available for general population in the United States [27] and some for working population in Germany [28].	Carpal Tunnel Syndrome	Change in DASH 1 year post-op was significant (38.2 to 22.0). Concluded that highly responsive to surgery for CTS [29].
		Dupuytren's contracture	Looked at change in DASH following surgery for Dupuytren's and found significant reduction [30].
		Traumatic hand injury	DASH can be used to assess impairment in functional status of traumatic hand injury [31].
		Distal radius fracture	Patients with high self-reported pain or disability (DASH) at increased risk of prolonged work loss [32].
		Median nerve repair	Reported that DASH fulfilled criteria for being useful in monitoring individuals with median nerve repair [33].
		Lateral epicondylitis	Used DASH to assess the effect of laser treatment. DASH did not show any improvement [34].
		Upper extremity arterial trauma	Patients with blunt trauma tended to have higher DASH scores [35].
		Upper extremity disorders	Compared the DASH and Quick DASH questionnaires in upper extremity musculoskeletal disorders before and after surgery. Scores similar and Standard Response Means (i.e. standardised changes with intervention or treatment) similar [36] Looked at performance of DASH in individuals who had upper limb problems, lower limb problems or controls. Those with upper limb problems had highest score but those with lower limb problems also had slightly raised scores. DASH may not be specific for upper limb issues [37]. Looked at 11 different diagnostic groups and evaluated impairments 2-5 years post-operatively. Found that with DASH profiles of patterns of response could be developed for each diagnostic group [38].

Name	Purpose	Diagnostic group(s)	Comments
		Osteoarthritis	Patients treated for basal joint osteoarthritis of thumb. DASH standard response mean was 0.84. Authors concluded that DASH was useful tool to evaluate outcome in this disorder [39].
		Hand-arm vibration syndrome	DASH score related to the severity of HAVS, particularly the sensory component [40, 41]. Also related to Quality of Life (SF-36) and increases when co-existing problems such as Carpal Tunnel Syndrome [41].
	Comparison with other questionnaires/scores	Carpal Tunnel Syndrome	Compared DASH, SF-36 (Quality of Life) and CTSI (Carpal Tunnel Syndrome Instrument) before and after CTS surgery. Concluded that CTSI best for detecting changes following surgery [42]. Compared six different outcome measures. The Boston Carpal Tunnel Questionnaire (BCTQ), Michigan Hand Outcome Questionnaire (MHQ), Patient Evaluation Measure (PEM) are comprehensive questionnaires with good validity. DASH has a potential role in assessment of CTS but requires more validation [22]. Patients undergoing CTS release completed DASH, SF-36, Visual analogue scale for pain, grip and two-point discrimination. Concluded that DASH more sensitive to changes over 3 month period [43]. Compared responsiveness of Michigan Hand Outcomes questionnaire (MHQ) and DASH after CTS surgery. Both DASH and MHQ were responsive to surgery [20]. Compared DASH with BCTQ before and after surgery. Also looked at the reproducibility of the questionnaire. Concluded that DASH was reliable, responsive and practical outcome instrument in CTS [44] .
		Upper limb problems	Review comparing the DASH with the Levine questionnaire, the PRWE (Patient-rated wrist evaluation score) and the Gartland/Werley score. DASH repeatable and responsive to even very small changes, but less valid for use in patients with wrist disorders [45]. Systematic review of 16 instruments available for shoulder disability. Overall DASH received best ratings for clinimetric properties [46].

Name	Purpose	Diagnostic group(s)	Comments
		Median and Ulnar nerve lesions	Study comparing the Rosen score (derived from Rosen's hand protocol) with DASH in individuals undergoing repair for median and ulnar nerve lesions. Two scores correlated. Authors recommended that patient's estimation of impact on activities of daily living be included [47].
		Osteoarthritis	Compared 3 self-report measures Australian/Canadian osteoarthritis index (AUSCAN), PRWE and DASH. All three are valid assessments of pain and/or disability of hand osteoarthritis [48].
		Rotator cuff injury	Compared DASH, simple shoulder test (SST), Western Ontario Rotator Cuff (WORC) and SF-36 before and after 6 month post-op for rotator cuff injury. WORC, SST most responsive to improvement. DASH and SF-36 least responsive [49].
	Comparison with other outcome measures	Hand-arm Vibration Syndrome	DASH score related to Purdue pegboard score (manual dexterity) and handgrip strength [11].
		Flexor tendon injuries	Compared DASH with grip, pinch strength and active motion. Poor correlations between DASH and outcome measures, so suggested that DASH insufficiently sensitive for functional outcome assessment [50].
		Replantation of thumb	24 patients with thumb replantation re-examined after 6.5 years. Examined range of motion, grip strength, sensibility and DASH. DASH scores correlated with grip and pinch strength and cutaneous sensation [12].
		Rheumatoid arthritis	Compared performance of DASH and Moberg picking-up test (MPUT) and other outcome measurement tests. DASH correlated with hand function (MPUT r=0.6) [15].
			Compared DASH with Grip ability test (GAT) in early rheumatoid arthritis. DASH and GAT strongly correlated but DASH more discriminating measure in assessing upper limb ability [14].
		Upper extremity problems (not defined)	Compared DASH with objective measures of grip strength and range of motion. No correlation between DASH and range of motion, some groups had moderate correlation between DASH and grip [13].

Name	Purpose	Diagnostic group(s)	Comments
Health assessment questionnaire (HAQ) Developed at Stanford University as a measure of outcome in patients with wide range of rheumatic diseases. Considered a generic rather than disease-specific instrument. Usually self-administered. Obtains information regarding functional ability, medication use, symptoms and medical history.	Comparison with other outcome measures	Rheumatoid arthritis	Bjork (2007) did the HAQ and a grip ability test in patients with rheumatoid arthritis and controls. Did regular follow-ups over a 5 year period. Found that the HAQ was related to grip force in individuals with rheumatoid arthritis [51]. Bodur (2006) assessed hand disability with HAQ. Found that grip strength and pinch strength correlated with hand disability measured using the HAQ [52].
Health surveillance questionnaires	Sensitivity to particular diseases or changes following injury/surgery/treatment	Hand-arm vibration syndrome (HAVS)	Elms *et al* (2005) identified questions related to signs and symptoms of HAVS that had a high sensitivity for screening individuals for both vascular and sensory components of HAVS [9]. The questions that were identified for sensory HAVS were: 1. Do you suffer from numbness in response to the cold?; 2. Do you suffer from tingling in response to the cold?; 3. Do you suffer from tingling (for longer than 20 minutes) after using vibratory tools? and 4. Do you suffer from numbness (for longer than 20 minutes) after using vibratory tools?. These questions had a sensitivity of 94%, specificity of 52%, with 86% of the cohort correctly assigned. Questions that were most useful for vascular HAVS were: 1. Have you ever suffered with your fingers going white on exposure to cold? and 2. Do you suffer from numbness during attacks of whiteness? These questions had a sensitivity of 98%, specificity of 88% and 94% of the cohort were correctly assigned.

Name	Purpose	Diagnostic group(s)	Comments
			Authors proposed a new staging system based upon the response to three self-reported questions 1) Numbness in hand or fingers at night, 2) Drop things easy?, 3) Difficulty with buttoning. Established their own system of staging related to the answers to these questions whilst disregarding assumed progression of disease. Furthermore this system allows classification of individuals who demonstrate reduced manipulative dexterity and/or reduced sensory perception in whom complaints of numbness may not be present. They compared this with staging using quantitative testing. They found that in 60% of cases the two ways of staging agreed [53]. The authors recommended that this staging method should be applied to a more severe population to ensure its validity.
ABILHAND questionnaire Developed as a measure of manual ability perceived by the patient. Series of 56 questions regarding difficulty in performing manual activities. Usually administered by interview.	Comparison with other outcome measures	Rheumatoid arthritis	Tests of pinch/grip/key grip, maximal grip and purdue pegboard had moderate correlation with the output of the ABILHAND questionnaire [18]. Output of questionnaire was sensitive to changes following treatment.

Name	Purpose	Diagnostic group(s)	Comments
Evaluation of Activities of Daily Living (EDAQ) Self-administered questionnaire measuring difficulty in performing activities of daily living. Originally developed for use in rheumatoid arthritis. Consists of 102 daily activities, split into 11 domains.	Sensitivity to particular diseases or changes following injury/surgery/treatment	Hand-arm vibration syndrome	Study showed that individuals referred to a hand surgery department with severe HAVS symptoms had more difficulties with activities of daily living. Workers from a heavy manufacturing plant with HAVS symptoms also had more difficulties with activities of daily living, particularly working in cold weather. Subjective scale for describing HAVS symptoms used [16].
	Comparison with other outcome measures	Hand-arm vibration syndrome	Found that manual dexterity as measured using the bean transfer test were associated with difficulties in performing everyday activities, particularly picking up coins, turning the pages of a newspaper, buttoning clothes and pouring from a teapot [17].
Michigan hand outcomes (MHQ) Obtains information regarding performance of everyday activities, pain and appearance of hands.	Sensitivity to particular diseases or changes following injury/surgery/treatment	Distal Radius Fracture treatment Carpal Tunnel Syndrome	Kotsis (2007) showed that both MHQ and physical tests (grip, pinch, range of motion) were responsive in measuring outcome of treatment [19]. All domains of the MHQ significantly improved after CTS release. Pain scale had a large standardized response mean and function scale showed medium responsiveness [20].

Name	Purpose	Diagnostic group(s)	Comments
Patient Evaluation Measure (PEM)	Sensitivity to particular diseases or changes following injury/surgery/treatment	Carpal Tunnel Syndrome	Strong correlation between PEM and DASH scores, but PEM had greatest responsiveness to change. Significant correlation between individual items of PEM and objective measures [21]. Compared the responsiveness of the Boston CTS questionnaire, Michigan hand outcome questionnaire PEM and DASH. Found that all had good validity, reliability and responsiveness, but more information was needed for DASH [22].
Boston questionnaire Specific questionnaire for Carpal Tunnel Syndrome	Sensitivity to particular diseases or changes following injury/surgery/treatment	Carpal Tunnel Syndrome	Good validity, reliability and responsiveness and compared well with Michigan hand outcome questionnaire, PEM and DASH [22]. High internal consistency for both symptom and function scales. Correlated with visual analogue scale, SF-36, pinch and grip strength scores [23].
Levine-Katz questionnaire Specific questionnaire for Carpal Tunnel Syndrome	Sensitivity to particular diseases or changes following injury/surgery/treatment	Carpal Tunnel Syndrome	Found that pre-operative duration of symptoms did not affect the outcome of surgery according to questionnaire. More severe the symptoms the greater the change in the questionnaire [24]. Questionnaire used to show that patients have improved significantly following carpal tunnel release [26] and that measurements 2 weeks post surgery are reliable and responsive to outcome [25].

4 MEASUREMENTS OF MANIPULATIVE DEXTERITY AND MUSCLE STRENGTH

The musculoskeletal component of HAVS is poorly understood and ill-defined, but includes pain in the hands or wrists, reduction in muscle strength and reduction in manipulative dexterity (this is also related to changes in sensory perception). At present, the musculoskeletal component is not classified separately for HAVS unlike the sensory and vascular components, which have their own severity scales [4, 54]. However, the musculoskeletal component does seem to be an important factor in determining the perceived disability, lack of function and quality of life an individual with HAVS experiences [11]. The musculoskeletal component of HAVS may be an important, but poorly investigated, area that warrants further investigation.

