Sensory and autonomic function and ultrasound nerve imaging in RSI patients and keyboard workers

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Sensory and autonomic function and ultrasound nerve imaging in RSI patients and keyboard workers

Dr Bruce Lynn PhD
Jane Greening PhD MCSP &
Rachel Leary MSc MCSP
Dept of Physiology
University College London
Gower Street
London WC1E 6BT
United Kingdom

This study examines the neurophysiological function of small sensory and autonomic and large sensory fibres in RSI patients and in office workers who intensively use visual display screen (DSE) equipment. Flare response in relation to iontophoresis of histamine was used as a measure of small sensory C-fibre function, vasoconstriction following ice challenge to the neck as a measure of efferent autonomic function and vibration threshold as a measure of large sensory (Aβ fibre) function. All measurements were carried out over both hands in each subject. Significant differences on all three measures of nerve fibre function were found in the RSI patient group and on 2 measures for the office workers. Vibration thresholds were elevated by 45% in patients and by 21% in office workers. Flare areas were reduced by 33% in patients and by 30% in office workers. Reflex vasoconstriction was reduced by 20% in patients but showed no significant changes in office workers. In a separate part of the study we have used ultrasound images of the median nerve at the proximal carpal tunnel in a group of office workers to measure the amount of nerve movement occurring during 30 degrees of wrist extension to 30 degrees of flexion. Interestingly four out of the ten office workers showed a very small or reversed nerve movement. Finally as a means of validating our previous work looking at median nerve movement using MRI and ultrasound we have made a comparative study of nerve movement using both ultrasound and MRI in a group of controls, office workers and patients. The two methods were in good agreement. Overall, for RSI patients a clear picture emerges of modest reductions in peripheral nerve function, involving both large and small fibre systems. Such changes would be consistent with our hypothesis that a minor neuropathy is present in diffuse RSI. Office workers have a similar trend, although it is not so marked, indicating possible early changes in peripheral nerve function in this occupational group.

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Foreword

This report comprises 2 separate sections. Chapter 1 is a report on the cross sectional study of sensory and autonomic function in RSI patients and “at risk” office workers who do more than 40% of their work at display screen equipment. Chapter 2 deals with 4 aspects of median nerve imaging relevant to the examination of neural mobility. The two chapters have been written so that each is self-contained with its own introduction, results and summary.

This work was funded under 2 contracts. Contract 1 was with the British Occupational Health Research Fund (BOHRF)(044:E:1997) although the contract was funded 50% by the Health and Safety Executive (R55.073). Contract 2 took over the last 6 months of the old BOHRF contract and extended it. This contract was with the HSE (4132/R55.090).
CHAPTER 1

SENSORY AND AUTONOMIC FUNCTION IN RSI PATIENTS AND "AT RISK" OFFICE WORKERS

1.1 INTRODUCTION

1.1.1 Background
Repetitive strain injury (RSI), also called non-specific arm pain (NSAP), is a chronic pain condition of the upper limb. Confusingly the term RSI is often used to describe upper limb conditions with a clear cause such as tenosynovitis and carpal tunnel syndrome, as well as those with diffuse and non-specific arm pain. In the context of this report RSI is used to describe those patients with non-specific arm pain only. Patients complain of diffuse regional arm pain and tenderness with loss of function that is associated with a lack of objective physical signs. The condition does not conform to traditional medical models of musculoskeletal disease or injury, for example, specific soft tissue inflammation such as tenosynovitis, or of specific nerve entrapment such as carpal tunnel syndrome. As such RSI has become a highly controversial subject among medical practitioners (e.g. Hutson 1994; Mann 1994; Hocking 1992; Semple 1991). Even more controversially the condition appears to be associated with particular work practices and conditions. Occupation examples are office workers who spend long hours using display screen equipment, musicians and production line workers. All have tasks that involve highly repetitive use of the hands combined with constrained and static postures, all of which have been identified as risk factors for the condition (Serina et al. 1999; Latko 1999), although this is again contested (Hadler 1997).

1.1.2 The social and economic costs
People with the condition complain that their hand function becomes extremely limited and many have difficulties both with every day and with work activities. In this way RSI has a significant effect not only on individual sufferers and their families, but also on employers due to prolonged sickness, payment for treatment, cost of ergonomic interventions and, where workplace conditions have been shown to cause the condition, compensation settlements. Figures for economic cost or even prevalence are difficult to find, partly because of the different terminology used by different countries. However Jayaraaman (1994) reported that in the UK RSI was responsible for a loss of £400 million in lost working days/year. A recent report by the European Commission (February 2000) stated that work related musculoskeletal disorders of the upper limb and neck cost the European Union up to 2% of its annual gross national product.

1.1.3 Diagnosis of RSI
The UK recently identified surveillance case definitions for work related upper limb pain syndromes (Harrington 1998) and specific subjective criteria for RSI (termed in this report “non specific forearm pain”) were identified. The report sets out diagnostic criteria for a number of specific upper limb disorders including carpal tunnel syndrome, wrist tenosynovitis, epicondylitis and shoulder capsulitis. A “diagnosis of exclusion” of non-specific diffuse forearm pain is proposed for cases where there are complaints of diffuse arm pain, muscle weakness without atrophy, muscle tenderness and allodynia without specific signs of tissue inflammation. These diagnostic criteria have been used to formulate our clinical screening tool for the examination of subjects in this study.
Clinicians who examine these patients using tests of upper limb peripheral nerve mobility (Butler 1991), invariably report positive tests i.e. restricted movement and reproduction of symptoms (Byng 1997). Palpation of peripheral nerve trunks may also be painful and produce paraesthesia in some patients (Hall and Elvey 1999).

1.1.4 The hypothesis relating RSI to nerve injury
Our hypothesis is that patients with RSI have developed minor neural irritation leading to change in nerve fibre function. Recent animal and human experimental work suggests that minor neural irritation can lead to significant neuropathic symptoms (see Greening and Lynn 1998a for review). The overall aim of this study was to investigate neurophysiological function of the small motor and sensory fibres in the median nerve in 2 groups of subjects. Firstly RSI patients and secondly a group of office workers who spend much of their working time using display screen equipment doing repetitive hand tasks. We further planned to give all subjects a thorough clinical examination both to check the RSI diagnosis and to provide clinical measures that could be related to the neurophysiological changes.

1.1.5 Specific aims of the cross sectional study

1.1.5.1. To investigate clinical responses to tests of upper limb neural dynamic and other neural clinical provocation tests
As part of the clinical assessment of subjects, responses to upper limb dynamic tests for the median, ulnar and radial nerve were graded (see section 1.3). A correlation between these results and tests of neurophysiological function has been sought (see section 1.7.1).

1.1.5.2. To investigate large sensory fibre function
Our previous work identified elevated vibration threshold for the median nerve in both a RSI patient group and a group of “at risk” office workers (Greening and Lynn 1998b). This result indicated a change in the function of large sensory fibres (Aβ). As part of this present study we have again measured vibration threshold this time in a blind fashion and with greater subject numbers. (See section 1.4)

1.1.5.3 To assess small sensory fibre function
RSI patients have been reported to show a reduced flare response on the anterior aspect of the forearm following the application of capsaicin (Helme 1992), a reduction that is consistent with small sensory fibre loss. Since our previous work on vibration threshold found greatest changes in the territory of the median nerve, we wished to measure flare response over the glabrous skin supplied by the median nerve in the hand. Due to difficulties in producing flare in glabrous skin, this is an area not normally used in studies of neurogenic flare responses. However we have produced a method that reliably produces flare response in this area and have been able to measure neurogenic flare in response to iontophoresis of histamine (see Section 1.5)

1.1.5.4. To investigate autonomic reflex response
Approximately one third of patients describe marked temperature and colour changes in their hands while a minority have clear signs of autonomic dysfunction (Cohen 1992). We have used laser Doppler flowmetry to investigate autonomic circulatory responses in the hands following ice challenge to the area of the Cervical 7th vertebrae (McGlone and Dhar 1996). The resulting reflex vasoconstriction includes the hands. We have therefore examined this autonomic reflex in the median area of the hands (section 1.6).
1.2. SUBJECTS: RECRUITMENT, CHARACTERISTICS

1.2.1 Subject recruitment
Patients were recruited from physiotherapy clinics, rheumatology and orthopaedic clinics and from members of the RSI Association. Office workers were recruited on the basis that their use of display screen equipment (DSE) took at least 40% of their working time. They were recruited from a variety of locations that included local hospitals (medical secretaries), legal firms, publishing companies and secretarial support staff in the University. Office worker subjects had done similar work for an average of 9 years (range 2-23 years). Control subjects were recruited from undergraduate and postgraduate UCL students, non secretarial UCL staff and from clinical physiotherapy departments. None reported DSE use greater than 40% of their working week.

