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ORIGINAL ARTICLE

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Vibrotactile sense in patients with different upper limb disorders compared with a control group

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Abstract *Background*: Upper limb disorders (ULDs) are common, and so are the difficulties with regard to their specific diagnoses. According to diagnostic consensus criteria, specific diagnoses include neuropathy and muscular- and connective-tissue disorders (MCDs). There is a need for valid objective diagnostic tools to reveal underlying mechanisms for specific diagnoses. *Objective*: To investigate the possible differences in vibration perception threshold (VPT) and tolerance to suprathreshold stimulation (STS) between controls and specific diagnostic ULD patient groups with uni- and bilateral neuropathy and/or MCD. *Methods*: In 161 ULD patients and 40 controls, the VPT of the median, ulnar, and radial nerves innervating the hand was examined by vibrometry using the ''method of limits''. The tolerance to STS of the anterior forearm was tested in 128 of the patients and all controls. *Results*: The ULD patients in all diagnostic groups had significantly higher VPT ($P < 0.05$) in all the nerves in limbs, with and without diagnoses compared with controls. Only patient groups defined with neuropathy demonstrated significantly higher VPT in the limb with diagnoses compared with the contralateral limb without diagnoses. The highest VPTs were found in the patient group with unilateral neuropathy and MCD, and for the radial nerve, VPT was significantly higher than that for patients with unilateral MCD alone. These findings were confirmed by almost similar findings in STS responses. *Conclusions*: The ULD patients generally demonstrated increased VPT compared with controls, indicating a neurogenous component independent of specific ULD diagnosis. Contralateral significant findings in limbs without diagnoses compared with controls indicate central neurogenous affection and/or the possibility of certain exposures elevating VPT before a positive status of a limb diagnosis is attained. Significantly higher VPT values in *limbs with neuropathy* diagnoses compared with *limbs without* and not in *MCD alone*, may indicate peripheral sensibilization or nerve affection only in the group with a specific diagnosis of neuropathy. These findings underline the importance of specific diagnoses among ULD patients.

Keywords Vibratory perception threshold · Vibrometry · Compression neuropathy · Paraestesia · Allodynia

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Background

Upper limb disorders (ULDs) are common among patients in the primary and secondary health sector, among patients on sick leave, early retired persons, and among patients notifying work-related disorders (Feuerstein et al. 1998; Hagberg and Wegman 1987; Parker 1996; Polanyi et al. 1997; Travers 1988), and they cause substantial financial consequences (Andersson 1999; Franzblau and Werner 1999). These patients represent a challenge with respect to diagnosis and treatment. Typical symptoms are pain, weakness, and numbness/tingling that suggest the involvement of the peripheral nerves. This is supported by studies finding an elevated vibration perception threshold (VPT) level among computer users with symptoms in the hand and forearm region (Jensen et al. 2002), in patients with repetitive strain injury (RSI) (Greening and Lynn 1998b), vibration-induced neuropathy (Lundborg et al. 1987), and carpal tunnel syndrome (CTS) as the earliest detectable objective sign (Dellon

1980; Gelberman et al. 1983). The changes in vibration sense as revealed by tuning fork or vibrometry have been found to correlate closely to the patient's subjective perception in sensibility (paraestesia and numbness) (Gelberman et al. 1983; Szabo et al. 1984).

Some studies have stated that the VPT testing procedure is of less or doubtful value (Gerr et al. 1995; Werner et al. 1994, 1995), because of limited correlation to electrophysiological findings. However, nerve conduction velocity might not be an optimal choice of "gold standard" as it tests the nerves at a limited distance, while VPT testing reflects the entire somato sensory pathway (Gerr et al. 1991). In compression neuropathy, nerve conduction correlates less with patients' symptoms than measurements of the vibratory sense do (Ellemann et al. 1999; Gelberman et al. 1983; Gerr et al. 1991). When factors influencing the VPT are controlled, the reliability of VPT is high (Gerr and Letz 1988; Goldberg 1979; Grunert et al. 1990; Hilz et al. 1998).