The types of testing that have been used to assess changes in manipulative dexterity and muscle strength in HAVS was reviewed extensively in the Faculty of Occupational Medicine review in 2004 [2] and the main findings were:

1. The Purdue pegboard and Moberg pickup test have been widely used in several areas of clinical medicine and also had some limited use within HAVS diagnosis and staging. They can be feasibly used in the 'doctor's office' situation.

2. Handgrip strength has been widely used as a test of hand-transmitted vibration changes in muscles of the hand and forearm, but abnormality appears at the later stages of HAVS. Handgrip strength had been suggested as having safety implications as well as an indicator of vibration-induced disease severity. Quantitative pinch grip measurements (key, palmar, tip-pinch) are suggested as measures of intrinsic muscle strength within the hand; there is some limited evidence that such tests are more sensitive to the effect of vibration than handgrip strength.

The current work has updated the review of this area to include literature published since 2004 in order to establish if any new information has been published regarding the usefulness of these techniques in HAVS. The current review has also looked at other clinical areas to identify simple, portable tools that are available, that are currently not being used in the HAVS area, but could be in the future. Table 2 gives an overview of the published work in this area since 2004.

4.1 Measures of manipulative dexterity

In general, few papers were published in this area since 2004 (Table 2). However, three publications were identified which investigated the use of such techniques in those with HAVS or who were exposed to vibration. Two of these publications involved the use of the Purdue pegboard (PP) for measuring manipulative dexterity [53, 55]. One study involved a one-year follow-up of vibration exposed individuals and found that the results of the Purdue pegboard test are related to the vibration exposure and that any deterioration in the measurement was associated with the sensory and vascular symptoms reported [55]. As such, the authors suggested that these results show that the PP is a useful testing method for the clinical assessment of hand function in workers exposed to hand-transmitted vibration. Unfortunately, this particular study did not give any information regarding the level of disease in these workers and therefore it is not possible to say from this work whether the PP is a late indicator of disease, or changes gradually throughout the disease process. Interestingly, another study published using the PP in hand-arm vibration syndrome found that the PP was more likely to find positive cases of a reduction in manipulative dexterity than self-reporting of problems [53].

This study reported a new novel method of staging based upon the answers to three questions regarding nocturnal numbness, dropping objects and difficulty in buttoning. The staging obtained using this method was then compared to the staging obtained using quantitative testing. In 60% of cases the staging with the two methods agreed, but the frequency of higher stages of sensory disease occurring was greater when quantitative testing was used. These results suggest that individuals may underestimate the level of abnormality in their manipulative dexterity and sensory disturbance.

There has also been a report on the use of the red bean transfer test for measuring manipulative dexterity in HAVS [17]. Sakakibara *et al* have reported that the results of this test correlate well with an increased vibration perception threshold, reduced grip force and difficulties in picking up coins, and suggest that this test assesses manual dexterity in HAVS.

4.2 Measures of muscle strength

It has been shown that vibration exposure can lead to changes in the muscle [56] that are likely to result in changes in muscle strength. In general, measurements of muscle strength in the HAVS arena have tended to concentrate on maximal handgrip [57-60]. There were no further publications from 2004 investigating the usefulness of handgrip strength in HAVS, although there were some published in other diseases such as rheumatoid arthritis and diabetes (Table 2).

The measurement of handgrip strength is dependent upon both intrinsic muscles of the hand and extrinsic muscles (e.g. the forearm). It has been argued that the measurement of handgrip strength will be driven by the strongest muscles involved (e.g. forearm) and thus may mask any pathological changes in the smaller muscles. Necking *et al* have assessed the strength of handgrip, thumb pinch, abduction of the thumb (abductor pollicis brevis muscle), radial abduction of the index finger (first dorsal interosseous) and ulnar abduction of the little finger (abductor digiti minimi) in HAVS [61]. They found that the best indicator between the HAVS and control groups was the strength of abduction of the index finger. It has also been shown that maximal handgrip can recover following ulnar or median nerve injury before the intrinsic muscles recovered. Therefore, the measurement of isolated intrinsic muscles may be a more sensitive measure of changes due to disease than simply assessing maximal handgrip [62]. Measurement of intrinsic muscle activity (abductor pollicis brevis) had also been shown to improve following carpal tunnel release [63]. This appears to be a simple technique for which there are pieces of equipment available that are portable.

Main findings related to measurement of manipulative dexterity and muscle strength

- The musculoskeletal component of HAVS is the most poorly defined and studied area of this disease. However, this component appears to be a strong determinant of upper limb disability in HAVS cases and warrants further investigation.

- There has been little information published in this area since 2004.

- The Purdue pegboard is still the most widely used technique for assessing manipulative dexterity in HAVS and appears to be more sensitive in detecting manual dexterity problems than self-reporting.

- The Purdue pegboard and handgrip measurements are related to self-reported disability in individuals with HAVS.

- Maximal handgrip may be of some use in HAVS, but it is likely that the simple measurement of strength in key intrinsic muscles of the hand may result in more sensitive measures to detect changes in disease.

Table 2 Summary of papers published using measures of manipulative dexterity of grip strength

Name	Test description	Diagnostic group(s)	Comments
Red bean transfer test Manipulative dexterity	Time taken to transfer 30 beans from one place to another	Hand-arm vibration syndrome and controls	Reported that an increase in transfer time correlated well with an increased vibration perception threshold and reduced grip force. The transfer time was also related to difficulties in hand function such as picking up coins. The authors concluded that the bean transfer test assesses manual dexterity among HAVS patients [17]
Grip ability test (GAT) Manipulative dexterity	Assesses the ability of an individual to perform tasks such as putting a stocking over the non-dominant hand, putting a paper clip on an envelope, pouring water from a jug. Score based on time to complete 3 items.	Rheumatoid arthritis	Study showed that the GAT was significantly lower in individuals with rheumatoid arthritis when compared to healthy referents [51]
Purdue pegboard Manipulative dexterity	Individual moves pegs and places in holes on a board, one-at-a-time. Score relates to the number of pegs placed in the board in 30 seconds.	Exposed to hand-arm vibration and controls	Investigated manipulative dexterity using the purdue pegboard at entry to study and after one year follow-up. Purdue pegboard scores were significantly lower in the exposed population. Over the follow-up deterioration of manipulative dexterity was associated with sensorineural and vascular symptoms in the fingers of the exposed workers. Purdue pegboard scores also decreased with increasing vibration exposure. *Unfortunately it is not clear from this study what stage of disease the exposed workers have and at what point purdue pegboard changes* [55].
		Hand-arm vibration syndrome	Authors proposed a new staging system based upon the response to three self-reported questions regarding nocturnal numbness, dropping objects and difficulty in buttoning. They compared this with staging using quantitative testing. They found that in 60% of cases the

Name	Test description	Diagnostic group(s)	Comments
			two ways of staging agreed, but that the frequency of individuals grades at higher SN stages was higher when testing was used. This was predominantly due to more positive cases for the Purdue pegboard test compared to self reports [53].
Sollermans hand function test Manipulative dexterity and grip strength	Consists of functional activities involving pinch grip, lateral pinch, tripod pinch, picking up coins, picking up nuts and placing on bolts. Buttoning buttons.	Peripheral nerve injury	Evaluated tests that may be useful in investigating peripheral nerve injuries. Of the tests that they investigated concluded that two-point discrimination, manual muscle test, DASH and Sollermans hand function test were useful [33].
Moberg pick-up test (MPUT)		Finger joint arthroplasty	Used DASH and MPUT in individuals with finger joing arthroplasty. DASH correlated well with MPUT and authors concluded that MPUT suitable tool for precision grip testing [15].
Grip or Pinch strength	Maximal grip strength measured using Jamar dynamometer/GRIPPIT etc. or pinch dynamometers Measures both intrinsic and extrinsic muscle strength (e.g forearm)	Rheumatoid arthritis	Maximal grip force related to hand function as measured using the HAQ [51, 52]. In early rheumatoid arthritis investigated DASH, GAT, handgrip and motion. Strong correlation between self-report DASH and GAT. Handgrip correlated with these. Concluded that in an early rheumatoid arthritis population that handgrip is an accurate indicator of upper limb ability [14].

Name	Test description	Diagnostic group(s)	Comments
		De Quervains disease	Pinch and thumb strength measurements were reliable and showed decreased strength on symptomatic side [64].
		Type 2 diabetes mellitus	Hand grip and key pinch grip were significantly lower in individuals with type 2 diabetes mellitus [65].
		Thumb replantation	Evaluated functional and subjective results after thumb replantation. Did range of motion, grip strength, pinch strength and DASH. DASH scores correlated with grip/pinch strength [12].
Isolated muscle strength	Measures the strength of intrinsic hand muscles, excluding the effects of extrinsic muscle activity	Hand-arm vibration syndrome and age-matched controls	Assessed the strength of handgrip, thumb pinch and using equipment called the Intrinsometer measured the strength of the palmar abduction of the thumb (abductor pollicis brevis), the radial abduction of the index finger (first dorsal interosseous) and the ulnar abduction of the little finger (abductor digiti minimi). Grip and pinch strengths were lower in the vibration exposed group. However, the best indicator between groups was abduction of the index finger. The authors concluded that it is important to measure intrinsic hand muscle function in HAVS [61] (not included in original FOM review). Grip and pinch strength may not be able to detect changes in intrinsic hand muscles due to the dominant contribution of extrinsic hand muscles.
		Ulnar/median nerve injury	Used Rotterdam Intrinsic hand myometer which is a hand-held, portable device that can assess various muscles in the hand. Study assessed the reliability of this device when compared to grip and pinch strength measurements. Intrinsic muscle strength on the ulnar side did not recover even when hand grip strength showed recovery. Concluded that if just measure maximal hand grip then this may mask changes in the intrinsic muscles [62].
		Carpal Tunnel Syndrome	Measured the strength of the abductor pollicis brevis before and after carpal tunnel release. Found that this improved following surgery [63].

5 MEASURES OF CHANGES IN SENSORY PERCEPTION OR DAMAGE TO NERVE FIBRES

The sensory component of HAVS is characterised by symptoms of numbness, with or without tingling, with reduced sensory perception, and in more severe cases reduced manipulative dexterity. The changes in manipulative dexterity may be a consequence of changes in sensory perception or changes in the muscles or joints of the hand. The severity of the disease is classified according to the Stockholm Workshop Scales (SWS) [4, 54] and amended scales have been published in HSE guidance [1]. Whilst it may be possible to diagnose and classify the severity of disease by using simple clinical examination and medical history alone, because of the subjectivity involved it has been suggested that quantitative testing would be useful to aid in accurate diagnosis [3, 4, 6-8, 66-71]. In particular, to move from a stage 1Sn to a 2Sn on the SWS an individual must have reduced sensory perception, which may only be possible to demonstrate by using quantitative testing. Quantitative testing has been used quite widely in this area and a medical assessment process involving the use of tests of sensory perception (vibration perception and thermal perception thresholds) has been published [72] and used in the UK [72-75]. The amended SWS published in HSE guidance includes a sensory score derived from measures of vibration perception (VPT) and thermal perception thresholds (TPT), although this testing is optional in the HSE guidance [1]. The types of testing that had been used to assess changes in sensory perception or nerve damage in the HAVS area was reviewed extensively in the Faculty of Occupational Medicine review in 2004 [2] and the main findings were:

1. Most of the quantitative tests that have been used for investigating the neurosensory deficit or problems in tactile acuity in vibration induced damage have also been applied in other clinical diagnostic areas, where peripheral neuropathy or functional hand deficits are investigated.