1.2.2 Key characteristics of subjects (Table 1.2.1).

<table>
<thead>
<tr>
<th>Group</th>
<th>Number</th>
<th>Age</th>
<th>% Male</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>NSAP (RSI) Patient</td>
<td>47</td>
<td>31</td>
<td>22</td>
<td>40</td>
</tr>
<tr>
<td>Office Worker</td>
<td>40</td>
<td>30</td>
<td>21</td>
<td>40</td>
</tr>
<tr>
<td>Control</td>
<td>44</td>
<td>27</td>
<td>20</td>
<td>39</td>
</tr>
</tbody>
</table>

The subject groups were well-matched for gender and age range. The average age of the control group was slightly less than the others, and the distribution bimodal (see Fig 1.2.1.).

![Fig. 1.2.1 Cumulative frequency histogram showing age distribution between the three groups.](image)
1.2.3. Subject Screening Procedure
Subjects were excluded from the study either by the initial screening questionnaire or at a subsequent clinical screening examination if they suffered systemic illness, connective tissue disorder or had experienced obvious trauma to the neck or upper limbs.

1.2.3.1 Screening questionnaire
At initial contact all subjects were sent a pre screening questionnaire designed to exclude subjects unsuitable for the study (see appendix 1.2.1). Subjects able to answer in the negative to all questions were invited to attend for the clinical screening examination, carried out prior to neurophysiological testing.

1.2.3.2 Clinical screening examination
All subjects were interviewed to ascertain suitability for inclusion into the study and to record demographic details. Subjects were questioned in general terms regarding site, extent and characteristics of any symptoms. They were not systematically asked about each part of the upper half of the body, but rather were required to describe the affected areas unprompted by the examiner. Results were recorded on a standardised sheet (see appendix 1.2.2). Symptoms recorded were pain, allodynia, hyperalgesia, paraesthesia and numbness.

Clinical examination was carried out to ensure that patients conformed to the subjective criteria for non specific arm pain (NSAP) and that they were not suffering with any other upper limb pathologies, for example, carpal tunnel syndrome, tenosynovitis or tendinitis (Harrington et.al. 1998). In addition the upper limb tension tests for the median (ULTT1), radial (ULTT2) and ulnar (ULTT3) nerves were performed (Byng, 1997; Slater et.al. 1997). As previously described, tests of upper limb neural mobility frequently produce painful responses in patients with RSI (1.1.3). Several tests of nerve mobility in the upper limb have been suggested (Butler 1991). These are based on anatomic observations and in vitro studies, for example, Wilgis and Murphy (1986); Millesi et al. (1990). Note however that in one cadaver study only the ULTT1 was found to be both sensitive and specific in transmitting tension exclusively to the median nerve (Kleinrensink et.al. 2000).

ULTT1 - Median Nerve
This test involves passive combined shoulder abduction to 90 degrees, forearm supination, wrist and finger extension with the application of elbow extension to mechanically “tension” the brachial plexus and particularly the median nerve. In this study, the elbow extension was carried out last and the degree of elbow extension obtained was used to grade the result of the test.

Clinical findings from the upper limb tension test 1 (ULTT1) were graded as follows:
0 = full range of arm movement without symptoms;
1 = moderate lack of elbow extension (90°-150°) with mild symptoms reproduced;
2 = severe lack of elbow extension (<90°) with marked symptoms.

ULTT2 - Radial Nerve
This combines shoulder abduction while the elbow is held in an extended and pronated position with the wrist and fingers flexed
For the ULTT2 grading was based on the degree of arm abduction
0= full range of arm movement without symptoms;
1= moderate lack of shoulder abduction (15-30 degrees) with mild symptoms;
2 = severe lack of shoulder abduction <15 degrees with marked symptoms.
ULTT3 - Ulnar Nerve
This test is performed in 90 degrees of shoulder abduction with the forearm pronated and wrist flexed with elbow flexion as the applied movement. This test was performed with the degree of elbow flexion as the graded movement.

0= full range of arm movement without symptoms;
1= 90 degrees of elbow flexion to full flexion and mild symptoms;
2= Full elbow extension to 90 degrees of flexion with marked symptoms.

Patients with bilateral arm pain were asked to rate which side they thought was more severely affected.

On the basis of interview and clinical examination one office worker was excluded from the study. Demographic and clinical data was later entered onto a spread sheet

1.2.4 Overall picture from clinical screening

1.2.4.1. Patients
All of the subjects in the patient group complained of symptoms in the upper limb. Six subjects had predominantly unilateral symptoms (all on the right side). Of these six subjects, five were right hand dominant. Mean time of symptom onset was 2.7 years (SD 2.4, range 2 months to 11 years). On a 10cm visual analogue scale (VAS), average pain intensity was 4.8cm (SD 1.5).

1.2.4.2. Office Workers
Of the 40 subjects in the office worker group, 9 were found to have diffuse non-specific symptoms in their upper limbs. Of these, 6 had experienced symptoms between answering the screening questionnaire and subsequent interview, though they did not have any symptoms at the time of testing. The other 3 subjects had current symptoms with a mean time of symptom onset of 0.5 years (range 0.25 to 1 year: SD 0.2). On a 10cm VAS, average symptom intensity was 2.6cm (SD 1.1). Although symptom free, a number of office workers gave positive results on some of the nerve tension tests or the neural provocation tests. For example, 9 office workers failed to reach full arm movement on the ULTT1 on the right, and 6 failed on the left. The grade was in all cases 1, i.e. moderate. Overall, 16 (40%) of office workers had some symptoms or had positive results of some tests. None of the office workers had severe or long standing arm pain, and none was seeking medical help currently.

1.2.4.3. Controls
Three control subjects had mild clinical signs and symptoms in their upper limbs. All had previous injury to their upper quadrant more than 5 years previously. The injuries were whiplash, a fractured hand and tennis elbow. Because signs and symptoms were so mild these subjects were retained.
1.3. CLINICAL PICTURE FOR THE NSAP (RSI) PATIENT GROUP

1.3.1 Introduction
A mass of information was collected on signs and symptoms in the patients. Patients reported areas of pain or tenderness and of paraesthesias or of numbness and these were recorded on body charts. Tension tests and provocation tests were carried out for median, ulnar and radial nerves. Patients rated their overall pain on a VAS. This section will briefly summarise the findings. First we had to reduce the data to a relatively few standard scores, this is described in the next section. Section 1.3.3 summarises some of the key findings.

1.3.2 Scores and weighting for clinical tests and symptoms

1.3.2.1 Body chart symptom area
Data from the body charts was summarised as follows. First the presence (score=1) or the absence (score=0) of complaints of pain or allodynic symptoms were noted for each of 7 areas indicated on the body chart. The 7 areas were:
- Neck plus back;
- Shoulder girdle plus upper arm, left and right;
- Elbow plus forearm, left and right;
- Wrist plus hand, left and right.
Scores were added to give a 0 – 7 scale, with the higher scores indicating more widespread symptoms. Symptoms of paraesthesia or numbness on the body chart were scored separately, but using a similar set of areas and scoring system. For comparison of left and right sides, sub-scales were constructed for the 3 upper limb areas on each side.