Recent studies have used the Somedic vibrameter testing at a fixed frequency of 100 Hz (Greening and Lynn 1998b; Jensen et al. 2002). Test results are expressed as displacement of the tissue (skin deformation), that is, the amplitude in micrometers. This is found to be an adequate stimulus of the *Pacinian corpuscles*, the main types of mechanoreceptors (Goldberg 1979) responding to innocuous stimuli above 65 Hz and most sensitive between 125 and 250 Hz. The Somedic vibrameter is constructed to test the VPT solely by the "method of limits," a yes/no procedure requiring the subjects to respond as to whether a stimulus is present or absent. This method is non-invasive, easy to perform, and less time-consuming than methods measuring at different frequencies. VPT measurement by the "method of limits" is found more reliable than the "forced choice method" (Gerr and Letz 1988) and is less time-consuming. Allodynic responses to suprathreshold stimulation (STS) are further indices of nerve dysfunction (Greening and Lynn 2000), which may reflect changes of central sensory processing.

In the present study, findings of VPT and responses to STS, in a sample of ULD patients recruited via general practitioners (GPs) and subsequently grouped by diagnoses defined according to acknowledged diagnostic criteria (Sluiter et al. 2001), were compared with findings in a control group without symptoms of ULD. The aim was to explore possible differences in VPT and STS responses between diagnostic groups and controls, in order to reveal if vibrometry is a useful tool in the diagnostic procedure of ULD. Further, in order to evaluate sensibility testing by light touch and pinprick, this simple clinical test was compared with VPT testing.

Subjects and methods

Subjects

Patients and controls were recruited via 21 GPs in the counties of Esbjerg and Varde, Denmark. The inclusion criteria for ULD patients were: age 16–65 years and reporting upper limb symptoms to a GP; and the exclusion criteria were: history of acute trauma, pregnancy or alcoholism, and disorders predisposing to upper-limb conditions, that is, rheumatoid arthritis, cardiac diseases, hypothyroidism, diabetes mellitus, amyloidosis, polyneuropathy, and B_{12} vitamin deficiency. A total of 277 patients were identified out of which 108 patients refused participation in the present study. Among the 169 patients who agreed to participate, eight were excluded at symptom interview due to predisposing disorders (five) and acute trauma (three). Thus, the present study included 161 patients: 113 women, median age 44 (range 19–64) years, median BMI 25 (range 18–47); and 48 men, median age 45 (range 28–65) years, median BMI 25 (range 18–36). These patients were allocated to the diagnostic groups specified in the following. Additionally, three GPs identified a control group of 49 controls by the same in- and exclusion criteria as mentioned previously for the patients, the only difference being an absence of upper-limb complaints within the last year. Among these, nine did not meet the requirements and were thus excluded at the symptom interview preceding the vibratory measurements because of predisposing diseases, and upper-limb complaints. The final study control group included: 40 participants, median age 47 (range 17–65) years, median BMI 25 (range 18–43). Twenty-five of these were women, median age 47 (range 17–60) years, median BMI 25 (range 18–43). Fifteen were men, median age 48 (range 18–65) years, median BMI 25 (range 18–29). Patients and controls did not differ significantly according to age and BMI.

The period of data collection was September 2001–January 2003. The study was approved by the Local Ethic Committee, and all participants signed informed consent.

Diagnostic groups

Diagnoses were mainly based on a consensus criteria document for work-related ULDs (Sluiter et al. 2001). Additionally, the criteria for *myofascial pain syndrom*e (Kaergaard and Andersen 2000) and *frozen shoulder* (Harrington et al. 1998) were included. The diagnoses were differentiated into two main categories: (1) neuropathy and (2) non-neuropathic conditions concerning the muscular- and connective-tissue disorders (MCDs). The total list of specific ULD diagnoses in the present study for MCD was: myofascial pain syndrome, rotator cuff syndrome, frozen shoulder, medial epicondylitis, lateral epicondylitis, de Quervain's syndrome, and osteoarthrosis of distal upper extremity. Correspondingly, for neuropathic conditions: neuropathy of the radial nerve at the radial tunnel, neuropathy of the ulnar nerve at elbow level and Guyon's canal, and neuropathy of the median nerve at the carpal tunnel.

Clinical testing was conducted by one examiner following a scheme testing all separate clinical signs

occurring in all the diagnoses in the test panel comprising 119 test results on each side. All patients were tested by all clinical tests in both limbs, and on another day the diagnostic interpretation was made according to a route diagram showing the findings fulfilling the criteria.