2. Quantitative neurosensory tests, such as VPT and TPT, have been used in a number of HAVS investigative studies and in the context of occupational health surveillance. There is some evidence that the neutral zone of TPT may be more diagnostically sensitive than VPT measurements as a single test frequency, but at least three studies suggest that a combination of both VPT and TPT neutral zone measurements may be more diagnostically useful than either technique alone.

3. Measurements such as two-point discrimination and depth sense perception appear to become abnormal at a severer stage than VPT measurements. Semmes-Weinstein monofilaments have been widely used in several areas of clinical medicine and also had some limited use within HAVS diagnosis and staging. They can be feasibly used in the ‘doctor’s office’ situation.

The current work has updated the review of this area to include literature published since 2004 in order to establish if any new information has been published regarding the usefulness of these techniques in HAVS. The current review has also looked at quantitative techniques used in other clinical areas (e.g. diabetic neuropathy) to establish if any techniques are currently used successfully in other areas, which could be easily transposed to the HAVS area. It has also focussed upon techniques that may be portable or simple to use, and could be used in the office setting rather than a laboratory setting. Table 3 gives an overview of the published work in this area since 2004.

5.1 Simple measurements that could be used in the office setting

No papers were identified involving individuals diagnosed with HAVS, or who had a history of being exposed to vibration, investigating simple techniques for the measurement of sensory perception. However, papers were identified investigating the usefulness of monofilaments, two-point discrimination, pressure-specified sensory device and cold perception in a variety of circumstances including diabetes, nerve injury/repair and carpal tunnel syndrome (Table 3). One technique that has been used in diabetic neuropathy with some success was the Neuropen [76]. This device consists of one 10g monofilament on one end and a sharp tip on the other, looks like a pen, and is both simple and cheap. It was found that when the monofilament was used this device had a sensitivity and specificity of 87.8% and 57% respectively for detecting neuropathy in the diabetic foot [76]. However, a study by a different group using Semmes-Weinstein monofilaments found that using a 2g monofilament yielded a better sensitivity and specificity (60% and 73.8% respectively) than the 10g filament when compared to VPT testing using a tuning fork [77]. It seems that using one specified monofilament can be used reasonably successfully to screen for diabetic neuropathy. If such a technique could be used in HAVS this would be a great advantage to enable accurate diagnosis and case management decisions to be made by occupational health professionals.

Another simple technique that has been applied in diabetic neuropathy is a test of cold perception called the NeuroQuick [78, 79]. This technique applies a cold air stimulus to the skin and a detection threshold is obtained. It has been found that the results of this test correlate well with motor/sensory nerve conduction velocities, VPT and TPT and was more sensitive than TPT in diabetes. It appears that this technique may be useful in assessing small nerve fibre dysfunction in diabetes but it did not prove useful in chronic painful dysaesthesia [78].

One further technique that has been used in diabetic neuropathy, and may be possible to use in an office setting, is the pressure specified sensory device (PSSD). This technique performs measurements of 1 or 2 point discrimination and records the pressure applied to the skin. It has been suggested that this technique may be particularly useful in detecting early entrapment problems in conditions where there is likely to be a slowly progressing polyneuropathy [80].

5.2 Complex measurements performed in a laboratory setting

5.2.1 Vibration and thermal perception threshold testing

These two methods have been used quite extensively in a variety of clinical areas, including HAVS diagnosis. The two tests assess different types of nerve fibres and receptors, with the vibration perception threshold (VPT) assessing large myelinated nerve fibres and mechanoreceptors and the thermal perception threshold (TPT) assessing smaller myelinated and unmyelinated nerve fibres and temperature receptors. McGeoch has investigated the relationship between the results of these two tests in 57,000 miners seeking compensation for HAVS [75]. Although the tests correlated with each other, it was found that one test could not be replaced with another, and therefore the use of one test alone was not recommended in HAVS. Brammer *et al* has developed two metrics combining measurements of VPT in a prospective study of forest workers [81]. They found that they could determine four patterns of change in VPT that was related to the hand and nerve affected by vibration. In addition, the VPT measurements were related to reported symptoms of numbness. Vibration perception threshold testing has also been shown to be a useful technique for the early detection of neuropathic deficits in diabetes [82].

As TPT evaluates smaller nerve fibres it has been suggested that this technique should be better at detecting early damage due to vibration [83]. A recent study involving individuals studying auto mechanics, construction and catering found that these vibration exposed individuals showed early signs of changes in TPT [84]. It has been suggested that conventional electro-diagnostic investigations are inadequate for evaluating the status of small fibre systems [84] as nerve conduction studies are heavily dependent upon the responses of large myelinated nerve fibres, which have larger action potentials and faster responses. This has been confirmed by another study evaluating individuals reporting symptoms consistent with small fibre neuropathy (tingling, pricking sensation, numbness) [85]. This study reported that TPT detected 72% of the cases with small fibre neuropathy, whereas nerve conduction studies did not.

5.2.2 Nerve conduction studies (NCS)

The measurement of nerve conduction velocity evaluates large myelinated nerve fibres and is not mediated by a receptor. It is therefore unlikely to be useful in early disease that may affect smaller nerve fibres. It has been widely used in the diagnosis of various aetiologies including carpal tunnel syndrome, but its use in HAVS has been more limited. Recently, Hirata measured sensory nerve conduction velocities in the median, ulnar and radial nerves of individuals with HAVS and controls. They found that HAVS could affect all three nerves, with the ulnar nerve being most affected, the median nerve second and the radial nerve third. Many individuals had multi-focal neuropathy and digital neuropathy [86].

The measurement of sensory nerve conduction velocities is affected by skin temperature, and thus careful control of skin temperature is required. This is demonstrated by the study of Cherniack where the differences between the sensory nerve conduction velocities in individuals exposed to vibration and individuals not exposed to vibration were reduced when systemic warming (by performing exercise) as opposed to segmental cutaneous warming was used [87]. This also suggests that the confounding effect of vibration exposure on sensory nerve conduction velocity may be controlled by systemic warming, and thus may improve the technique for the comparison of those with or without HAVS.

Nerve conduction studies have historically been used to aid in the diagnosis of carpal tunnel syndrome (CTS), and as CTS often co-exists with HAVS, they may be useful in the differential diagnosis of the two conditions. However, the detection of CTS on a background of polyneuropathy is difficult, but Ayse has suggested a way in which this may be achieved by comparing the conduction velocity of the palmar cutaneous nerve and the wrist to 1st digit conduction velocity [88].

Recent work has reported information on a new hand-held NCS device that has been evaluated in CTS [89]. The performance of this new device was compared to standard NCS and found that it detected 85.5% of median nerve lesions. It was concluded that this new device was reliable and reproducible for detecting CTS.

5.2.3 Current perception threshold (CPT)

This technique works by applying an electrical stimulus through the skin to stimulate a sensory nerve and cause a change in sensation. By stimulating at a frequency of 2000Hz large myelinated nerve fibres are activated, at 250Hz medium-sized myelinated fibres are tested and testing at 5Hz stimulates small unmyelinated fibres. This electrical selectivity means that a large range of different nerve fibres can be tested giving a good overall picture of nerve damage.

The stimulus can be applied to numerous sites of the body (dermatomes), which potentially allows better mapping of the nerves affected and the cause of any problem. This technique has generally been based in a clinical setting, but there are now more portable versions of this technique available.

There is only very limited information regarding the use of this technique in HAVS at present. One recent study compared the outcome of CPT to NCS in individuals referred to a HAVS assessment centre. It was found that neither CPT or NCS correlated very well with the Stockholm Workshop Scales and the authors felt that CPT was insufficient for diagnostic purposes but may have a role in screening (80% sensitivity to detect stage 2 or above, but low specificity) [90]. However, there have been some methodological concerns published about this paper, particularly concerning the fact that neuroselective data (i.e. measurements at the three different frequencies of stimulation) for the CPT was not presented [91].

This technique has been applied in diabetic peripheral neuropathy and CTS, and in both cases the testing frequency of 2000Hz was found to be the most useful [92, 93].

5.2.4 Other techniques

One interesting technique that has been published recently involves eliciting nerve-axon reflex vasodilatation by the iontophoresis of acetylcholine through the skin [94]. This has been used to evaluate small unmyelinated nerve fibre function in diabetic neuropathy. The technique of laser flowmetry was used to measure the changes in blood flow and it was found that a response of <50% was highly sensitive (90%) and specific (74%) for diabetic neuropathy, and may be an early indicator of damage.

Main findings related to measurement of sensory perception

- The current review of the literature further supports the findings of the FOM review that both TPT and vibration perception (VPT) should be used in assessing abnormality in HAVS, and that neither test are redundant.
- Simple techniques such as the Neuropen (based on monofilaments) and the NeuroQuick (cold perception) have been established in the diabetic literature and show some promise, but have not been evaluated for HAVS to date.
- There is limited information regarding the usefulness of nerve conduction studies in HAVS. However, they have been used to detect nerve conduction problems at multiple sites (i.e. median, radial and ulnar nerves) in individuals with HAVS. Diagnosis of CTS on a background of HAVS is difficult, but it has been suggested that this may be possible using nerve conduction measurements. A new hand-held device has been reported in the literature.
- It is still unclear how useful current perception threshold testing is in HAVS. This requires further evaluation.
- New novel techniques that involve the delivery of substances through the skin to elicit the nerve-axon reflex have been shown to be useful in diabetic neuropathy and may be useful in HAVS diagnosis.

Table 3 Summary of papers using measurements of sensory perception or nerve damage

Name	Test description	Diagnostic group(s)	Comments
Monofilaments Simple portable test that does not need to be used in a laboratory setting, it can be used in the doctors office.	Measure light touch/pressure sensation	Diabetes	Used a new device called the Neuropen that has a 10g monofilament on one end of the pen and a sharp tip on the other. These measure pressure perception and pain respectively. Evaluated peripheral nerve function in feet of diabetic patients. Sensitivity of Neuropen to detect neuropathy was 87.8% (monofilament), 91.8% (neurotip) and 82.0% for both. Authors concluded that Neuropen sensitive device for assessing nerve function leading to an inexpensive method to identify patients with moderate to severe neuropathy [76] *Very simple cheap device that looks like a pen. If it were to be used in HAVS would need to evaluate whether a 10g monofilament would be appropriate.* Evaluated effectiveness of Semmes-Weinstein monofilaments for diabetic peripheral neuropathy. Used a 2g and 10g monofilament and compared to vibration perception testing using a tuning fork. Found that the 2g filament most useful diagnostic test with 60% sensitivity and 73.8% specificity [77].
		Nerve injury	Jerosch-Herold (2005) reported that only the WEST or Semmes-Weinstein monofilaments and shape texture identification were the only tests for tactile gnosis that met criteria for standardised tests in nerve injury and repair [95].
		Median/ulnar nerve injury	Investigated predictors of cold intolerance and relationship to sensory recovery. Measured sensory recovery using Semmes-Weinstein monofilaments. Found a relationship between sensory recovery and cold intolerance sensitivity score. Those with poor recovery had more cold intolerance [96].
		Leprosy	Sensory perception measured by Semmes-Weinstein monofilaments was related to hand ability (Jebsen-Taylor Hand Function Test). The highest correlation was with tasks entailing manipulation of small objects. However, the monofilament test alone was not sufficient as an indicator of hand function and must be supplemented with other hand function tests [97].