1.3.2.2 Upper limb tension tests
All upper limb tension tests scored from 0-2 depending on severity of response, as described in the section 1.2.3.2 above on the clinical screening examination. Positive responses for the ULTT1 test were common in the patient group and were scaled 0-2 for right and left upper limbs. Positive responses for the ULTT2 and ULTT3 test were less common and the results from these two tests were combined on a 0-4 scale.

1.3.2.3 Nerve provocation tests.
Compressed or otherwise injured nerves often have a lower threshold than a normal nerve to direct mechanical pressure. This may be due to a diminution of the threshold of the nerve fibres running within the nerve sheath to mechanical stimulation or to sensitisation of the sensory fibres innervating the nerve sheath (nervi nervorum). The pressure provocative tests used as indicators for particular sites of nerve irritation or entrapment have been described by Mackinnon (1992). Eleven tests were used as follows:

**Median nerve provocation tests:**
- FDS. isometric contraction of flexor digitorum muscle for 30sec
- Pronator. isometric contraction of pronator teres muscle for 30sec
- P Prox. CT brief pressure applied by the examiner to the proximal carpal tunnel area

**Ulnar nerve provocation tests:**
- FCU. isometric contraction of the flexor carpi ulnaris muscle for 30sec
Cub fossa. brief pressure applied by the examiner over the ulnar nerve at the proximal cubital fossa
Guyons. brief pressure applied by the examiner to the ulnar nerve over Guyons canal in the hand

Radial nerve provocation tests:
 - Supinator. isometric contraction of supinator muscle for 30sec
 - ECRB. isometric contraction of extensor carpi radialis brevis (ECRB) muscle for 30sec
 - SRN Wrist brief pressure applied by the examiner over the sensory radial nerve at the wrist
 - Rad Tunnel brief pressure applied by the examiner over the radial nerve at the elbow

Any report of either marked local pain or positive symptoms in that particular nerve distribution was scored 1. Results were added for the median nerve to give a 0-3 scale on each side or a 0-6 scale overall. Results from the radial and ulnar tests were combined to give 0-7 scales for each upper limb and a 0-14 scale overall.

1.3.2.4 Overall scales.
Three overall scales were computed, one each for left and right upper limb and one for all areas. For left or right the score was formed by taking 6 elements and giving them equal weight. The 6 elements were:
 - Body chart pain/tenderness score
 - Body chart paraesthesia/numbness score
 - UTT1
 - UTT2 and UTT3
 - Median nerve provocation tests
 - Radial and ulnar nerve provocation tests

To normalise the score, it was converted to % maximum possible. Thus 100% represents both types of symptoms in all areas, plus maximum grade on all tension tests and positive signs on all nerve provocation tests.

For the overall scale for all areas the same approach was adopted. However, now for the nerve tension tests and the nerve provocation tests, the combined score for left and right was used. For the body chart scores, a new combined score was calculated for right, left and the neck/back. Finally a 7th component was included, the VAS pain score. Thus overall this scale comprised:
 - Body chart pain/tenderness score for right and left and neck, plus back
 - Body chart paraesthesia/numbness score for right and left, neck and back
 - UTT1 right and left
 - UTT2 and 3, right and left
 - Median nerve provocation results right and left
 - Radial and ulnar nerve provocation results right and left
 - VAS score

Again the resulting scale was normalised to % max possible, so as before 100% would mean all areas positive, all tests at maximum grade, plus a max (10) score on the VAS!

Note that these overall scales reflect both the extent and the intensity of signs and symptoms. Thus someone with strong pain in wrist and hand only will score the same as someone with less pain, but in a wider distribution.
1.3.3 Results of clinical examination of patients

1.3.3.1 Overall symptom scores
For the left side the overall symptom score averaged 26% (range 0% - 62%) (Fig 1.3.1). On the right side the symptom score averaged 38% (range 11% - 71%) (Fig 1.3.1). For the combined scale including both sides and the VAS, the average was 33% (SD 12%, range 8-67%) (Fig 1.3.2).

![Fig 1.3.1](image1)

![Fig 1.3.2](image2)

Fig 1.3.1. Normalised symptom scores for patients, right and left sides. Error bars 1 s.e.

Fig 1.3.2. Frequency distribution of overall combined normalised scores for 47 NSAP (RSI) patients

1.3.3.2 Upper limb tension tests

**ULTT1** This test was commonly positive with 85% of the patients scoring 1 or 2 on one or both sides. Thirty patients, 64%, had bilaterally positive responses. Sixteen (34%) patients scored 2 (restricted elbow extension<90 degrees and severe pain) on left or right (or both). Fig 1.3.3 shows proportion of right and left positive responses.

**ULTT2/3** 73% of patients had positive results on the ULTT2 or ULTT3 on either left or right sides (or both). 18 subjects had bilateral responses. However, only 2 subjects had severe movement restriction, i.e. they scored 2 on the severity scale. Fig 1.3.4 shows the combined ULTT2/3 positive responses for right and left upper limbs.
1.3.3.3. Neural provocation tests

Table 1.3.1 shows the patient % of positive tests for the right and left sides, i.e. reproduction of symptoms on isometric muscle contraction sustained for 30 seconds or when direct digital pressure was applied over the peripheral nerve.

<table>
<thead>
<tr>
<th></th>
<th>Median</th>
<th>Ulnar</th>
<th>Radial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FDS</td>
<td>Pronator</td>
<td>PProx CT</td>
</tr>
<tr>
<td>Right</td>
<td>26</td>
<td>38</td>
<td>62</td>
</tr>
<tr>
<td>Left</td>
<td>6</td>
<td>13</td>
<td>19</td>
</tr>
</tbody>
</table>

Key: see section 1.3.2.3

Overall, only 9 subjects (19%) had no positive responses on nerve provocation tests. The direct pressure tests over nerves generally produced more positive scores than the muscle contractions. A positive response to median nerve pressure at the proximal carpal tunnel was present most often, in 62% of RSI patients on the right side. The most common contraction response was to pronator muscle on the right, with 38% getting some pain.

1.3.4 Summary

NSAP patients have a wide range of signs and symptoms in the upper limb. Most were bilaterally affected, with worst problems on the right, usually the dominant side. Nerve tension tests were regularly positive with the ULTT1 (median) test most frequently positive. Nerve provocation tests involving direct pressure applied to nerves were also frequently positive, again most commonly, but not exclusively, that for the median nerve. Therefore on clinical testing the patient group demonstrate clear signs of multiple sites of nerve mechanosensitivity. This may in part explain the chronic and diffuse nature of their symptoms.
Section 1.4

VIBRATION THRESHOLD IN RSI PATIENTS AND OFFICE KEYBOARD WORKERS

1.4.1 Introduction.

Changed vibration sense has been found in many examples of peripheral nerve dysfunction, for example, diabetic, toxic, uraemic, alcoholic and vibration induced neuropathies (Lindblom and Goldberg, 1979, Lundborg 1988, Lundborg et al. 1992, Hilz et al. 1998). Dellon (1981) considered that altered vibration perception was the earliest clinical finding in peripheral compression neuropathy. Changes to vibration perception have been observed in the earliest stages of carpal tunnel syndrome (CTS) (Lundborg 1988, Jetzer 1991). Quantitative sensory testing that includes vibration perception measurement has been recommended for the evaluation of patients "at risk of subtle sensory dysfunction", e.g., cumulative trauma disorders (Schaumberg and Berger 1992). Increases in vibration threshold have been observed in medical transcriptionists (Doezie et.al. 1997) and we have found similar increases in office workers who do a lot of DSE work. We also found increased vibration thresholds in RSI patients (Greening and Lynn, 1998b). Goldberg and Lindblom (1979) demonstrated methods for the measurement of vibration threshold (VT) using skin deformation measured in µm. The normative psychophysical threshold values for vibratory perception have been evaluated. Vibration thresholds in the hand average between 0.20 – 0.40 µm for normal healthy subjects aged between 20 – 49 years (Hilz 1998, Goldberg and Lindblom 1979,). Hilz (1998), used the Somedic AB vibrometre, Goldberg and Lindblom (1979) an earlier version of this device. With both studies vibration frequency was constant at 100Hz, with probe pressure contact maintained at 550g.