Patients were divided into five main groups according to their ULD diagnoses. Three groups with unilateral diagnoses (contralateral side without specific diagnosis): *MCD alone* ($N = 33$), median age 44 (range 23–56) years, median BMI 23 (range 20–32); *neuropathy alone* ($N = 32$), median age 46 (range 20–62) years, median BMI 26 (range 20–48); and *neuropathy and MCD* ($N = 50$), median age 50 (range 19–65) years, median BMI 25 (range 18–36). Additionally, one group of patients had at least one of the aforementioned diagnoses in both limbs (bilateral diagnoses) ($N = 33$), median age 44 (range 24–64) years, median BMI 28 (range 18–38). This group was too small to divide into subgroups of MCD and neuropathy. Finally, one group of patients had none of these specified diagnoses in any limbs ($N = 13$), median age 44 (range 21–64) years, median BMI 27 (range 20–32). No significant differences according to age and BMI were found between subgroups with unilateral and between subgroups with/without bilateral diagnoses.

Measurements

The VPT was measured in all 161 patients, and the STS recordings were performed in the last 128 examined patients. The VPT and STS were measured in all 40 controls. Six controls [five women, median age 50 (range 17–60) years, and one man, age 23 years] were retested within median 9.5 (range 2–17) days. Sensibility testing by light touch and pinprick was only performed in patients. The diagnoses of the patients/controls were not known by the examiner at the time of vibrometry testing.

Methods

Vibrometry testing

Within 1 week after seeing their GPs, all subjects were examined by one examiner (author, LHL) with a vibrameter (Somedic) testing at a fixed frequency of 100 Hz and expressing results in micrometers (0.0–400.0 μm). The test was performed after the subjects had been resting for a period of more than 20 min ahead of all other clinical tests applied in the diagnostic procedure. Both sides were randomly tested defined by date. The test was performed in a noiseless room, at a room temperature of 22–23°C, with the subject sitting in a standardized relaxed position, with eyes closed. This was in order to increase the subject's concentration and to prevent the subject from looking at the display. All vibrometry determinations were performed with the subject's hand/arm resting on a rice pillow, and with the vibrameter probe (diameter 13 mm) exerting a pressure of 650g at the test site.

Vibratory perception threshold

The VPT was measured by the "method of limits" as the mean value of three consecutive measurements of appearance and disappearance thresholds at each location (Goldberg 1979). Appearance threshold is determined by slowly increasing the stimulus (0.01 μm per step) from zero to the point where the subject reports that the vibratory sensation is first perceived. At this point the examiner reads the vibration stimulus level that is recorded as "appearance threshold." Likewise "disappearance threshold" is determined by decreasing the stimulus from slightly above appearance level to the point where the subject reports that the sensation disappears. The VPT was determined at three areas homonymously innervated by the three sensory nerves of the hand: The median nerve between the first and second metacarpals at the palm, the ulnar nerve at the dorsum of the fifth metacarpal bone, and the radial nerve dorsally at the second metacarpal bone. These three test locations were used and referred to in all measurements in this study, except for the comparison of vibrometry with sensibility by light touch and pinprick in which equivalent areas of the median and ulnar nerves at the pulpa of the second and fifth fingers were tested. During a maximum of five pretests, all subjects were familiarized with the test procedure.

Suprathreshold stimulation

The STS test was performed with the subject's forearm resting in a supinated position. The subject was informed that the vibrameter would induce a tingling at and around the location, where the probe was placed. Normally, this test would imply no other sensation. The subject was instructed to report any other sensation in the area of stimulation and/or distally/proximally to this. The probe was placed just distally to the pronator teres muscle, and the amplitude increased from zero to a maximum of 400 μm in about a minute. In case of any other sensation than tingling during this procedure (i.e., an allodynic response), the type and intensity of the sensation were registered. The subject was instructed to complain in case of any uncomfortable sensation, and the test would be terminated.

The test results were scored: 0 = normal response, light tingling at or around the test location; 1 = abnormal response, severe tingling, burning sensation, pain, electric feeling and the like, and maximal stimulation endured; 2 = abnormal response, and maximal stimulation not endured.

Sensibility testing by light touch and pinprick

Sensibility by light touch and pinprick was assessed bilaterally for the median and ulnar nerves at the second and the fifth pulpae, respectively. The sensibility was scored on a visual analog scale (Strauch et al. 1997).