Name	Test description	Diagnostic group(s)	Comments
Two-point discrimination Simple portable test that does not need to be used in a laboratory setting, it can be used in the doctors office.		Nerve repair Carpal Tunnel Syndrome Diabetes Median nerve transsection	Lundborg *et al* (2004) reviewed issues regarding the use of two-point discrimination. It is the most frequently used test for assessment of sensory outcome after nerve repair. However, there is enormous variability in measurement, and this may be due to lack of standardisation of technique and pressure applied [98]. Two-point discrimination and testing of atrophy and strength of the abductor pollicis brevis were specific but not sensitive [99]. Changes in two-point discrimination are likely the result of loss of nerve fibres, which will only occur in severe disease [100]. Two-point discrimination showed a significant improvement following surgical decompression of peripheral nerves in diabetes [101]. Two-point discrimination fulfilled the criteria for being useful in assessing recovery [33].
Pressure-specified sensory device (PSSD) Computer operated but may be possible to use this off-site.	Performs measurements of 1 or 2 point discrimination and records the pressure applied to the skin as the output.	Diabetes	Evaluated the ability of PSSD to detect the early entrapment problems in Diabetes. Results revealed higher sensitivity of PSSD in comparison to standard clinical tests in detection of early-stage entrapment [80]. *Authors make the point that patients with diabetes suffer from slowly progressing polyneuropathy, and that standard tests of nerve function are not sufficient to diagnose superimposed nerve compression. This may be very similar in the case of HAVS and the development of CTS.*

Name	Test description	Diagnostic group(s)	Comments
Cold perception (measured using the NeuroQuick) Hand-held device that can be used for screening and marketed as a simple 'bed-side' test. Measures cold perception by applying a cold air stimulus to the skin. A threshold of detection is obtained.	Measure of small nerve fibre dysfunction	Diabetes Chronic painful dysaesthesia (any limb)	Study evaluated the use of a hand-held screening device (NeuroQuick) for detection of diabetic polyneuropathy. Test based upon detection of sensation associated with cold air being applied to the skin. Compared the results of NeuroQuick (NQT) with motor/sensory nerve conduction velocity, vibration perception thresholds and thermal perception thresholds. The NQT correlated well with all nerve function tests and in polyneuropathy NQT was abnormal. The authors concluded that NeuroQuick was a valid reliable screening tool for quantitative assessment of small nerve fibre dysfunction and was more sensitive that laboratory thermal perception thresholds [79]. *This seems to be an interesting technique that may be useful in HAVS. However, it has only been applied to the foot so far, and it is unclear whether it is suitable to be applied to the hand.* This study compared the usefulness of the 'neuroquick' device to standard cold detection threshold (CDT) on the most affected limb. Found that when patients were categorised according to the results of CDT that the neuroquick had a 50% sensitivity, 92.6% specificity with positive/negative predictive values of 78%. The authors felt that this showed that the neuroquick was not a good screening tool in this chronic pain condition [78].
Vibration perception threshold (VPT) Usually a laboratory based test	Evaluates the mechanoreceptors and large myelinated nerve fibres.	HAVS	McGeoch looked at the correlation between the results of VPT and TPT in 57,000 miners. Found that although the tests were correlated that one test could not be replaced for another, and therefore the use of one test was not recommended [75]. Brammer et al has evaluated two metrics calculated from VPT measurements in a prospective study of forest workers. VPT was used at frequencies of 4-6.3Hz and 20-32Hz. Significant reduction in thresholds found in 5 hand at beginning of study (13.9%) and 15 hand at follow-up 5 years later (41.7%). Four patterns of changes in VPT could be seen related to the hands affected and the nerves affected. Found that measurements of VPT were related to numbness [81].

Name	Test description	Diagnostic group(s)	Comments
		Diabetes	Early detection of problems essential in preventing more severe problems e.g. ulcers and amputations. However, screening has been mostly sub-optimal. This paper reports the usefulness of VPT measures to accurately identify at-risk diabetic patients, including those with early neuropathic deficits [82].
		Healthy volunteers	This paper establishes normal values for both VPT and TPT measurements using the HVLab equipment. It investigates the effects of age and gender on the measurements. It reports that there was no effect of age over the 20-65 year range and that there was not effect of gender on VPT measurements. However, there may be some effect of gender on TPT [102].
Thermal perception threshold (TPT) Usually a laboratory based test	Evaluates thermal receptors and small myelinated (Adelta) and unmyelinated C fibres.	Small fibre neuropathy with normal nerve conduction studies.	Investigated the usefulness of TPT (using Medoc equipment) in evaluation of small fibre neuropathy (presenting with symptoms of tingling, pricking sensation, numbness). Compared 25 patients with 120 controls. TPT detected 72% of cases of small fibre neuropathy, even though NCS were normal. Using both warm and cold thresholds was better than just one [85].
		Vibration exposed workers	Investigated TPT in individuals studying auto mechanics, construction and catering. Measured TPT and found that cold threshold was reduced in those exposed to vibration. Odds ratios were only just significant at 1.06 and 1.02 for the right and left hands respectively. However, association lost in multivariate analyses. Authors conclude that conventional NCS are inadequate for evaluating the status of small fibre systems and that TPT is the preferred option. Both cold and warm measurements required [84].
Nerve Conduction Studies (NCS) Laboratory based test.	Evaluates large myelinated nerve fibres and is not receptor mediated.	HAVS	Hirata applied nerve conduction testing to the median, ulnar and radial nerves of the hand. Study involved 34 patients and 23 age-matched controls. Found that 52.9% of patients had multi-focal neuropathy. Found that vibration affected all three nerves and particularly lead to digital neuropathy [86].
		Vibration exposed workers	Investigated the effects of segmental cutaneous warming to systemic warming (exercising at 100W for 12mins on a bicycle) on sensory nerve conduction velocity (SNCV). Following systemic warming the SNCV increased in the fingers and differences between vibration exposed workers and controls were lost when compared to segmental warming [87].

Name	Test description	Diagnostic group(s)	Comments
		Polyneuropathy with or without CTS	Ayse *et al* suggested that it is difficult to diagnose CTS on the background of polyneuropathy (e.g. Diabetes or HAVS). In this study nerve conduction velocities of the median nerve from the wrist to the digits were compared to the palmar cutaneous nerve (a branch of the median nerve that does not go through the carpal tunnel). This was conducted in normal healthy controls, individuals with CTS, and those with defined polyneuropathy with or without CTS. They found that the ratio between the sensory nerve conduction velocities of the palmar cutaneous nerve and the 1st digit was significantly different between those with CTS with or without polyneuropathy and the control group. There was also a significant difference between those with polyneuropathy only and those with both polyneuropathy and CTS. The authors proposed that to diagnose CTS in these circumstances that the ratio of sensory nerve conduction velocities of the palmar cutanteous nerve and median nerve 1st digit to wrist segment may be useful [88].
		CTS	Chang *et al* investigated different measuring aspects of eletroneurography in CTS. Recommended that measuring the wrist to palm motor conduction velocity is useful. They also suggested comparing the ulnar and median nerve responses [103].
Nerve Conduction Studies (NCS) New hand-held equipment.	Evaluates large myelinated nerve fibres and is not receptor mediated.	CTS	This study evaluated the usefulness of a new hand-held nerve conduction device in CTS. Sensory nerve conductions in the median and ulnar nerves compared in people with CTS and controls. Compared these measurements to standard NCS. Correctly classified 97% of those without median nerve lesions and 85.5% with median nerve lesions. The authors conclude that this test is reliable and reproducible [89].

Name	Test description	Diagnostic group(s)	Comments
Current Perception threshold (CPT) Usually laboratory based test but are more portable versions now available. Test works by applying electrical current through skin at specific sites related to cutaneous innervation of specific nerves (dermatomes). Nerves stimulated directly by increasing current applied. When patient perceives a change in sensation the threshold is reached.	Can be used to evaluate a range of different nerve types by selecting a different frequency of stimulation. Large myelinated AB fibres are stimulated at 2000Hz, medium myelinated fibres (A delta) at 250Hz and small unmyelinated fibres (C) at 5Hz. Test is receptor independent. Can be used to test a range of nerves and one system allows various sites to be tested over the upper limbs and the rest of the body to allow isolation and diagnosis of problems.	HAVS Diabetes CTS	Compared the outcome of CPT with nerve conduction studies (NCS) in 162 individuals referred to a HAVS assessment centre. 96% were diagnosed as having sensory HAVS. Found that median or ulnar nerve neuropathies proximal to the hand were common and digital neuropathy was found in one worker. 33% had CTS on the right side and 22% on the left. Ulnar neuropathy was detected in 11 and 9% of the right and left hands respectively. Neither CPT or NCS had strong correlation with Stockholm Workshop Scales. Authors stated that CPT was insufficient for diagnostic purposes but may have a role in screening (80% sensitivity to detect stage 2 or above but low specificity). Authors recommended that NCS should be done in workers assessed for HAVS to detect neuropathies proximal to hand [90]. One group has responded to this article with a letter to the journal. They make the point that neuroselective data (i.e. subdividing according to the frequency of testing stimulus) was not presented and that an advantage of CPT is the neuroselectivity. Greater than 95% of a sensory nerve is made up of small nerve fibres that are not tested using NCS [91]. Investigated peripheral neuropathy in type 2 diabetes and controls. At all frequencies (2000, 250 and 5Hz) the diabetic patients had significantly different levels compared to controls. The measures made at 2000Hz correlated with nerve conduction measurements. Authors concluded that CPT most useful in detecting abnormalities of myelinated nerve fibres rather than unmyelinated fibres [92]. CPT applied to individuals with/without CTS and following wrist extension. The neurometer was used at 5, 250 and 2000Hz. The best frequency was 2000Hz, which had a greater threshold in those with CTS [93].

Name	Test description	Diagnostic group(s)	Comments
Nerve-axon reflex vasodilatation Involves delivery of drugs through the skin to elicit increases in blood flow as a result of nerve stimulation. Measurements likely to be laboratory based.	Used to evaluate small unmyelinated nerve fibre (C-fibre) function	Diabetes	Neuropathy symptom score, neuropathy disability score, VPT, heat detection threshold used to establish neuropathy in diabetes. Established the neurovascular response to 1% acetylcholine iontophoresis in forearm and feet using laser flowmetry. Found that a response of <50% was highly sensitive (90%) and specific (74%) in identifying patients with diabetic neuropathy. Authors concluded that this test can reliably detect small-fibre dysfunction. Furthermore, this was reduced in early stages, suggesting that small-fibre impairment is an early event [94].