In our previous study on vibration perception, thresholds were significantly raised for an area of skin innervated by the median nerve in both patient and office worker groups (Greening and Lynn 1998b). In this study we wished to repeat the vibration perception threshold measurement in a blind fashion and in larger subject groups. Although we had planned to repeat vibration threshold following keyboard use (Greening and Lynn 1998b) in-practice this turned out to not be possible since individuals use of the keyboard quickly demonstrated who were in the patient and control groups, effectively un-blinding the examiner.

1.4.2 Methods

The Vibrametre (Somedic AB, Stockholm, Sweden) allows for the direct measurement of amplitude of the vibrating probe and controls for the application of pressure. Pressure was kept constant, via a monitor on the control unit, at 550g (the weight of the stimulator). The probe is 13 mm in diameter and vibrates at a constant 100 Hz (twice AC frequency). The vertical peak -to - peak amplitude of the probe is measured by an accelerometer and is displayed digitally in µm on the control unit.

All subjects were familiarised to the vibrating stimulus by trial runs carried out over the radial or ulnar styloids. These were repeated until subjects were able to (within 20%), consistently indicate onset of stimulus. The stimulus was then applied over areas of the hand supplied by the median, radial and ulnar nerves. These were; the palmar surface of the head of the 2nd metacarpal bone, the dorsal surface over the shaft of the 2nd
metacarpal and the dorsal surface over the shaft of the 5th metacarpal (see Greening and Lynn 1998b for method details). Across subjects the initial hand stimulated was randomised. At least three threshold readings were made at each site, values more than +/-20% were discarded. The average appearance threshold measurements, i.e. point at which the subject first felt onset of the stimulus, were calculated as a measure of vibration threshold.

1.4.3 Statistical analysis

This was carried out using SPSS Windows software (Student-Newman-Keuls test, 1-way anova) Critical P value 0.05.

1.4.4 Results.

Analysis for side (left v right) or age demonstrated no significant effects. Right and left side vibration threshold data were averaged and compared by group as shown in Fig 1.4.1.

![Fig1.4.1 Average vibration threshold for all areas and all groups](image)

In the control group the areas innervated by the median, ulnar and radial nerves showed similar vibration thresholds. In contrast, areas supplied by the median nerve were elevated in the patient group. On average the median nerve area vibration threshold for the patient group was 0.63±0.05µm (95%CI: 0.52-0.74, n=45), for the office workers this was 0.52±0.03µm (95%CI:0.46-0.58, n=37). The control group average for vibration
threshold for the median nerve was 0.43±0.01µm (95%CI:0.38-0.46, n=42). Student-Newman-Keuls test 1-way Anova showed that the patients were significantly different from both office and control groups (p=0.002). A planned one way comparison of median nerve threshold, between office workers and controls, showed a significant difference (p=0.01).

Threshold values for the ulnar nerve also differed between the patient group compared to the office and control groups. Average values for the patient group were 0.52±0.04µm (95%CI:0.42-0.62), control average 0.41±0.02µm (95%CI:0.36-0.45) and office worker average, 0.42±0.01µm(95%CI: 0.38-0.45). 1-way ANOVA demonstrated that the ulnar nerve threshold in the patients group differed significantly from both the office workers and control groups (p=0.04). Controls and office workers did not differ significantly from each other. Control, office and patient average thresholds for the radial nerve were 0.41±0.01µm, 0.40±0.01µm and 0.44±0.03µm respectively, with no significant differences.

1.4.3 Discussion

These results are in line with our previous work on vibration threshold. The patient group clearly has raised vibration threshold over skin areas supplied by both the median and ulnar nerves. Compared to our previous study, ANOVA in this study did not demonstrate significant differences between office workers and the control group, although a planned one way comparison did reach significance for median nerve threshold. Unlike our previous study, the office workers intensively using keyboard equipment showed, as a group, lower vibration thresholds than the patients. In the previous study the threshold elevations for the median nerve in patients and office workers were similar (patient 0.68±0.07µm, office 0.72±0.08µm). Threshold values in the control group were in line with previously reported data (see section 1.4.1). In the context of the wide dynamic range of vibration sensitivity, the changes in vibration threshold reported here are small, but are clearly significant.

1.4.4 Summary

In the patient group median nerve vibration threshold is raised by an average of 45% compared to the control group and the ulnar nerve vibration threshold by an average of 21%. The office workers also have raised vibration thresholds in the median area, by 21%, but the rise is significantly less than in the patients.
Section 1.5
FLARE RESPONSES
1.5.1 Introduction.

The red flare surrounding a small injury to the skin has long been known to be due to the release of vasodilator substances from afferent (sensory) nerve endings activated by the injurious stimulus. A convenient way to elicit flare is by histamine stimulation, and tests of flare produced in this way are used to assess whether skin is normally innervated. The particular nerve fibres that produce flare are small, unmyelinated (C) fibres, specialised to detect injurious stimuli. These "nociceptor" afferents play a key role in pain production and in triggering the chronic changes in the central nervous system that accompany partial nerve injury. Having shown a loss of function in the large afferents subserving vibration, it was of considerable interest to see if small nociceptor fibres were also affected. There was already an indication in the literature that this might be the case. It was reported by Helme et al. (1992) that flare on the forearm was reduced in RSI patients. However, our studies on vibration led us to expect the main changes in the median nerve area. The aim of this part of the study was therefore to look in the median nerve distribution for reduced flare in patients and office workers.

1.5.2 Methods

Flare is not visible on the palmar surface of the hand, the principle area innervated by the median nerve. However, by using laser Doppler (LD) imaging it is possible to demonstrate flare responses (Lynn, Greening, et al. 1999). LD imaging used the Lisca Perfusion Imager (Lisca Development Ab, Linkoping, Sweden) and involves scanning a low power HeNe laser beam over the skin and measuring the Doppler shift in the reflected light. During the study, the laser power supply failed and had to be replaced. This was preceded by a period where the scanner was unreliable. In consequence, not all subjects were scanned, and the biggest loss of subjects was from the office worker group, where data was obtained on only 29 subjects. Because of variations between skin areas and subjects in skin thickness, in the geometry of the microvasculature and other factors affecting the size of the reflected signal, it is not possible to measure skin blood flow in absolute units with this method. However, it is possible to make accurate assessments of relative blood flow within a skin area and over a period of time, using an arbitrary flux scale where the measured flux changes will be proportional to the changes in skin blood flow.

The stimulus used was histamine iontophoresis. A cotton wool pad (9mm diameter) soaked in 1% histamine was pressed lightly on the skin. An electric current of 500µA was then passed for 20sec through this electrode, with a reference return electrode on the forearm. Preliminary experiments showed that the histamine stimulus was more reliable if preceded by two 20 sec periods of iontophoresis of saline to the same location on the palm of the hand. The area tested was on the palm of the hand, midway between the thumb and the index finger and about 2cm from the radial edge of the hand. This area is innervated by the main part of the median nerve that runs through the carpal tunnel. Small markers made of black adhesive tape were stuck to the skin 2 or 2.5cm distal and proximal to the stimulus position, so the distance between them was 4 or 5 cm. The area scanned was 4.5-6cm across and scans took about 1 minute. The procedure was to scan once (scan C1), then do a saline iontophoresis and scan again (C2). A further saline iontophoresis was followed by a third scan (C3), then histamine was iontophoresed and a final scan
(S1) was made. The final scan started within 30 sec of ending the histamine iontophoresis. Right and left hands were scanned. Across subjects the order of scanning right and left was randomised.