Values of 10 were defined as normal, values ≤ 7 as severely abnormal, and values in between were defined as slightly abnormal. To be classified as normal, both the light touch and the pinprick responses should be scored as 10, for slightly abnormal no scores should be ≤ 7, and for severely abnormal at least one of the scores should be ≤ 7. The mean VPT was assessed for each of the three groups defined by sensibility score.

Statistics

The statistical package of EPI-info (version 2.0) was used for double registration and checking of the database, and SPSS (version 11.0) for further statistical analyses. The VPT mean values for the right and the left limbs were compared by the non-parametric Wilcoxon rank test, and comparison of VPT between different independent groups by the non-parametric Mann–Whitney rank test. The VPT means were grouped according to manual sensibility findings, and those in various control age groups were compared with each other by the non-parametric Kruskal–Wallis test. Bland Altman's plot (Bland and Altman 1986) and intraclass correlation coefficient were used to prove repeatability of VPT test results in controls. Comparison of the severity of STS responses to VPT level in patients was performed by Spearman's correlation coefficient. Critical *P*-value was 0.05.

Results

VPT and STS responses in controls

For the six controls retested, the VPT results are presented as first/second test mean values (range): median nerve right side 0.62/0.63 (0.47–0.83/0.49–0.84) μm, and left side 0.62/0.60 (0.40–0.97/0.42–0.82) μm; ulnar nerve right side 0.45/0.45 (0.32–0.56/0.34–0.52) μm, and left side 0.44/0.42 (0.30–0.67/0.36–0.49) μm; and radial nerve right side 0.41/0.43 (0.31–0.55/0.36–0.53) μm, and left side 0.38/0.38 (0.21–0.59/0.27–0.49) μm, respectively. Figure 1 shows the VPT mean differences between test and retest values plotted against VPT mean values to depict repeatability (Bland and Altman 1986). The mean values of VPT differences between test and retest results for the median (−0.006), ulnar (−0.009), and radial (0.010) nerves were all close to zero and within 3% of the overall mean values, respectively. The standard deviations of the VPT mean difference for the median, ulnar, and radial nerve were 0.103, 0.076, and 0.053, thus the coefficients of repeatability were 0.206, 0.152, and 0.106, respectively. The mean-centered coefficient of variation for the median, ulnar, and radial nerves were 24.1, 19.2, and 24.8%, respectively. Also the correlation between test and retest results was good: the intraclass correlation coefficients for the median nerve at the right/left hand were 0.651/0.954, for the ulnar nerve 0.784/0.796, and for the radial nerve 0.934/0.928, respectively.

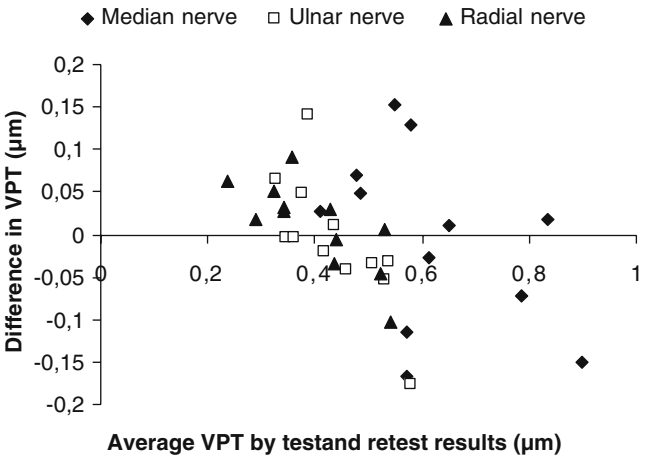

Fig. 1 VPT test and retest data in controls. Differences between test and retest versus mean values

In two of the 40 (5%) controls, allodynic responses to STS were found at one side, both tolerated maximal stimulation. In the six controls retested, normal STS responses were found at both sides in all tests.

No significant difference between the VPT values of the right and the left hand was found for any of the three sensory nerves. The mean values (range) for right/left VPT were for the median nerve 0.70/0.68 (0.47–1.16/0.38–1.52) μm, the ulnar nerve 0.48/0.49 (0.19–0.77/0.25–0.98) μm, and the radial nerve 0.45/0.46 (0.24–0.90/0.19–0.84) μm, respectively. However, significant differences in VPT between age groups were found at all locations (Kruskal–Wallis *P*-values = 0.000–0.006) (Fig. 2).