6 MEASURES OF VASCULAR FUNCTION

Diagnosis and staging of the vascular component of HAVS is currently heavily reliant upon accurate self-reporting of the extent and frequency of blanching symptoms by the individual. However, we have previously found that this self-reporting is often not repeatable (unpublished) and could result in misclassification of the severity of disease according to the Stockholm Workshop Scales (SWS). This may be particularly so in relation to reporting of frequency of attacks [104] under the amended SWS recommended in HSE guidance [1]. Recent published work has further looked at the issues of self-reporting of symptoms by either asking individuals to provide photographic evidence of a blanching attack when it occurs, or use colour charts to help describe the symptoms that they experience [105, 106]. The former study found that in those seeking compensation for vibration white finger (VWF) that 17% failed to return the camera and of those that did Raynaud's phenomenon could not be confirmed in 43% of the cases. Clearly, some of this inconsistency and over-reporting of symptoms may be due to the fact that these individuals were seeking compensation, however it did appear that some individuals felt that they were experiencing symptoms consistent with VWF, but that they had misinterpreted their symptoms. This misinterpretation of symptoms seems to be reduced by using colour charts to aid in diagnosis [105]. Negro *et al* used medical interview with and without accompanying colour charts to aid in the diagnosis of VWF in a population of forestry and stone workers. They found that overall the use of colour charts reduced the number of false positive diagnoses of VWF obtained. Whilst these simple techniques would not help to improve the accuracy of self-reporting of the frequency of attacks they may help in the accurate identification of true Raynaud's phenomena.

This reliance upon self-reporting of symptoms for the diagnosis of VWF and the concerns over accuracy of classification has instigated a body of work to attempt to establish an objective test of vascular function that could be used for diagnostic purposes. The published literature in this area was thoroughly reviewed for the Faculty of Occupational Medicine review [2] in 2004 and the main findings were:

1. Measurements of finger skin temperature (FST) after cold challenge had been widely used. Those based on simple, single outcome metrics of the rewarming rate show a wide spread of reported sensitivities and specificities, including poor values, and also poor intra-individual variability. This suggests limited value of such FST tests in supporting a physician's diagnosis of an individual based on medical/work history and reported symptoms.

2. The finger systolic blood pressure (FSBP) test has largely been reported to have superior diagnostic power to the FST in detecting a vascular abnormality. Historically, additional body cooling or environmental cooling has been shown to increase the diagnostic power of the FSBP test. A series of epidemiological studies from a single centre using FSBP without body cooling have shown a consistently high positive and negative predictive power for detecting an abnormal vascular response rather than discriminating between stages of severity.

3. Data supporting the use of nailfold capillaroscopy or the nail compression test in diagnosing HAVS is very limited.

4. No current vascular test has been shown to accurately stage the extent of abnormality in an individual as defined by the SWS.

The current work has updated the review of this area to establish if any new information regarding the usefulness of these techniques has been published. However, the current review has also covered other related areas, such as the diagnosis of primary Raynaud's (PR) phenomenon, to establish if other techniques have been useful in other related areas, which could be easily transposed to the HAVS area. It has also aimed to look for new novel techniques that have been used to investigate vascular function. Table 4 gives an overview of the published work in this area since 2004.

6.1 Measurement of finger skin temperature (FST)

Since 2004 several studies investigating the diagnostic value of this technique have been published including a review of the topic [107] (Table 4). Overall, there has been a large range of different immersion temperatures, immersion durations, room temperatures and outcome measures used, all of which may potentially influence the diagnostic value of this technique. This has made it difficult to distinguish between the usefulness of the measurement technique (i.e. finger skin temperature) and other factors such as the temperature of provocation, or time of provocation. Overall, Harada has reported that this technique has the ability to distinguish between individuals with or without self-reported VWF with a sensitivity of 24-100% and a specificity of 52-100% [107]. Work conducted at HSL has shown that the UK standard cold-provocation test (15°C for 5 minutes) has relatively poor diagnostic power comparing those with stage 2/3V HAVS to normal healthy controls (sensitivity 71%, specificity 77%) and that this was not improved by making more sophisticated measurements using infra-red thermography [108, 109]. It is still unclear if the diagnostic value of this technique may be improved by using a different cold-provocation temperature (e.g. 10°C).

Thompson *et al* have published work showing that measurement of FST and skin blood flow using photoplethysmography following cold provocation correlate with each other, but do not correlate as well with the SWS [110, 111] in individuals with VWF. The fact that these two tests correlate with each other would suggest that they are indeed measuring some abnormality in vascular function. The finding that they did not correlate with the SWS suggested to the authors that the SWS may be less sensitive in detecting vascular pathology than objective tests.

Measurement of FST may be useful in discriminating between primary and secondary Raynaud's phenomenon (sclerosis or autoimmune disease). A simple stand-alone technique has been used to measure FST following a cold-provocation at 16°C for 60 seconds. The authors reported a sensitivity of 73.9%, specificity of 94.6% and a positive predictive values of 95.3% [112]. This technique was simple and could easily be used in the office setting.

6.2 Measurement of finger systolic blood pressure (FSBP)

Since 2004 several studies have been published using this technique (Table 4) and in general there is better agreement in methodology and findings related to this test than with measurement of FST. Normal values have been published for the HVLab equipment and the effects of gender and age upon measurement investigated [113]. Harada has produced a review of the literature in this area and found that when measurements were conducted in the supine position the sensitivity ranged between 50-100% and the specificity between 77-100% for detecting VWF [107]. Work at HSL, in which individuals were studied in the seated position, gave a poorer discrimination between controls and those with VWF with a sensitivity ranging between 44 and 61%, and a specificity of 91 to 95% [109]. This led us to question whether the posture in which

the test was done had an important effect upon the sensitivity of the test. A further study was performed to investigate the effect of posture on the measurement of FSBP and discrimination between controls and those with primary Raynaud's (unpublished work [114]). It was found that the posture in which the test was done did not have a significant effect upon the measurement, but the seated position did reduce the variability of the measurements in the control group, thereby improving discrimination between the groups. However, the sensitivity of the technique in the seated position was still poor (30-56%). Consequently, we are not convinced that the reason we have generally found the FSBP test to be poorer diagnostically than other groups is because of the posture in which the measurements have been performed. Most of the other work published in this area has used the Medimatic equipment, whereas we have used the HVLab multi-channel plethysmograph. It is unclear whether these two pieces of equipment could give different measurements in the same individuals. To our knowledge there is no reported comparison of the measurements of these two pieces of equipment. Fujiwara [115] has reported the simultaneous measurement of zero-value FSBP% with observed blanching using the HVLab multi-channel plethysmograph and reported that they rarely saw this with the Medimatic equipment. They suggest that the Medimatic and HVLab may give different degrees of cold-challenge as the Medimatic can cool only one finger at a time, whereas the latter can cool 4 fingers at once.

In addition, it has been reported that measurement of FSBP can be predictive of individuals developing VWF over time [116-118] and relate to the dose of vibration exposure [117].

6.3 Measurements using laser doppler techniques

Laser doppler is a simple non-invasive technique that can be used to measure blood flow in the skin, this is a direct measure of blood flow as opposed to FST which measures skin temperature as a surrogate for blood flow. Several different techniques using laser Doppler have been published since 2004, which appear to have some usefulness in this area (Table 4). It is reported that they are able to distinguish between controls and those with vascular problems, and between different types of Raynaud's phenomenon. One group have used laser doppler perfusion imaging before and after cold-provocation (10°C for 10 minutes) in those with VWF and controls. They found that the measurements of skin blood perfusion were different before, during and after cold provocation in the groups. If any value before, during or after provocation was abnormal (compared to controls) then the individual was deemed to have an abnormal response. The sensitivity of this technique was 80% and the specificity was 84.6%[119]. Overall, this looks like it could be a promising diagnostic technique, but it is unclear whether it is the measurement technique that yields this good diagnostic value, or the fact that a relatively cool provocation was used (cf section 6.1). In Harada's review it was reported that in papers where the sensitivity and specificity of using FST was reported that the varied between 22-73% and 43-98% for a 10 minute provocation at 10°C [107].

Other studies have looked at alternative ways in which vascular function can be studied, other than simply doing cold-provocation testing. Stoyneva investigated the venoarteriolar reflex (VAR) in individuals with primary and secondary Raynaud's phenomenon (including vibration exposure) using laser Doppler flowmetry [120]. This reflex is a local mechanism, which is elicited by lowering the hand, and protects the capillary against increases in hydrostatic pressure. They found that the loss of VAR was different in the diagnostic groups and could distinguish between the groups. The authors suggested that this may be a useful technique as it is simple, non-invasive and distinguishes between different forms of Raynaud's phenomenon. However, this was a relatively small study (15 controls, 15 primary Raynaud's, 15 with Raynaud's secondary to systemic sclerosis, and 15 with Raynaud's secondary to vibration

exposure) and no information regarding the sensitivity or specificity of this technique was presented. Another group has reported that the 'time to peak' blood cell velocity measured by laser doppler anemometry is different following occlusion between primary Raynaud's phenomenon and VWF [121].

6.4 Other techniques

One technique that has been used in the literature is photoplethysmography [122]. Dyszkiewicz used this technique in a study of 128 vibration exposed individuals and 41 controls before and after cold provocation (10°C for 5 minutes). Individuals were also examined according to a questionnaire, VPT and witnessing of blanching. The investigators found that 59% of the exposed group were positive on both photoplethysmography and questionnaire, but negative on other tests. Furthermore, around 33% were positive on the photoplethysmography but negative on all other tests and the questionnaire. The authors suggest that this technique is highly specific and had greater sensitivity than the other test in detecting pre-clinical forms of VWF.

One novel technique has been published since 2004, which involves obtaining a blood sample from the individual and then investigating gene expression. Early work in a very small pilot study (5 men with HAVS and 3 controls) has suggested that individuals with HAVS have specific patterns of gene expression and some genes are up-regulated compared to controls [123]. This technique is only at an early stage but could prove to be very useful in the diagnosis of VWF.

Main findings related to measurement of vascular function

- The addition of simple techniques such as colour charts or photographs of attacks to the medical examination can improve the reliability of detection of true Raynaud's attacks and thus may help in accurate diagnosis.

- There is still no good evidence that the measurement of finger skin temperature (FST) following cold-provocation is a good diagnostic test for VWF. However, it should be appreciated that a large range of measurement conditions have been used and therefore it is difficult to establish whether it is the measurement of FST that is not reliable or something else about the measurement conditions (e.g. water temperature).

- In the literature as a whole the measurement of finger systolic blood pressure (FSBP) appears to be a good diagnostic technique and seems to relate to the development of VWF over time and vibration exposure. Most of the work reporting these findings has come from one group (Bovenzi *et al*) and used the Medimatic equipment. We have been unable to show that FSBP is a good diagnostic technique using the HVLab equipment. It is unclear at the moment whether the reason we are unable to substantiate these findings is because of the use of different equipment, or some other factor.

- There is still no objective technique that is reliably related to the staging on the Stockholm Workshop Scale.

- Measures using laser Doppler technology may be promising in this area and novel ways of establishing vascular function (e.g. venoarteriolar reflex) may prove useful.