Flare images were analysed as follows. The baseline flux was measured from the last control scan (C3), using the average of the flux in 1cm square areas in the 4 corners. The flux in these 4 corners was also measured for the post-histamine scan (S1) to check that background had not changed radically. A difference image was computed by subtracting the C3 scan from the S1 scan on a pixel by pixel basis and allowing for any small changes in marker position. The flare area was computed as the number of pixels with flux more than 33% above background on the difference image. The area used for counting pixels was limited to an area selected to include the flare response, but exclude any peripheral parts of the image that contained isolated areas of elevated flux. In a number of cases there were large shifts in background flux between scans. When this occurred we either used the C2 or C1 scans, or if all control scans were very different, used the background value from the corners of the S1 scan, and calculated the number of pixels on this scan at a flux more than 33% above background. In some instances, blood flow was very variable over time, with waves of vasodilatation and vasoconstriction lasting 3-30 sec. This resulted in vertical bands of alternating dilation and constriction on scans, as the scan pattern was distal-proximal, then step medial or lateral. An example is shown in the bottom scans in Fig 1.5.2. In such cases flare areas were calculated on the basis of the background at the edge of the scan in the flare area, i.e. in the centre of the image, not in the corners. This approach was only needed in < 10% of instances. The intensity of flare responses was measured by calculating the average flux increase 6.5-9.5mm from the centre of the flare, or from the mid-point between the markers if no flare was detectable (see Fig 1.5.1). Thus we measured the average flux at 2-5mm from the edge of the stimulator. This distance range was chosen (1) to be clear of the stimulator itself (radius 4.5mm), and (2) to include the nearest skin region since flare extent was usually limited.

1.5.3 Results
Fig 1.5.2 shows several "typical" flares. Flare responses were very variable in all subject groups. The upper subject is the same as in Fig 1.5.1, and shows a clear flare. Subject B is an example of a clear local response to histamine, but no detectable flare. Subject C is one of the few subjects with no response at all to the histamine. Subject D is an example of a subject with very variable skin blood flow, as discussed above. Despite the uneven backgrounds, it is clear that there is a strong flare response, clearest in the proximo-distal direction.

| Table 1.5.1 |
|-----------------------|-----------------------|-----------------------|
| Flare parameters in different groups. Average of right and left sides. |
| Group           | Background flux | Flare intensity* | Flare area |
|                 | Arbitrary units | Arbitrary units    | mm sq      |
| Control         | 37             | 510               | 28         | 215              | 32      | 545      | 60      |
| Office workers  | 29             | 505               | 36         | 127              | 32      | 383      | 67      |
| RSI Patients    | 42             | 509               | 21         | 123              | 16      | 367      | 35      |

* Flare intensity given as increase over baseline flux at 2-5mm from the edge of the stimulator.
Fig 1.5.1 Typical flare. Left hand. Background (509 units) subtracted.
Fig 1.5.2 Representative flare scans from 4 subjects. See text for details.
Fig 1.5.3. Flare parameters for left (L) and right (R) hands for controls (c), office workers (ow) and rsi patients (p). Upper part, flare area, calculated for 33% above background. Middle part, flare intensity, flux units above background at 4-10mm from the edge of the iontophoresis electrode. Lower part, baseline skin blood flux before histamine stimulus.
Average trends between the groups are shown in Table 1.5.1 and Figure 1.5.3. Background flux did not differ between the groups, although it was generally lower on the right hand than the left (p<.001, paired comparison). Both flare area and flare intensity were significantly lower in the office workers and the patients than in the controls (p<.05, Student-Newman-Keuls test, 1-way anova). There was no difference on these measures between the patients and the office workers. Within the patients, neither flare size nor intensity correlated with symptom score. Flare size and flare intensity did not correlate with subject age. There was a weak (p=.052) trend for background flux to increase with room temperature.

There was a significantly higher flux on the left than the right (see Fig 1.5.3). This was true for all groups and for both baseline flux and the peak flux during flare. There was no difference in the flare area, or in the intensity increase between right and left. This difference in flux between sides is puzzling as no similar difference was seen in the reflex studies where baseline flux was measured by single point laser Doppler flowmetry (see section 1.6)

1.5.4 Discussion
Despite the variability from subject to subject, a marked trend for reduced flare was seen in both the RSI patient and the office worker groups. Flare area was 30% below control levels in the office workers and 33% down in the patients. Flare intensity was 41% below control levels in the office workers and 43% below in the patients. Since there was no tendency for flare size to vary with age over the limited age range (20-40) of our subjects, this difference is not due to the small age difference between the patients and office workers and the controls. A similar reduced flare area has previously been reported in the fore-arm for RSI patients (Helme et al. 1992). The pattern of change in both the patient and the at risk office groups is similar to that seen with vibration threshold elevation (Greening & Lynn 1998b and this study). It therefore appears that reduced nerve function affects both large and small sensory fibres in these two groups.

1.5.5 Summary
In RSI patients flare area is reduced by 33% and flare intensity is reduced by 43% compared with controls. Office workers show similar falls in flare area and intensity.
1.6 SYMPATHETIC VASOCONSTRICTOR REFLEXES

1.6.1 Introduction
If there is a general loss of peripheral nerve function in RSI, then somatic and autonomic motor function should be affected in addition to sensory function. There is no evidence of loss of function for the somatic (skeletal muscle) motor systems of the upper limb. However, signs of autonomic dysfunction (e.g. cold pale skin) are occasionally reported. The aim of this part of the study was to look quantitatively at a test of autonomic function in the upper limb and to see if there was any trend for reduced function in RSI patients or in "at risk" office workers. The test chosen was the fast vasoconstrictor reflex seen following brief application of an ice pack to the neck (McGlone and Dhar 1996). This involves the sympathetic division of the autonomic nervous system. The afferent fibres are from thermoreceptors in a region not likely to be affected in RSI. The efferent fibres are sympathetic post-ganglionic fibres that run mostly with the main nerve trunks. Any peripherally derived reduction is therefore likely to be due to a change in the efferent fibres.

1.6.2 Methods
Subjects sat with both hands, palm surface up, on a table. Small light guides were taped to the skin, one on each hand, over the head of the second metacarpal bone, i.e. on the medial palm, within the median nerve distribution. The light guides were connected to a 2-channel laser-Doppler blood flow monitor (Moor Instruments MBF3D). Laser light is sent from a low power near infrared laser via one of the paired optic fibres in each light guide. Light back scattered from the skin was collected by the other optic fibre in the light guide. A small proportion of the reflected light was from moving blood vessels and so is Doppler shifted in frequency. The flow monitor measures the amount of the Doppler shifted light and the size of the shift. The product of these 2 measures is computed in real time and will be proportional to skin blood flow. The exact volume of skin sampled is not known and neither is the orientation of all the micro-vessels, so it is not possible to calibrate the monitor in absolute units. Arbitrary flux units are used instead. However, the laser-Doppler monitor does allow accurate measurement of changes in blood flow at a single sampling position.

Subjects were tested 2 times at 1-2 min intervals. The stimulus was the placing of a small ice pack onto the back of the neck for 5sec. A marker signal was placed on the recording manually at the time of ice application (e.g. see Fig 1.6.1). The following parameters were measured: (a) the average baseline flux during 30sec before stimulation, (2) the flux at the time of stimulus application, and (3) the minimum flux reached during the reflex. The reflex fall in flux was expressed as % value at time of stimulation. Where no reflex was visible (13% of trials) a value of zero was assigned for the % fall.