VPT in different diagnostic groups of patients compared with controls

The VPT in all diagnostic groups was compared with the VPT in controls (Fig. 3). The data in the patient group with unilateral diagnoses were divided into *limbs with* and contralateral *limbs without diagnoses*, and into the *right* and *left limbs* for those with bilateral diagnoses or

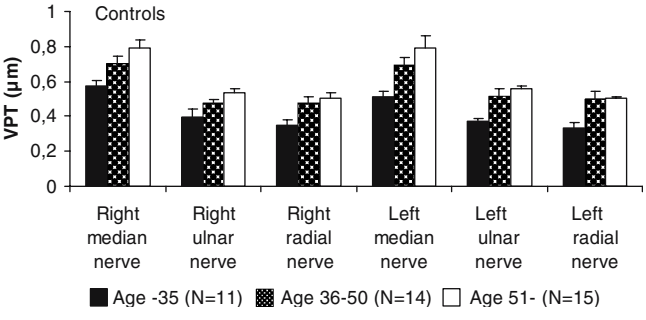

Fig. 2 VPT in controls divided into different age groups (mean values with SEM given as *bars*)

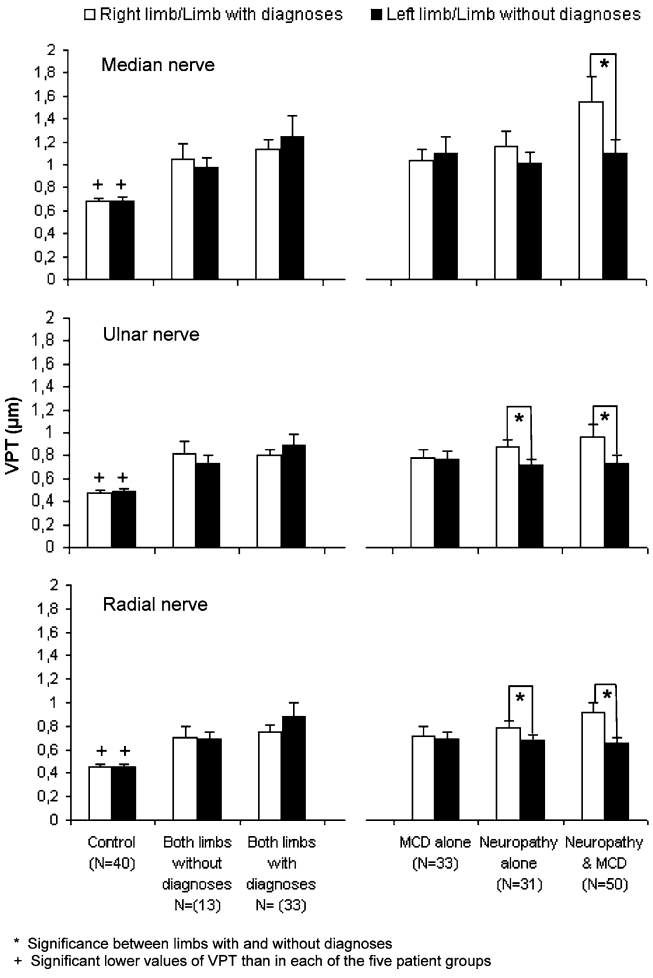

Fig. 3 VPT in controls and patients divided into various diagnostic groups (mean values with SEM given as *bars*)

without specific diagnoses. In all diagnostic groups, the VPT was significantly higher in both limbs compared with controls (*P*-values in unilateral diagnoses = 0.000–0.004; bilateral diagnoses = 0.000–0.005). One outlier was found in the group of unilateral neuropathy (VPT in *limb with diagnoses* for the median, ulnar, and radial nerves, respectively; 4.69, 1.32, and 1.56 µm, and in *contralateral limb* 15.65, 6.02, and 3.72 µm, respectively) and excluded from these statistical analyses.

VPT comparison between limbs in patients

In patients with unilateral diagnoses, VPTs were compared between limbs with and contralateral limbs without diagnoses, and a significant difference was found for all three nerves in the diagnostic group of *neuropathy and MCD*, and for the ulnar nerve ($P = 0.007$) and the radial nerve ($P = 0.036$) in the group of *neuropathy alone* (Table 1and Fig. 3). In bilateral diagnostic groups, the VPTs of the right versus left limb were compared. As expected, no significant differences were found (Table 1and Fig. 3).