- New novel techniques such as measuring changes in gene expression are being developed for use in HAVS and may prove to be useful in the future.

Table 4 Summary of papers using techniques to measure vascular function

Name	Test description	Diagnostic group (s)	Comments
Nailfold capillaroscopy	Used to assess the size and shape of the capillaries in the nail fold.	Systemic sclerosis	Small study comparing the results using 'gold-standard' widefield capillary microscopy with simple ophthalmoscope and dermatoscope. Found that both the simple instruments provided moderate reliability to detect giant and dilated capillaries. The authors suggest that these simple office based tests could be used instead of the more complex technique [124].
Finger skin temperature (FST) Measures changes in finger skin temperature as a surrogate of blood flow. Usually performed following a cold-provocation test.	Usually used to assess changes in blood flow following a cold-provocation test. Measures the speed of rewarming of the skin, which gives an indication of the vasodilatory/ release of vasoconstriction in the skin capillaries.	Individuals classified as having VWF.	This study compared those with stage 2/3V HAVS with normal healthy controls. Used cold provocation test of 15°C for 5 minutes. Found that sensitivity and specificity was 71% and 77% respectively [109]. Using infra-red thermography to calculate temperature gradients along the fingers did not improve the diagnostic ability of this test [108]. Study of 189 suspected HAVS cases in Korea, where 58 had cold-provocation (10°C for 10 mins). Significantly lower FST in group with VWF at 5 and 10 minutes compared to controls [125]. Harada has published a good review of studies using FST in VWF diagnosis [126]. Reports that studies have used a wide range of different water temperatures, immersion times, adaptation periods, room temperatures and outcome parameters, making comparison difficult. Sensitivity ranged from 24-100% and specificity from 52-100%. Little information regarding the sensitivity and specificity of cold-provocation at 15°C has been published and there has been little work on the ISO-14835-1 test (12°C for 5 minutes). A couple of publications by Thompson *et al* have investigated the relationship between FST and photocell plethysmography with diagnosis via the Stockholm Workshop Scale [110, 127]. Found that the two testing techniques correlate with each other, but that neither technique alone or in combination demonstrated sufficient sensitivity and specificity to serve as objective correlate for SWS vascular stage. The authors suggest the SWS may be less sensitive in detecting vascular pathology than objective test.

Name	Test description	Diagnostic group (s)	Comments
		Primary and secondary Raynaud's phenomenon (not including VWF)	Compared 56 controls and 83 cases of RP (16 primary, 51 sclerosis, 16 autoimmune). Used a duosensor which consists of infra-red thermometry and laser Doppler (only thermometry reported here). Did cold challenge of 16°C for 60 seconds and calculated time for 63% of precooling temperature to be reached. Using 6 minutes cut-off sensitivity was 73.9%, specificity 94.6% and positive predictive value was 95.3%. Authors suggest simple stand alone device which could be used in office setting [112]. Further work by this group established a cold response index by taking a log transform of the time to 63% recovery. Found significant differences between controls and 1° RP and controls vs scleroderma [128].
Colour charts for vibration induced blanching	Used to aid diagnosis of HAVS	Vibration exposed workers	Study used medical interview alone, or medical interview with colour charts for diagnosis of VWF. Involved 146 forestry and stone workers studied with a 1 year follow-up. Assuming that diagnosis with colour charts the gold-standard the sensitivity and specificity was 88.2% and 93.8% compared to medical interview alone. Overall, using colour charts reduced false positive responses and may assist in more accurate diagnosis [105].
Finger systolic blood pressure (FSBP) Test involves applying water perfused cuffs to the test fingers to measure the systolic blood pressure following cold-provocation.	Changes in FSBP before and after cold-provocation gives a measures of vasoconstrictive response in the digital arteries.	Individuals classified as having VWF.	This study compared those with stage 2/3V HAVS with normal healthy controls. Measured changes from 30°C to 15°C. The sensitivity and specificity ranged between 44 and 61% and 91 and 95% respectively, depending upon FSBP parameter used [109]. Follow-up study of 73 vibration exposed workers who claimed unsuccessfully for VWF. Average follow-up 4.1 years with range of 1-11 yrs. FSBP (at 10°C) was associated with the development VWF symptoms during the follow-up period. Also found 6 subjects with abnormal FSBP but no symptoms at baseline, who developed symptoms over the follow-up period. Authors suggest that this shows that FSBP is useful at picking up individuals prior to them developing symptoms [116].

Name	Test description	Diagnostic group (s)	Comments
			Harada has published a good review of studies using FSBP in VWF diagnosis [126]. Overall, better agreement between studies than with testing using FST. In supine position sensitivity ranged from 50%-100% and specificity 77-100%. One study in seated position had poorer sensitivity of 48% and specificity of 95% [109]. This suggested that posture may be important but a recent HSL study showed that posture made little difference to the measurements [114]. Bovenzi conducted a 9 year follow-up study of 128 forestry workers using anti-vibration chain saws. At beginning of study $FSBP_{10°C}$ was lower in those with VWF compared to controls and workers without VWF. FSBP was lower in workers who developed VWF during follow-up [118]. A further one year follow-up study by the same group has also shown that moderate/severe VWF had increased responses compared to controls and exposed workers with no symptoms. New cases of VWF over follow-up had reduced FSBP. FSBP was found to be related to the dose of vibration exposure [117]. Nasu *et al* have conducted a multicentre study in Japan investigating the diagnostic value of $FSBP_{10°C}$. Study involved 154 controls and 135 vibration exposed individuals. Studied at two room temperatures (21 and 23°C). At 21°C sensitivity and specificity for detecting VWF was 73.9% and 82.5% and at 23°C was 65.2% and 87.5% [129].
		Normal healthy controls	Paper presenting normal values for the HVLab equipment and investigating the effects of gender, age and fingers measured. Any differences were small and it is suggested that a single criterion may be used to decide on abnormality [113].

Name	Test description	Diagnostic group (s)	Comments
Laser Doppler techniques			
1) Laser Doppler flowmetry	Measures blood flow and blood flux at the test site	Primary and secondary Raynauds phenomenon (including vibration exposure)	Measured the venoarteriolar reflex (VAR), which is a local mechanism protecting capillary against increases in hydrostatic pressure. Reflex precipitated by lowering of hand. Found that VAR indices were significantly different between 2° RP and controls, and between 2 RP and 1° RP. Loss of VAR established in 10% 1° RP, 53.3% Sclerosis and 36.7% of vibration group. No loss in control subjects. Authors suggested that may be useful technique as it is simple, non-invasive and distinguishes between different forms of RP [120].
2) Laser Doppler anemometry	Measures blood cell velocity	Primary Raynaud's phenomenon and those with VWF	78 patients with primary Raynaud's and 16 with VWF studied. Measured 'time to peak' blood cell velocity following occlusion which was significantly different between groups (30.37 and 19.29 seconds). Authors conclude that this technique could be a useful measure for differential diagnosis [121].
3) Laser Doppler Perfusion Imager	Measure tissues perfusion with a probe that is not in contact with the skin	Individuals with VWF	Compared 12 individuals with VWF and 13 controls before, during and after cold provocation (10°C for 10 minutes). Significant differences in perfusion during immersion and after between controls and VWF, with VWF not having significant increases in perfusion. This technique was better than measuring FST in same individuals [130]. Further work by this group has studied 46 patients with HAVS and 31 healthy controls [119]. The HAVS group were split into those with or without VWF. Using same cold challenge as above measured skin blood perfusion in distal phalanx of middle finger. These measurements were associated with vascular staging and had a sensitivity and specificity of 80% and 84.6% when comparing those with or without VWF, and 80% and 93.5% when compared to controls.

Name	Test description	Diagnostic group (s)	Comments
4) Power Doppler ultrasonography	Imaging technique able to look at the vascularity and blood vessel characteristics in tissues.	Primary and secondary Raynaud's Phenomenon (not including VWF)	Used technique in 41 patients with primary Raynaud's and 11 with secondary Raynaud's before and after cold challenge (7°C for 3 minutes). Authors report that the technique is good and reliable at detecting Raynaud's and can distinguish between primary and secondary forms [131].
Photoplethysmography	Measures the pulse wave in blood vessels that is analysed to give indices of blood flow.	Vibration exposed individuals	128 individuals exposed to vibration and 41 controls before and after cold provocation (10°C for 5 minutes). Also examined individuals using questionnaire, VPT and visual verification of blanching. Found that 32% of exposed group were negative on all tests. 59% were positive on photoplethysmography and questionnaire, but negative on all other tests. Around 33% were negative on all other tests and questionnaire. Authors suggested that this technique was highly specific and had greater sensitivity that the other tests in detecting preclinical forms of VWF [122]. *This statement is not supported by any evidence at the moment, as this study did not look at those who subsequently developed VWF.*
Gene expression	Measures the regulation and expression of genes important in vascular and sensorineural disease.	HAVS	A small pilot study looking at this novel technique for HAVS diagnosis. Looked at the expression of genes in a blood sample taken from 5 individuals with HAVS and 3 controls. Found that several genes had increased expression in HAVS compared to controls, including those related to vascular or sensorineural disease [123].

7 TESTS USED IN EXCLUSORY DIAGNOSIS

Hand-arm vibration syndrome is currently a diagnosis of exclusion. The symptoms commonly reported in HAVS are not specific for this disease and can occur in a number of other problems. Symptoms of whiteness in the fingers in response to cold also occur in conditions such as primary Raynaud's phenomenon and secondary Raynaud's phenomenon resulting from causes other than vibration. Individuals with hypothenar hammer may report whiteness in the fingers, which could be confused with HAVS. Symptoms of tingling and numbness in the fingers could be a consequence of a range of problems including entrapment neuropathies (e.g. carpal tunnel syndrome), thoracic outlet syndrome, cervical spondylosis and diabetic neuropathy. Therefore, in making a diagnosis the occupational health physician must firstly be able to exclude all other possible causes of the symptoms. There is little information published in the literature regarding the prevalence of other disorders in individuals with HAVS, or the prevalence of potential misdiagnosis of HAVS. It has been reported that a presumptive diagnosis of CTS in vibration exposed populations may vary between 9 and 38%, whilst this is higher in those with HAVS (20-60%) [2]. The difficulty of differential HAVS diagnosis is also highlighted by a small amount of data collected on ten consecutive HAVS referral cases to HSL (unpublished). All of these cases were presumed to have HAVS by an occupational health provider but when they were examined at HSL only 4 of these were deemed to have HAVS. Those that did not have HAVS had a range of problems including ulnar nerve entrapment, cervical disc lesion, thoracic outlet syndrome and small joint arthropathy. Three out of the four individuals with HAVS also had additional problems including thoracic outlet syndrome, CTS and cervical spondylosis.

Differential diagnosis is heavily dependent upon taking accurate medical histories, occupational histories and clinical examination. This simple clinical examination may involve Phalen's and Tinel's tests for carpal tunnel syndrome (CTS), Allen's test for the patency of hand arteries and Adson's and Roo's tests for detecting thoracic outlet syndrome (TOS). However, if other tests were available that had reliably been shown to be able to discriminate between conditions that present in similar ways, then this may help in accurate diagnosis and reduce the chance of misdiagnosis. The published literature in this area was thoroughly reviewed for the Faculty of Occupational Medicine review [2] in 2004 and the main findings were:

1. Phalen's and Tinel's tests have been widely used in HAVS studies to screen for possible CTS. The reported ranges of positive predictive values for either test indicate that by themselves these tests are not useful in defining a case of CTS.