1.6.3 Results
Baseline flux levels varied considerably between subjects, but overall there were no significant differences between groups (see Fig 1.6.3 and Table 1.6.1) (1-way ANOVA, Student-Newman-Keuls test). Baseline flux was also the same on right and left sides. Reflex fall in flux was very variable both between
Fig 1.6.1  Vasoconstriction reflexes in response to ice (applied at the vertical dashed lines). Relatively large responses with, unusually, little reduction on trial 2. Time scale is continuous from the upper to the lower part. Note the typical variable baseline. Recordings from similar locations within the median nerve distribution on each hand.
subjects and between the 2 hands in a given subject. The reflex falls were greater when the baseline flux was higher (see Fig 1.6.2). To allow for this, we have expressed the reflex as a percentage of the value at the time of stimulation. Office workers and control subjects had reflex falls of 64% and 60% respectively while patients showed a significantly smaller fall, 48% (see Fig 1.6.3, Table 1.6.1)(1-way ANOVA, Student-Newman-Keuls test). The proportion of trials with no reflex response was also greater in the patients. In 20 out of 44 patients at least one trial of the 4 had no reflex. In contrast in control subjects only 6/42 were zero and in office workers only 4/37. These proportions are significantly different (chi2=0.0002), and just the difference between controls and patients has chi²=8.5, p=0.004.

![Graph showing the relation of reflex fall in blood flow to baseline flow. Data for control subjects. R, right side, L left side, 1, first trial, 2, second trial.](image)

**Table 1.6.1.**

<table>
<thead>
<tr>
<th>Category</th>
<th>N</th>
<th>Baseline Flux</th>
<th>% Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>se</td>
</tr>
<tr>
<td>Control</td>
<td>42</td>
<td>90.3</td>
<td>10.3</td>
</tr>
<tr>
<td>Office worker</td>
<td>37</td>
<td>77.6</td>
<td>8.3</td>
</tr>
<tr>
<td>Patient</td>
<td>44</td>
<td>66.2</td>
<td>7.0</td>
</tr>
</tbody>
</table>

There was no difference in reflex size with age, or between left and right sides. However, the reflexes on the first trial were nearly always bigger than those on the second, and the proportion of trials with no reflex was also higher for the second than for the first trials.
1.6.3a. Mean baseline flux in the 3 groups. b. Mean reflex fall in flux. Error bars +1 se. Data as in Table 1.6.1.

1.6.4 Discussion
Despite the variability of sympathetic reflexes, clear differences emerged between groups. The RSI patients had slightly smaller (by 20%) reflexes compared with controls, while office workers were very similar to controls. There was no significant trend with age, so the small age difference between controls and patients cannot account for the difference in reflex size. The difference between office workers and patients was equally clear, but cannot be explained by any age difference since these 2 groups were very similar in age range and average age.

1.6.5 Summary
The brief sympathetic vasoconstriction induced by a remote cold stimulus in the skin of the hand is reduced by around 20% in RSI patients. No such change is seen in "at risk" office workers.
1.7 DISCUSSION AND SUMMARY

1.7.1 Correlations between neural tests and clinical signs

Pain score on the VAS was related to vibration threshold ($r=0.28$, $p$ just > .05) and if the group is divided into those scoring above 5 on the VAS scale and those scoring less, then a very significant difference emerges (Fig 1.7.1a, $p=.002$). A similar trend was present for the flare and sympathetic reflex measures (Fig 1.7.1 b and c), with those with more pain having smaller responses on the nerve function measures. However, neither of these trends is close to statistical significance. For the overall normalised score of signs and symptoms, there is a non-significant trend for vibration threshold to rise with increasing clinical score (1.7.1d). For the other 2 measures there is almost no trend (fig 1.7.1 e,f). It may be relevant here that the overall scale is strongly influenced by the spatial extent of signs and symptoms, and rather little by their magnitude. When comparing with point measures of extent of physiological changes, this may explain in part the lack of correlation. The VAS scale, on the other hand, is an intensity scale and, as already discussed, does correlate positively with the neural measures. No differences in the neural measures were seen in relation to the ULTT1 scores on either limb. Also, there were no differences between left and right hands, even in the minority of subjects with markedly unilateral clinical signs.

Overall, given the clear trend between patients and controls, the lack of strong trends within the patient group in relation to clinical measures is surprising. It is interesting that the clearest pattern occurs with the simple measure of overall pain. It should however be borne in mind that all the measures used, but especially those involving blood flow monitoring, are quite variable. As the group is subdivided to look for trends, $n$ values fall, and negative findings should not be over-emphasised.

1.7.2 Discussion of changes revealed by the cross-sectional study

NSAP patients consistently show reduced function on all three neurophysiological measures. The changes are modest, but statistically secure. An increase in vibration threshold of around 45% is significant, but the dynamic range of this sense is 100 to 1000-fold. Therefore, the change seen in NSAP patients represents only a small proportion of the sensory range. Similarly, the reduction in vasoconstrictor reflex is only by on average 20%. The reductions in flare size and intensity (by 33% and 43% respectively) are, however, quite marked. All the measures show considerable variation from subject to subject. Because of this, none is suitable as a single diagnostic test. Even when combined, because there are no strong correlations between them, it is not possible to construct a measure that will, in an individual case, clearly designate a subject as a patient.

Although on their own none of the trends would be impressive, when looked at overall and across the groups as a whole, a very clear picture of diminished peripheral neural function emerges. Clearly the loss of function seen previously with vibration, and confirmed here, is not restricted to large sensory functions. Small fibre functions, whether related to sensory fibres (flare) or to autonomic motor fibres (vasoconstriction), are also affected. As we have proposed previously (Greening and Lynn, 2000), the simplest interpretation of such a picture is that RSI patients have a minor neuropathy.
Fig 1.7.1 Neural scores in patients in relation to severity of clinical signs and symptoms. Vibration threshold (a,d), flare area (b,e) and sympathetic reflex (c,f). Patients divided into 2 equal groups (N is 21-23) above or below either a score of 5 on the pain VAS (a-c) or score of 31% on the overall signs and symptoms normalised scale (d-f). Error bars, + 1 s.e.
The reason for the neuropathic lesion may lie in the reduced nerve mobility (see Chapter 2).

Office workers who spend at least 40% of their working time using DSE present an interesting contrast. They have reduced flare, to a similar extent to the reduction seen in the patients. They have a slightly elevated vibration threshold. However, there is no sign of any fall in the sympathetic reflex. It appears that flare may be a very sensitive indicator of possible nerve injury. Unfortunately, it is the most difficult of the 3 measures to carry out. Other measures of small sensory fibre function may be more useful. For example the measurement of sensory thresholds for innocuous warming or cooling might offer an easier way to evaluate small fibre function. However, flare does have the advantage that it is quite objective and does not require subjective responses.

1.7.3 Summary of cross-sectional study

1. In the median nerve area of the hand, RSI patients have a 45% rise in vibration threshold, a 43% fall in axon reflex flare intensity and a 20% reduction in a sympathetic vasoconstrictor reflex.
2. The extent of sensory or reflex changes does not correlate closely with our clinical scoring of severity, although there is a strong association between the ratings of ongoing pain and the extent of elevation in vibration threshold.
3. In the same area of the hand, "at risk" office workers have a 21% rise in vibration threshold, a 41% fall in flare intensity, but no change in the sympathetic reflex.
4. The picture emerging from this extensive programme of testing in RSI patients is of a modest reduction in function associated with both small and large peripheral nerve fibres. All aspects investigated so far show changes in the RSI patients. Office workers who do a lot of keyboard-type work show some of the same changes.
Chapter 2

ULTRASOUND IMAGING OF MEDIAN NERVE MOVEMENT

2.1 INTRODUCTION TO IMAGING STUDIES

A possible way that arm nerves could be injured would be by the pressure exerted on them by adjacent muscles and tendons during limb movements. In practice, nerve can slide easily during limb movements, thus avoiding any strong localized stresses on nerves. The pattern of nerve movement can involve not just longitudinal sliding. For example, in the carpal tunnel the nerve moves radially during wrist flexion (Greening et al, 1998). We have shown in a previous studies (Greening et al., 1999; Greening et al., 2001) that this sliding is reduced, absent, or even reversed, in patients with non-specific arm pain.