VPT comparison between diagnostic groups

The VPT was compared between groups of *unilateral* diagnoses, and the only significant difference was found between the groups of *neuropathy and MCD* and *MCD alone* in limbs with diagnoses for the radial nerve ($P = 0.025$) (Fig. 3, significance not shown). The same picture of significance was found when grouping both the groups with *neuropathy alone* and *neuropathy and MCD* and comparing with the *MCD alone* group. No significant difference of VPT was found between *both limbs with* and *without diagnoses*.

Suprathreshold stimulation

The STS results in patient groups with unilateral/bilateral diagnoses of *limbs with diagnoses*/*right limbs* and contralateral *limbs without diagnoses*/*left limbs* are shown in Table 2. The highest percentage of allodynic STS responses was found in the group of *neuropathy and MCD* within a total of 71.4% of the diagnosed limbs (19 limbs with "score 1" plus 11 limbs with "score 2" out of 42 limbs). Correspondingly, in the group of *neuropathy alone*, a total of 57.2% of the diagnosed limbs were found with allodynic STS responses (6 + 6 limbs out of 21 limbs), while in the group of *unilateral diagnoses of MCD alone*, such responses were found in 41.7% of the diagnosed limbs (9 + 1 limb out of 24 limbs). In the contralateral limbs without these specific diagnoses, the total percentages were 45.2, 19.1, and 16.7% for the three diagnostic groups, respectively. In bilateral diagnoses, the STS allodynic responses were found in a total of 76.6% of the right limbs and 66.6% of the left limbs. In the group *both limbs without diagnoses* the corresponding values were 18.2% of the right limbs and 45.5% of the left limbs.

The severity of STS responses and the VPT level were compared, but statistically significant correlation was not found between diagnostic groups, either on the right side or on the left side.

Comparison of VPT and sensibility testing by light touch and pinprick in patients

There was a significant difference in the VPT for the left median and ulnar nerves between groups defined by *normal*, *lightly*, and *severely disturbed* sensibility by light touch and pinprick. For the right-side limbs, the picture was similar, however, the difference was not significant (Fig. 4).

Discussion

Main findings

The VPT was significantly higher among ULD patients for all three nerves (median, ulnar, and radial) compared

Table 1 Comparison of VPT between limbs in five diagnostic groups of patients

	N	*P*-values		
		Limb with versus contralateral limb without diagnoses		
		Median nerve	Ulnar nerve	Radial nerve
Unilateral diagnoses				
MCD alone	33	0.386	0.491	0.741
Neuropathy alone	31	0.117	**0.007**	**0.036**
Neuropathy and MCD	50	**0.000**	**0.000**	**0.000**
		Right versus left limb		
Bilateral diagnoses				
Both limbs without diagnoses[a]	13	0.807	0.576	0.917
Both limbs with diagnoses[b]	33	0.339	0.611	0.755

Two-tailed significance $P < 0.05$. Significant findings are represented in bold

[a]Symptoms registered in at least one of the limbs

[b]Neuropathy found in all but one of the patients

Table 2 STS responses in five diagnostic groups of patients

	Number of patients *N*[a]	Score 0[b]		Score 1[b]		Score 2[b]	
		Limb with diagnoses *N* (%)	Limb without diagnoses *N* (%)	Limb with diagnoses *N* (%)	Limb without diagnoses *N* (%)	Limb with diagnoses *N* (%)	Limb without diagnoses *N* (%)
Unilateral diagnoses							
MCD alone	24	14(58.3)	20(83.3)	9(37.5)	3(12.5)	1(4.2)	1(4.2)
Neuropathy alone	21	9(42.9)	17(81.0)	6(28.6)	3(14.3)	6(28.6)	1(4.8)
Neuropathy and MCD	42	12(28.6)	23(54.8)	19(45.2)	15(35.7)	11(26.2)	4(9.5)
		Right limb	Left limb	Right limb	Left limb	Right limb	Left limb
Bilateral diagnoses							
Both limbs without diagnoses	11	9(81.8)	6(54.5)	2(18.2)	5(45.5)	0(0.0)	0(0.0)
Both limbs with diagnoses	30	7(23.3)	10(33.3)	10(33.3)	7(23.3)	13(43.3)	13(43.3)