2. There is some evidence that segmental nerve conduction velocity measurements across the hand and wrist may be useful in investigating co-existing CTS, rather than a sensitive indicator of vibration induced peripheral nerve damage. Although, there remains some concern whether such a technique can distinguish hand transmitted vibration induced damage to areas proximal to the carpal tunnel from classical compression CTS.

3. The value of the Allen test for investigating the patency of hand arteries has been questioned, as has its repeatability. In a referral setting the use of Doppler techniques rather than the Allen test have been suggested.

4. The value of Adson's and Roos's tests as independent indicators of TOS are unclear. Neurological symptoms of TOS are more common than vascular symptoms. The use of two or more provocation manoeuvres with pain or symptoms as positive outcomes or the combination of appropriate history or provocation of exacerbation of 'above head

height symptoms' has been suggested as increasing the diagnostic accuracy of TOS within a vibration exposed population.

The current work has reviewed published literature in this area since 2004, however there was little new work published in this area since the FOM review was published [2]. Table 5 gives a summary of the work that has been published and this falls into the areas of carpal tunnel syndrome, thoracic outlet syndrome, hypothenar hammer and primary raynauds phenomenon.

7.1 Carpal Tunnel Syndrome (CTS)

'Classical' carpal tunnel syndrome is the result of an increased pressure in the carpal tunnel causing compression of the median nerve at the level of the wrist. This results in symptoms of tingling, numbness or pain in the median nerve distribution of the hand and in severe cases atrophy of muscles in the hand innervated by the median nerve (abductor pollicis brevis). Classically individuals with CTS experience symptoms during the night that will wake them from sleep. This 'classical' CTS is fairly easy to diagnose based upon the reported symptoms, in particular the distribution of symptoms and night waking, and confirmed with nerve conduction studies demonstrating slowing in the median nerve across the wrist. However, in conditions where there is other nerve damage occurring, particularly diffuse nerve damage (e.g. diabetic neuropathy or HAVS), then it is difficult to diagnose CTS on this background of polyneuropathy. This issue has been highlighted in several studies recently [74, 80, 88]. Burke et *al* reported the difficulties in differentiating between HAVS sensory symptoms and CTS in miners seeking compensation for HAVS [74]. They report the difficulties in relying upon conventional nerve conduction studies (NCS) to diagnose CTS on a background of HAVS, and report that nerve conduction studies should be interpreted with caution. It has been hypothesised previously that individuals exposed to vibration may experience direct damage to the median nerve [132]. Therefore, for NCS to be useful it would need to be able to differentiate between direct nerve damage caused by vibration and slowing of nerve conduction caused by compression. It has also been found that in terms of reported symptoms the only symptom that sufficiently differentiated between CTS and HAVS was being woken at night by painful paraesthesia [74]. Other authors have conducted studies to establish if techniques could be used to detect entrapment neuropathies like CTS on a background of polyneuropathy. Ayse *et al* investigated using NCS of the 1^{st}, 2^{nd} and 5^{th} digits related to the palmar cutaneous nerve in polyneuropathy and CTS [88] . They report that this technique could distinguish between groups. This study did not include vibration exposed individuals and therefore this would need to be investigated in this group to establish whether this would aid in HAVS/CTS diagnosis. The pressure specified sensory device (PSSD) has also been used in distinguishing between polyneuropathy and entrapment neuropathy, with a higher sensitivity for detecting nerve entrapment compared to clinical tests (e.g. 2-point discrimination, Tinel's and Phalen's) [80].

7.2 Thoracic outlet syndrome (TOS)

Thoracic outlet syndrome (TOS) refers to compression of one or more of the neurovascular structures traversing the superior aperture of the chest [133]. In classic TOS the lower trunk of the brachial plexus within the scalene triangle is compressed by a cervical rib, or a fibrous band from an elongated C-7 transverse process, both of which will compress the trunk below [134]. Individuals may experience mild, deep, aching pain in the ulnar side of the forearm, occasionally extending to the hand, hand weakness and clumsiness. There may be wasting of the thenar eminence, which particularly affects the abductor pollicis brevis. There is also sensory loss on the ulnar side of the hand, but this sensory loss does not split the ring finger.

The value of simple clinical tests such as Adson's and Roo's tests are unclear [2], and recently it has been reported that there was a high false positive rate of 5 manoeuvres used for TOS in healthy individuals and those with CTS [135]. However, it has been reported that nerve conduction studies may be useful in diagnosing TOS [134].

7.3 Hypothenar hammer (HH)

This condition is caused by trauma to the vulnerable portion of the ulnar artery as it passes over the hamate bone leading to thrombosis, irregularity or aneurysm formation. It manifests as vascular insufficiency leading to symptoms of whiteness, followed by cyanosis, but redness (hyperaemia) is often not reported. It is usually unilateral and generally in the dominant hand. As the reporting of whiteness can be confused with HAVS, techniques that can be used to discriminate between HAVS and HH may be useful in obtaining a correct diagnosis. It has been highlighted that correct diagnosis is important to determine appropriate treatment and management advice, as some cases of HH require surgery or amputation [136].

Allen's test can be used to investigate the patency of the hand arteries, however there have been concerns regarding the use and repeatability of this test [2]. Two studies have recently reported that in cases that are presenting with HAVS-like symptoms and Allen's test is positive, then individuals should have further investigation using arteriography [136, 137] or colour Doppler mapping [137].

7.4 Primary Raynaud's phenomenon

This condition manifests itself as attacks of blanching in cold conditions in exactly the same way as HAVS. The only differences are that primary Raynaud's is an idiopathic condition, which may also affect other peripheral areas of the body (e.g. nose and feet), whereas HAVS affects the fingers and hands and is a consequence of vibration exposure. Therefore, much of the decision regarding whether the presenting condition is primary Raynaud's or HAVS comes down to careful questioning by the clinician regarding the time of onset of the symptoms, occupational vibration exposure and whether other parts of body are affected. Therefore, it can be difficult to discriminate between these two conditions and consequently if a test were available which had the capacity to do this, this would be useful in aiding accurate diagnosis. There was little information regarding this in the FOM review [2] however one technique was advocated as being able to discriminate between cases of VWF, asymptomatic vibration exposed workers and primary Raynaud's phenomenon [138-140]. This work was still very much in the research stage and involved eliciting the nerve axon reflex by injecting vasoactive chemicals such as histamine and endothelin-1 into the digital skin. Although promising this technique has not been studied and investigated further. Nowadays there are iontophoretic techniques available, which if possible to use for these vasoactive chemicals, would increase the feasibility and efficacy of performing this technique.

More recently two papers have been published which apply Doppler techniques, which are simple and non-invasive, either after occlusion or whilst activating the venoarteriolar reflex by changing the position of the hand. Both of these publications reported that these techniques may be used to discriminate between primary and secondary Raynaud's phenomenon.

Main findings related to exclusory diagnosis

- The prevalence of other problems in vibration exposed populations, which could lead to a potential of misdiagnosis of HAVS, is unknown.

- There is little information available regarding the differential diagnosis of HAVS from other problems and the tests that could be used to aid this.

- Carpal tunnel syndrome is known to be prevalent in individuals with HAVS, however even nerve conduction studies have difficulty in determining CTS on a background on polyneuropathy, such as could be the case in HAVS. New techniques of analysis of the results of nerve conduction studies and new tools (pressure specified sensory device) have been proposed to do this. Self-reports of being woken at night by painful paraesthesias in the hands may be useful in differential diagnosis.

- Nerve conduction studies may have a role to play in the diagnosis of TOS.

- Doppler techniques may be useful in the diagnosis of hypothenar hammer and the differential diagnosis between primary Raynaud's and HAVS.

- The iontophoretic injection of chemicals into the skin may also prove to be useful in the differentiation of primary Raynaud's and HAVS.

Table 5 Summary of published papers investigating techniques useful in exclusory diagnosis

Condition	Tests suggested	Differential diagnosis	Comments
Carpal Tunnel Syndrome (CTS)	Nerve conduction studies (NCS)	Polyneuropathy and CTS	Conventional methods in diagnosis of CTS patients with polyneuropathy (e.g. HAVS) are insufficient. Comparison of the median nerve with a neighbouring peripheral nerve may only be beneficial in diagnosis of entrapment neuropathy. Looked at healthy controls, CTS, polyneuropathy without CTS and polyneuropathy with CTS. Compared to palmar cutaneous nerve (PCN) to the 1st, 2nd and 5th digits. Found that the measurement PCN to 1st digit could distinguish between groups and therefore may be a good technique to the diagnosis of CTS on the background of polyneuropathy [88].
	Pressure specified sensory device (PSSD)	Polyneuropathy and entrapment neuropathy	Diabetic patients suffer from a slowly progressing polyneuropathy such that standard neurosensory and motor test are not sufficient in the diagnosis of superimposed nerve compression. *This may also be the case in HAVS.* Evaluated the PSSD in detection of superimposed entrapment in 25 diabetic patients. Nerve entrapment diagnosed in 60% of patients by PSSD but only 33% of these were picked up by standard clinical tests (e.g. 2-point discrimination, Tinel's. Phalen's). The authors suggest that the PSSD had a higher sensitivity for detecting entrapment than clinical tests [80].
	Symptoms	Cervical spondylosis and CTS	Study looked at the discrimination between CTS and cervical spondylosis based upon reported symptoms. 44 patients with CTS and 41 with cervical spondylosis were compared. There were differences in the symptomology of the two groups with 84% of CTS group reporting nocturnal paraesthesia, 82% hand paraesthesia aggravated by hand activity and 64% reporting hand pain. In the cervical spondylosis group the relative proportions were 10%, 7% and 10% respectively. However, neck pain was more prevalent in cervical spondylosis with 76% reporting this compared to 14% in CTS [141].
	Symptoms, NCS and intracarpal pressure measurements	CTS and HAVS	This study looked at CTS in miners seeking compensation for HAVS. Found that clear history of being woken at night by painful paraesthesia restricted to median nerve distribution probably only symptom sufficiently different from HAVS neurosensory complaints. Abnormalities in NCS should be interpreted with caution. Median nerve damage with tingling or numbness and loss of sensory perception is common in HAVS and NCS cannot discriminate between this and CTS. Catheter pressure measurements may prove to be the most effective means of diagnosing CTS in vibration exposed workers [74].