This part of the contract is involved with checking aspects of the methods used in previous work (2.2 and 2.4), with extending studies to at-risk office workers (2.3), and with developing a short digital video showing nerve movement during keyboard use (2.4).

2.2 A COMPARISON OF THE MEDIAN NERVE MOVEMENTS MEASURED BY MAGNETIC RESONANCE IMAGING (MRI) WITH THOSE OBTAINED USING ULTRASOUND IMAGING

2.2.1 Introduction

Our previous studies using both MRI and ultrasound imaging (Greening et. al. 1999, Greening et al 2001) obtained similar, but not identical, average figures for transverse nerve movement in patient and control groups. The control nerve movement was 3.2±0.5mm using MRI and 4.5±0.7mm using ultrasound. For the patient groups nerve movement was 1.0±0.64mm with MRI and 1.2±0.5mm with ultrasound. To check the reliability of the 2 methods, we have made a direct comparison in the same set of subjects of median nerve movement at the carpal tunnel using ultrasound and MR imaging.

2.2.2 Methods

2.2.2.1 MR imaging

We imaged 10 wrists from 9 subjects, 1 male and 8 female. Similar methods were used as in a previous study (Greening et. al. 1999). Subjects were imaged lying supine in an open access MR scanner (OPEN Viva, 0.2T,Siemens Medical Systems, Erlangen, Germany). Subjects were able to lie comfortably in a supine position so that the wrist could be imaged while the arm was abducted by 20 degrees from the side of the body with the elbow extended and the wrist immobilised in 30 extension and then 30 degrees of flexion by modified Futuro wrist splints. The arm was maintained in this position by a vacuum splint. The magnetic field strength of open scanners is lower than closed scanners, which employ field strengths in the region of 1.5 to 2 T, and image resolution is consequently of a lower quality. Surface coils, which act as both RF transmitter and receiver of the MR signal were positioned around the wrist to improve the signal to noise ratio. Foam padding was placed between the wrist splints and the coil to reduced “hot
spot” effects on images caused by tissue coming too close to the coil. The padding also helped to support the wrist and reduce the risk of arm movement. When obtaining images for comparison it is obviously important that the same slices from the data acquisition are compared. Initial fast location scanning was performed in the sagittal plane to identify the RF coil centre position and to confirm the angle of the radio-carpal joint.

The same number of slices at a constant slice thickness were acquired for each subject. Slice comparison at the level of the hook of hamate was chosen for our studies, since this is an easily visualised structure on the scans and the median nerve at this level is easily visible (see Fig. 2.2.1). Image slices at the level of the radio-carpal joint (the site where Ultrasound imaging was performed) were obtained, but proved to be unhelpful for quantifying nerve movement since the nerve at this level was not clearly visible at the resolution obtained with these images.

The carpal tunnel was imaged in neutral, 30° of wrist flexion and 30° of wrist extension. Imaging the axial plane was performed on 8 contiguous 5mm slices aligned perpendicular to the nerve axis using a T2 weighted fast spin echo sequence (TE102, TR 2136, FOV 180x180mm) in a scan time of 5 minutes. Flow saturation was employed to improve image quality. Pixel size was consistent between all images at 0.71x0.70mm. The procedure took approximately 40 minutes.

To measure nerve movement we calculated the distance, d, of the centre of the nerve (N) from the hook of hamate (H) in the direction from H to the medial edge of trapezium (T). Initially the co-ordinates of H, T and N were obtained off-line using an image measuring programme (Fig 2.2.1). Then a spreadsheet calculated the nerve-hamate distance, allowing for the angle between the image horizontal and the image co-ordinate axes.
2.2.2.2 Ultrasound imaging

In the same subjects and on the same wrists imaging was performed using a linear array ultrasound probe (width 26 mm) running at 10-22 MHz (Dynamic Imaging, Diasus). Subjects lay on an examination couch with their arm at the side with the elbow fully extended and the shoulder abduced for comfort by 10-20°. The forearm was pronated and the transducer held against the ventral surface of the wrist at the level of the distal crease line. This skin marking represents the level of the radiocarpal joint (just at the proximal edge of the carpal tunnel), and it was here that the clearest images of the median nerve were obtained. The arm posture was the same as that used for the MRI study. The scanning head was lightly strapped in place using a special holder. This holder located the scanning head at right angles to the skin and was held in place by an elastic strap adjusted to just keep the scanning head securely in place but without exerting excessive pressure on the wrist. The transducer was separated from the skin by a 6 mm thick “stand-off” layer of Sonogel (Vertriebs Gmbh).

The surface of the skin was marked using thin (approximately 2 mm wide) strips of tape (Fixamole, Belersdorf) fixed along the long axis of the palmar surface of the wrist. Two strips were positioned 10-17 mm apart and could be seen on images as bright lines at the skin surface that cast an acoustic shadow across the image (Fig 2.2.2). Co-ordinates of the markers and of the centre of the nerve were measured off-line. The distance of the centre of the nerve from the markers in the horizontal and vertical directions was determined from the co-ordinates. Where 2 markers were visible, nerve distance from the midway point between the markers was used. Change in nerve position was measured by subtracting the values in flexion from those in extension. As with the MR images, allowance was made for any deviation of the image horizontal and vertical from the co-ordinate axes. However, due to the way that the ultrasound transducer was positioned, its surface was usually close to horizontal. Any allowance for image angle relative to horizontal was therefore always small.

2.2.3 Results

Measurements were made on 9 subjects, 6 controls, 2 office workers and one patient (Table 2.2.1). In one control subject, both wrists were imaged.

<table>
<thead>
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<th>Category</th>
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<th>Rad mvt</th>
<th>Post mvt</th>
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<th>Post mvt</th>
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<tr>
<td>1</td>
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<tr>
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<td>3.38</td>
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</tr>
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<td>0.34</td>
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<td>0.74</td>
<td>3.58</td>
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</table>
Fig 2.2.2 Ultrasound image of the median nerve at the wrist.
On average, posterior movements were similar, but radial movements were more positive on the ultrasound images (p=.04, paired t-test). The 2 different methods correlate reasonably (Fig 2.2.2), with a correlation coefficient (r) of 0.69 (significant at the 5% level). Ranking subjects shows the close relation between the 2 measures (Fig 2.2.3), and the rank correlation coefficient is 0.78 (p<.01).

Fig 2.2.2
Measurements of median nerve transverse movement in the same subjects, using 2 different imaging methods.

Fig 2.2.3
Ranks of measurements in Fig 2.2.2

2.2.4 Discussion
The 2 methods of imaging do not give identical results, although there is a good correlation between them. Part of the difference will be due to the inherent variability in both methods. We have previously shown that measurements from repeat ultrasound images can differ substantially, with the standard deviation of the differences between pairs of measurements being 1.0mm (Greening et al, 2001). It is likely that repeat MR image measurements would be just as variable. However, the significant trend for ultrasound values for nerve movement to show a larger extent in the radial direction must be due to some non-random factor. The most likely reason for the difference is the different level at which the images were taken. The MR images at the proximal site used for ultrasound did not usually clearly show the median nerve. The ultrasound images from the distal site at the level of the hook of hamate used for MRI were poor due to the dense flexor retinaculum that overlies the carpal tunnel. Consequently we are comparing measurement from sites approximately 1cm apart. A small change in the relation of the nerve to the flexor tendons might result in less radial movement at the more distal site.