[a]Only 128 of the patients were tested by STS

[b]Score 0: no allodynic response; Score 1: allodynic response, enduring stimulation to maximum 400 μm; Score 2: allodynic response, not enduring stimulation to maximum 400 μm

with controls. This finding concerned all diagnostic groups of neuropathy and MCD, and also the group of patients without such specific diagnoses. Further, patients with unilateral neuropathy demonstrated significantly higher VPT values in the limbs with diagnoses compared with limbs without diagnoses, while no such contralateral differences were found among the patients with MCD alone. The highest values of VPT were found in the patient group with unilateral *neuropathy and MCD*, in which VPT of the radial nerve was significantly higher than for patients with unilateral *MCD alone*. These findings are confirmed by almost similar findings in the STS responses.

Vibrometry in controls

The findings in the control group are comparable with findings in other studies (Greening and Lynn 1998b; Jensen et al. 2002), although the VPT values of the ulnar and the radial nerves in the present study are slightly higher. Significant differences in VPT were found between all three age groups and confirmed other studies finding a correlation between age and VPT (Goldberg 1979; Hilz et al. 1998). The slightly higher VPT values in the present study may be due to a higher mean age that may also explain the different levels in VPT between two earlier studies (Greening and Lynn 1998b; Hilz et al. 1998). Psychological factors are well known causes of high intra variability of VPT (Fagius and Wahren 1981). In contrast to a healthy control group, the control group in this study consisted of patients with disorders bringing them to the GP, thus adding a distracting factor of concentration and motivation.

Repeatability was good at group level, but the interindividual variability in VPT values was high. This underlies the significant differences between age groups. Other studies have found a high reliability of test results (Gerr and Letz 1988; Goldberg 1979; Grunert et al. 1990; Hilz et al. 1998) under conditions where factors influencing the VPT are controlled.

Vibrometry in patients

In addition all diagnostic groups with unilateral diagnoses had a significantly higher VPT in contralateral limbs compared with controls. Recordings from the contralateral nonsymptomatic limbs are rarely found in the literature but the findings in the present study are in concordance with a study including different ULD diagnoses (Lundborg et al. 1992). In CTS patients, 47%

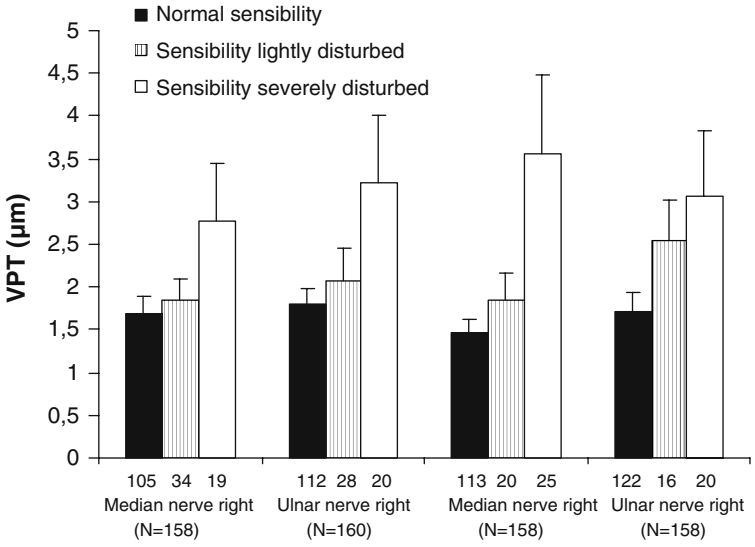

Fig. 4 VPT in patient groups defined by sensibility testing by light touch and pinprick (mean values with SEM given as *bars*)

had significantly increased VPT in all four recordings of the median and ulnar nerves at both the symptomatic and the nonsymptomatic side, and only 23% had isolated increased VPT in one recording. In patients defined with brachialgia, an even higher proportion (83%) had a significantly increased VPT in all four recordings. In another recent study of 20 computer users with unilateral tingling/numbness as the only symptom (Overgaard et al. 2004), VPT recordings from the median and ulnar nerves on both sides at seven different frequencies demonstrated increased VPT in all recordings compared with controls. In this small number of cases, however, statistical significance was found in two out of 14 measurements only.