Condition	Tests suggested	Differential diagnosis	Comments
Thoracic Outlet Syndrome (TOS)	Symptoms, NCS, electromyography	Cervical radiculopathy, entrapment neuropathy and TOS	Review paper describing the anatomical abnormalities and thus cause of some common upper limb problems e.g. cervical radiculopathy, entrapment neuropathy and thoracic outlet syndrome. Overall, disorders can be differentiated by the pattern of pain and symptoms, distribution of sensory or motor problems and measurement of NCV and electromyography [134]. Examined false positive rate of 5 manoeuvres used for TOS. Normal subjects and CTS patients were included. 94% of CTS group and 56% of normals had at least 1 positive test. Authors concluded that current manoeuvres for TOS result in a high false-positive rate in normals and those with CTS [135].
Hypothenar Hammer (HH)	Arteriogram		Paper reported three case studies where individuals presented with HAVS like symptoms and had positive Allen's tests. These cases were investigated further and found that they had evidence of tortuosity in the ulnar artery and occlusion of the digital arteries supplying the middle, ring and little fingers. In one case there was a history of using the hand as a hammer. In other cases there was evidence of arterial thrombosis. Authors report that correct diagnosis absolutely critical for appropriate treatment and advice. Some of these cases required surgery or amputation. Authors suggest that those with a symptom history and positive Allen's test should undergo further assessment, such as an arteriogram [136].
	Arteriography or colour Doppler mapping		Case reports of hypothenar hammer presented. Usually develops from chronic, repetitive blunt trauma over months or years. Unilateral involvement, usually dominant hand. Blanching of involved digits followed by cyanosis but redness not reported. Allen's test positive. Arteriography required for diagnosis but can also use colour Doppler mapping [137].
Primary Raynaud's phenomenon	Doppler	Primary Raynaud's and VWF	78 patients with primary RP and 16 with VWF studied. Measured 'time to peak' blood cell velocity following occlusion which was significantly different between groups (30.37 and 19.29 seconds). Authors conclude that this technique could be a useful measure for diagnosis [121].
	Doppler	Primary and secondary Raynaud's (including VWF)	Measured the venoarteriolar reflex (VAR), which is a local mechanism protecting capillary against increases in hydrostatic pressure. Reflex precipitated by lowering of hand. Found that VAR indices were significantly different between secondary Raynaud's and controls, and between secondary and primary Raynaud's . Loss of VAR established in 10% primary Raynaud's, 53.3% Sclerosis and 36.7% of vibration group. There was no loss in the controls. Authors suggested that may be useful technique as it is simple, non-invasive and distinguishes between different forms of Raynaud's phenomenon [120].

8 SUMMARY OF FINDINGS AND DISCUSSION

The review of the literature presented in this document covers the scientific literature produced following the publication of the evidence based Faculty of Occupational Medicine review in 2004 [2]. Other clinical areas that were likely to involve sensory, vascular, hand strength or manual dexterity measurements were also covered (e.g. diabetic neuropathy). The reasoning for this was that these other areas could reveal new novel techniques, or simple techniques that are well established in these areas, which may then be applied in the HAVS area. Overall, the review aimed to establish whether there were any simple techniques that could be used within HAVS health surveillance, particularly by occupational health professionals in the office or field environment. It also aimed to establish what the up-to-date evidence was on the usefulness of more complex quantitative tests was in diagnosis and health surveillance, and establish if any techniques could be used to aid in the differential or exclusory diagnosis of HAVS.

8.1 Simple office or field based testing

One of the simplest, cheapest methods available for collecting information is by questionnaire. The range of questionnaires that have been applied in upper limb disorders has been covered in the review (Table 1). The questionnaire that has been most widely used in recent years has been the Disability in the Arm, Shoulder and Hand (DASH) questionnaire. This questionnaire assesses the functional impact and disability of disease, and the score is correlated with quantitative testing (manual dexterity and handgrip). However, whilst the overall score has been shown to be useful, the individual usefulness of each question has not been investigated. It may be useful to investigate this, as those questions that appear to be most useful could be incorporated within a HAVS screening questionnaire.

New simple techniques have been revealed in the literature that may help in the measurement of hand strength and sensory perception. Evidence has been produced that the measurement of intrinsic muscle strength in the hand, rather than simply maximal handgrip, may be a useful and more sensitive technique for detecting disease [61, 62]. In the measurement of sensory perception techniques such as the Neuropen (based on monofilaments)[76] and the NeuroQuick (cold perception) [79] have been used in diabetic neuropathy and may be transferable to the HAVS arena, following some basic underpinning research. In addition, a new hand-held nerve conduction measurement device has been produced, which may be worth evaluating from the point of view of HAVS diagnosis and differential diagnosis with co-existing CTS [89].

There still does not appear to be a simple vascular test that could be used, however it has been shown that the use of simple colour charts [105] or photographs of attacks [106] could aid in better diagnosis, through better subjective reporting.

8.2 Complex Quantitative testing

This review has shown that the most widely used tests for determining sensory function in HAVS are still the vibration and thermal perception threshold tests (VPT and TPT) (Table 3). Nerve conduction studies may have a role to play in HAVS diagnosis, particularly in terms of determining where any abnormality may lie (e.g. which digit and thus nerve affected) [86]. They may also be useful in diagnosing other conditions such as CTS, or TOS. However, it is still unclear how useful they are in discriminating between CTS and HAVS, although authors have proposed new ways of dealing with the problem of detecting CTS on the background of

polyneuropathy [88], which may be found in HAVS. Other techniques that have been investigated in terms of assessing sensory function include the measurement of current perception threshold [90] and the application of substances through the skin the elicit the nerve-axon reflex [94]. Both of these methodologies may prove useful and require further investigation.

There is still no good evidence that the measurement of finger skin temperature following cold-provocation is a good diagnostic test for HAVS (Table 4). However, comparison across studies is difficult because of different methodologies used including water temperature, duration of immersion and different outcome measures. In contrast, the bulk of the literature published using the measurement of finger systolic blood pressure supports the use of this technique as it seems useful in the diagnosis of HAVS and shows longitudinal changes over time, which suggests that it may be useful in health surveillance (Table 4). However, several research projects conducted at HSL have failed to substantiate these findings. The reasons for this are unclear at the moment, but it is possible that differences in the equipment used may be a contributory factor. Given that there is still a need for a vascular test in HAVS, it may be worth exploring whether differences in the equipment used could explain these differences in findings.

There has been some literature published which shows that Laser Doppler technology may be promising in this area [119, 130] and that new novel ways of investigating vascular function may prove useful (e.g. venoarteriolar reflex) [120] . In addition, a new novel approach of investigating gene expression has also been developed [123], which may aid in HAVS diagnosis in the future.

8.3 Exclusory and differential diagnosis

The ability to exclude other causes of the symptoms reported in HAVS, or differentially diagnose HAVS and other co-existing problems is important in the accurate diagnosis of this condition. However, the prevalence of other disorders that may co-exist with HAVS, or be misinterpreted as HAVS is unknown at present, and further work in this area may be useful.

Differential diagnosis relies heavily upon the skill and experience of the occupational health physician taking the medical history and performing the clinical examination. Nerve conduction studies may be able to help in the diagnosis of TOS and CTS, although there may be difficulty in determining CTS on the background of polyneuropathy. Doppler techniques have been shown to be useful in both the diagnosis of hypothenar hammer [137] and the differential diagnosis of primary raynauds and HAVS [120, 121]. Iontophoretic injection of substances through the skin may also prove useful in differentiating between primary raynauds and HAVS [138-140].

8.4 Other findings

Symptoms of pain in the hands and arms and reductions in manual dexterity and handgrip are important drivers in upper limb disability [11]. These symptoms and signs in individuals exposed to vibration may be a consequence of changes in sensory perception, but may also be due to changes in the musculoskeletal system. This musculoskeletal component of HAVS is poorly understood and ill-defined. Further work is required to establish a greater understanding in this area, given that this aspect of HAVS is likely to be a major contributor to disability and lack of function.

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10 GLOSSARY

ABILHAND	Ability of the hand questionnaire
BCTQ	Boston carpal tunnel questionnaire
CDT	Cold detection threshold
CPT	Current perception threshold
CTS	Carpal tunnel syndrome
DASH	Disability of the arm, shoulder and hand questionnaire
EDAQ	Evaluation of activities of daily living questionnaire
FSBP	Finger systolic blood pressure
FST	Finger skin temperature
GAT	Grip ability test
HAVS	Hand-arm vibration syndrome
HAQ	Health assessment questionnaire
HH	Hypothenar hammer
MHQ	Michigan hand outcomes questionnaire
MPUT	Moberg pick up test
NCS	Nerve conduction studies
NCV	Nerve conduction velocity
PP	Purdue pegboard
PEM	Patient evaluation measure
PRWE	Patient rated wrist evaluation score
PSSD	Pressure specified sensory device
SNCV	Sensory nerve conduction velocity
SWS	Stockholm Workshop Scales
TOS	Thoracic outlet syndrome
TPT	Thermal perception threshold
VAR	Veno-arteriolar reflex
VPT	Vibration perception threshold
VWF	Vibration white finger

11 APPENDIX 1

Search terms used in the literature review were:

Hand arm vibration syndrome, vibration syndrome, vibration white finger, HAVS

Raynauds

Grip strength and hand arm vibration

Hand grip, hand grip and hand arm vibration

Laser Doppler, laser Doppler and hand arm vibration, laser Doppler and skin blood flow

Manipulative dexterity

Manual dexterity, manual dexterity and hand arm vibration syndrome

Purdue pegboard

Nine hole test

Handling small objects

Moberg pickup, moberg pick up, button test, bean test

Pinch grip, pinch grip and HAVS, key grip, key pinch, palmar pinch

Tactile perception, tactile perception and assessment, tactile perception and hand arm vibration

Monofilaments

Two point discrimination, two-point discrimination, 2pd, gap discrimination, gap detection, depth sense, depth perception

Sensibility test

Thoracic outlet

Vibration and disability

Vibration and function

Infrared thermography, infra red thermography, infrared, infra red, thermography

Nail fold capillaroscopy, capillaroscopy, nail compression test

Finger systolic blood pressure, systolic blood pressure

Cold provocation

Finger skin temperature

Dash

Activities of daily living, activities of daily living and vibration, activities of daily living and upper limb

Abilhand

Levine questionnaire

Health assessment questionnaire

Michigan hand outcomes questionnaire

Minnesota manual dexterity test

Minnesota dexterity

Jebsen taylor hand

Photoplethysmography

Current perception threshold

Nerve conduction velocity

Vibration perception threshold, vibrotactile

Thermal perception threshold

Quantitative sensory testing

Pssd, pressure threshold, pressure specified sensory device

Carpal tunnel syndrome

Thoracic outlet syndrome

Compression neuropathy

Differential diagnosis and HAVS

Diagnosis and epicondylitis

Hypothenar hammer

Intradermal injection

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HSE

Health and Safety Executive

A review of the literature published since 2004 with potential relevance in the diagnosis of HAVS

Health surveillance for those exposed to hand-arm vibration, and the diagnosis of hand-arm vibration syndrome (HAVS) is heavily dependent upon self-reporting of symptoms. However, this self-reporting may not be accurate for a number of reasons including the ability of individuals to recall symptoms, misunderstanding or misidentification of symptoms and fears regarding an individual's job, or ongoing litigation. Therefore techniques that could be used to obtain better information, or tests that could be applied to obtain a more accurate diagnosis may be useful in this area. In 2004 the Faculty of Occupational Medicine published an evidence based review of clinical testing and management of individuals exposed to hand transmitted vibration. More recent work, which is the subject of this report, is a short update review of the literature published in this area since 2004. It is the intention that this review is used to inform future research work in the area of assessment for HAVS.

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