2.2.5 Summary
During a 30° extension to 30° flexion wrist movement, the extent of radial movement of the median nerve is estimated as 1.5mm less using MR imaging than using ultrasound images. However, the 2 methods rank subjects in a very similar manner, with a rank correlation coefficient of 0.78.
2.3 MEDIAN NERVE TRANSVERSE MOVEMENTS DURING WRIST FLEXION IN “AT RISK” OFFICE WORKERS

2.3.1 Introduction
In normal subjects the median nerve moves radially by an average of 4.5mm at the distal wrist crease during a wrist movement from 30° extension to 30° flexion. This transverse sliding does not occur, or is very much reduced, in many patients with non-specific arm pain (NSAP (or RSI)). Office workers who do a lot of keyboard work show some of the same neurological changes as the patients in the median nerve area. It was therefore decided to look at median nerve movement in a small group of “at risk” office workers to see if any trend for reduced transverse sliding of the median nerve was present.

2.3.2 Methods
Ultrasound images were made and measured as described in the previous section (2.2). Six subjects who had taken part in the cross sectional study, and whose vibration threshold was therefore known, were imaged (Table 2.3.1). A further 4 additional subjects were recruited. In one case both wrists were examined, but otherwise the right wrist was imaged (except for one subject where we looked at the left wrist). In all but one case a standard physiotherapy test of median nerve “tension” (the ULTT1 test, see Chap 1, section 1.2.3) was carried out and graded 0-2, from normal to severely restricted.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Side</th>
<th>Radial Mvt</th>
<th>Posterior Mvt</th>
<th>Med vib thresh</th>
<th>ULTT1*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>mm</td>
<td>mm</td>
<td>µm</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>right</td>
<td>6.79</td>
<td>2.19</td>
<td>0.413</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>right</td>
<td>1.77</td>
<td>1.10</td>
<td>0.573</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
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<td>2.89</td>
<td>0.953</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
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<td>-0.43</td>
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</tr>
<tr>
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<td>0.577</td>
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<tr>
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<td>1.186</td>
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<td>right</td>
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<td>2.03</td>
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</tr>
<tr>
<td>10</td>
<td>right</td>
<td>4.85</td>
<td>0.34</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

# Vibration threshold in the median nerve area
* Upper limb tension test 1, graded 0-2 (see section 1.2.3)

2.3.3 Results
Average radial movement in the 10 office workers was 2.95±0.99mm. This is less than has been found in previous studies for normal subjects, but is more than is found in NSAP patients (Fig 2.3.2). Posterior movements of the median nerve in office workers are similar to those found in controls (Fig 2.3.2), and are nearly significantly greater from those found in patients (p=0.06, Mann-Whitney U test). The distribution of nerve movements in office workers is unusually wide (Fig 2.3.1) with 3 showing unusually small, or reversed, movements, but most having movement in the normal range. The 2 office workers with apparently reversed transverse movement did not have any problems
with arm pain or with the ULTT1 test. One of the three with a small degree of radial movement having a positive ULTT1 test and an elevated vibration threshold. They also had vibration thresholds close to the mean for the office group.

Fig 2.3.1 Frequency distributions of the extent of radial movement of the median nerve during a wrist movement from 30° extension to 30° flexion. The office workers (office) show a wide range compared with either the RSI patients or the controls. Patient and control data from Greening et al (2001) plus some additional data from this study.

Fig 2.3.2 Median nerve transverse movement. Mean and s.e. C – controls, n=22; OW – office workers, n=10; P – RSI patients, n=13.

Fig 2.3.3 Median nerve posterior movement. Mean and s.e. Group codes and numbers as for Fig 2.3.2
2.3.4 Discussion
There are signs that some office workers may have reduced median nerve movements in the wrist. There could be bias because the office workers were measured at a later time than most of the patients and controls. However, a small number of control subjects and patients were run at the same time as the office workers, and these later measurements fitted well with the earlier ones. Unfortunately, due to the wide range of movements across the small group tested, the average difference from the control values does not reach statistical significance. In view of the frequent presence of transient pain symptoms in the at risk office workers and of some changes in peripheral nerve function (see section A), a further examination of this question would be justified.

2.3.5 Summary
Three out of 10 office workers had unusually low or reversed values for the movement of the median nerve on wrist flexion. The majority, however, had values in the normal range.
2.4 THE EFFECT OF TENSION TESTING ON NERVE MOVEMENTS

2.4.1 Introduction
In many cases subjects being examined for nerve movement using ultrasound imaging had also been examined using nerve tension tests immediately beforehand. Since these tests involve manipulation of the upper limb, it is possible that they could alter nerve mobility. This short study was designed to check that doing nerve tension testing did not influence the observed nerve movements.

2.4.2 Methods
In 3 subjects (2 on one wrist, 1 on both wrists), the median nerve was imaged twice using the Diasus 10-22MHz ultrasound imager as described above (2.2.2). Between the 2 imaging sessions the tension test for the median nerve (ULTT1) was carried out. The time between the tests was 10-20 min.

2.4.3 Results
Table 2.4.1 gives the results. As noted in a previous reliability study (Greening et al, 2001), repeat measurements of nerve movement show significant variability. However, as the average values indicate, there was no systematic trend in the data collected after the ULTT1 testing. The average of radial movements in the 4 wrists was initially 1.78mm and after the testing was 1.53mm, a non significant difference of 14%. Note that the right wrist in the patient showed an unusual ulnar movement, and that this characteristic was retained after the ULTT1 test.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Category</th>
<th>Side</th>
<th>ULTT1 score</th>
<th>Radial movement, mm</th>
<th>Posterior movement, mm</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Before After</td>
<td>Before After</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>C</td>
<td>R</td>
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<td>4.34</td>
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<tr>
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<td>OW</td>
<td>L</td>
<td>1</td>
<td>2.37</td>
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<tr>
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<td>P</td>
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</tr>
<tr>
<td>3</td>
<td>P</td>
<td>L</td>
<td>1</td>
<td>2.25</td>
<td>0.63</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td>1.78</td>
<td>1.53</td>
</tr>
</tbody>
</table>

2.4.4 Summary
Carrying out the ULTT1 median nerve tension test has no effect on transverse median nerve movement in the wrist.
2.5. EXPLANATORY NOTES TO THE VIDEO ENTITLED “MEDIAN NERVE MOVEMENT AT THE WRIST – DURING KEYBOARDING”

An ultrasound probe was positioned on the anterior surface (front) of a subject’s right wrist close to the carpal tunnel. Figure 2.5.1 shows the ultrasound image obtained through the wrist. The image is magnified such that the distance between the small white markers at the very top of the image is 10mm. The left side of the image (labelled “radial side”) is towards the thumb, and the right side of the image is towards the little finger. The skin extends from left to right and can be seen to pass through the “anterior surface” label. The black band above this label, which extends from left to right, is a gap between the ultrasound probe and the surface of the wrist. Structures at the bottom of the image lie deep in the wrist. The median nerve, which supplies many of the muscles that control finger movement, is outlined in white. Since the nerve lies only a few millimetres from the surface of the wrist it may be at risk of compression. The dark patches to the right and below the nerve are the tendons to the fingers. These tendons move the fingers during typing.

With the probe attached, the wrist was rotated 180 degrees such that the anterior surface was inverted to face down, and the subject was asked to type for 20 seconds. During the video, the tendons (the dark areas to right and below the nerve) can be seen to move as the subject types. The nerve can also be seen to move during typing. This nerve movement may be important to accommodate tendon movement. If the nerve is somehow prevented from moving, the surrounding tendons to the fingers may compress the nerve as they move the fingers. This compression may be a cause of pain, for example, in carpal tunnel syndrome.

The video starts with a still frame. The 20sec of typing is then shown, with a small white arrow indicating the centre of the lower edge of the median nerve. Finally, the whole sequence is run again, but this time with no arrow. Nerve movement is predominantly side to side, and is sometimes very fast. The video is running at full speed, but is a bit jerky as the frame rate is only 10 frames per second (normal video rate is 24 frames per second).

The video, file name Nervemove.avi is in compressed AVI format and runs on MS Windows Media Player and should run on most video player software.

A copy of the file can be obtained by contacting HSE’s Health Directorate, Human Factors Unit at Bootle.

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