These findings may indicate changes in the central nervous system due to central inhibition with changes in sensitivity and sensory processing (Greening and Lynn 1998a; Woolf 1983). This also gives rise to the question whether these cases are associated with a general pathophysiologic disorder affecting the peripheral nervous system. Furthermore, exposure may play a key role as shown in a recent follow-up study among computer users and controls without computer work (Pilegaard and Jensen 2005). In that study, elevated VPT values were found also on the left hand among computer users with right-hand symptoms, and exposed groups with no symptoms had higher VPT levels than controls. This is in accordance with findings in the present study including ULD patients with various kinds of occupational and household exposures that are seldom unilaterally performed. Thus, in exposed subjects, elevated VPT may occur before a positive status of a limb diagnosis is attained according to the diagnostic criteria. Findings supporting an affection of both the median and ulnar nerves in the same limb in defined CTS conditions (Imai et al. 1990; Lundborg et al. 1992) might also be due to an alternative or additional localization of nerve compression at a proximal level, for example, the brachial plexus, thus involving more nerves at a time.

The STS recordings in this study are in agreement with another study (Greening and Lynn 1998b) with allodynic STS response in 14 of 17 patients (82%) with RSI. The clear trend of VPT—increasing from lowest values in the groups of *MCD alone*, and highest in *neuropathy and MCD*—is confirmed by an almost similar picture in STS responses. This may be explained by a gradual transition between the stages of MCDs and neuropathy, and minor nerve damage may occur at an early stage in all pain conditions. According to the minor nerve injury theory (Greening and Lynn 1998a), the inflammation in neuropathic conditions is sufficient to institute mechano, heat and cold allodynia. Further stages comprise Aβ-fiber loss, and reduced activity and spontaneous firing in C- and Aδ-fibers, all contributing to changed central sensitization and sensory processing.

In our study, only the patient group with unilateral neuropathy diagnoses demonstrated significant differences in VPT values in limbs when compared with contralateral limbs without neuropathy. This indicates a peripheral de-sensibilization or nerve affection more severe in the group diagnosed with neuropathy than in the group with MCD alone, thus supporting the ability of the diagnostic criteria to differentiate between neuropathic and non-neuropathic conditions.

It is remarkable that significantly higher VPT values and a high fraction of allodynic STS responses were also found in the small group of patients without specific diagnoses in terms of MCD and/or neuropathy. However, this group presents with symptoms of pain, and the findings indicate that the neurogenous tissue is likely to be involved in every pain condition. However, it should not be disregarded that the diagnostic criteria may simply have failed to classify the patients, or the pain condition may be related to an undiagnosed medical disorder predisposing to ULD and VPT disturbances.

According to a high intraindividual variation of VPT values in the present and other studies (Fagius and Wahren 1981; Halonen 1986), vibratory recordings seem

inapplicable as a differential diagnostic tool at an individual level. In epidemiologic studies, however, in which VPT variations seem to be randomly distributed among subjects (Fagius and Wahren 1981), the VPT may be used to differentiate between groups as shown in this study between patients and controls.

Sensory findings correlated significantly with VPT on the left side and showed a clear trend of correlation with that on the right side. Thus, light touch and pinprick seem to be valid tools in sensibility testing as validated by VPTs. Differentiation of sensibility testing by light touch and pinprick may be impaired by callous skin often present in finger pulpae of the dominant hands. Right-side insignificant results may rely on this and the small numbers in the groups.

Conclusion and further studies

The upper limb disorder patients generally demonstrated increased VPT values compared with controls, indicating a generally neurogenous tissue affection in ULD pain conditions independent of specific diagnoses. Contralateral significant findings in limbs without specific diagnoses compared with controls indicate a central affection of the nervous system. These findings also indicate that in exposed subjects, elevated VPT may occur before a positive status of a limb diagnosis is attained according to the diagnostic criteria. Significantly higher VPT values found in the limbs diagnosed with neuropathy, compared with contralateral limbs without diagnoses, indicate a peripheral de-sensibilization or nerve affection, which is more severe in the group with a specific diagnosis of neuropathy than in the group with MCD alone. These findings underline the importance of specific diagnoses among ULD patients.

Findings of impaired VPT and STS responses in the group of *both sides without diagnoses* and the poor differentiation in VPT between diagnostic groups question the validity of the present diagnostic criteria/diagnostic procedure. Further studies should develop better specific diagnostic criteria in a big patient sample to differentiate between subgroups, and report VPT and STS recordings from both sides.

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