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Pressure pain thresholds and musculoskeletal morbidity in automobile manufacturing workers

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Abstract *Objectives*: Reduced pressure pain thresholds (PPTs) have been reported in occupational groups with symptoms of upper extremity musculoskeletal disorders (UEMSDs). The purpose of this study was to determine whether automobile manufacturing workers ($n = 460$) with signs and symptoms of UEMSDs had reduced PPTs (greater sensitivity to pain through pressure applied to the skin) when compared with unaffected members of the cohort, which served as the reference group. The association of PPTs with symptom severity and localization of PE findings was investigated, as was the hypothesis that reduced thresholds would be found on the affected side in those with unilateral physical examination (PE) findings. *Methods*: PPTs were measured during the workday at 12 upper extremity sites. A PE for signs of UEMSDs and symptom questionnaire was administered. After comparison of potential covariates using *t* tests, linear regression multivariable models were constructed with the average of 12 sites (avgPPT) as the outcome. *Results*: Subjects with PE findings and/or symptoms had a statistically significant lower avgPPT than non-cases. AvgPPT was reduced in those with more widespread PE findings and in those with greater symptom severity (test for trend, $P \leq 0.05$). No difference between side-specific avgPPT was found in those with unilateral PE findings. Reduced PPTs were associated with female gender, increasing age, and grip strength below the gender-adjusted mean. After adjusting for the above confounders, avgPPT was associated with muscle/tendon PE findings and symptom severity in multivariable models. *Conclusions*: PPTs were associated with signs and symptoms of UEMSDs, after adjusting for gender, age and grip strength. The utility of this noninvasive testing modality should be assessed on the basis of prospective large cohort studies to determine if low PPTs are predictive of UEMSDs in asymptomatic individuals or of progression and spread of UEMSDs from localized to more diffuse disorders.

Keywords Occupational diseases · Musculoskeletal disorders · Algometry · Quantitative sensory testing

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Introduction

Clinical evaluation of upper extremity musculoskeletal disorders (UEMSDs), particularly those thought to involve the muscles or tendon complexes, typically involves physical examination (PE) techniques that are highly dependent on the judgment of the examiner. These techniques are not easily quantifiable (Buchbinder 1992; Viikari-Juntura 1999; Sluiter et al. 2000; Punnett and Gold 2003). This subjectivity and imprecision are of concern because such UEMSDs represent a high proportion of morbidity in the workplace (Fahs et al. 2000; Gerr et al. 2002; Silverstein et al. 2003).

Pressure pain threshold (PPT) testing is a psychophysical modality for examining the sensitivity of tissue. It allows quantification of the pressure applied to a subject's skin, at which a benign sensation becomes one of pain. Reduced PPTs have been seen in the occupational setting in fish and poultry workers (Madeleine et al. 2003), bank cashiers (Takala et al. 1991), medical secretaries (Hägg and Åström 1997) with shoulder and neck complaints, and assembly line workers with forearm or hand symptoms (Takala et al. 1992; Byström et al. 1995). The physiological mechanism of PPT changes is unclear, but may reflect nerve (Hall and Quintner 1996; Hong and Simons 1998) or muscle (Fricton 1990; Han and Harrison 1997) dysfunction.

Both intra- and inter-rater reliability for PPTs have been shown to be high, ranging from 0.68 to 0.92 (Takala 1990; Antonaci et al. 1998; Nussbaum and Downes 1998). Although dependent on the judgment of the examined subjects, within-subject variability in the short term (up to 1 week) is low (Kosek et al. 1993; Nussbaum and Downes 1998). Thus, even though subjective (like all quantitative sensory testing), PPTs could have potential as a reliable and sensitive means of detecting UEMSDs.

The objective of this study was to determine if the average pain pressure threshold was lower in automobile manufacturing workers with signs and symptoms of UEMSDs when compared with workers free of such symptoms and signs. Three specific hypotheses were tested: (1) those with PE findings on one side only have lower PPTs on the affected side than on the unaffected side; (2) those with proximal or distal findings exclusively have lower PPTs in the affected region; and (3) those with more widespread PE findings have a lower overall PPT than those with more localized PE findings.

Methods

Study subjects consisted of the 6-year follow-up population ($n = 519$) of automobile manufacturing workers in one engine plant and one stamping plant, originally described by Punnett (1998). This cohort was 87.1% male, with a mean age of 50.2 (±6.7) years, and mean seniority of 26.5 (±5.8) years. The study protocol was approved by the Institutional Review Board of the University of Massachusetts Lowell and by the joint company-union health and safety program. All subjects gave their informed consent prior to their inclusion in the study.

PPTs were measured at the trapezius, rhomboid, teres major, deltoid, wrist flexors and wrist extensors on both the left and right sides (location definitions in Appendix), using a force gauge with a 1-cm^2 rubber tip (FDN 100, Wagner Instruments, Greenwich, CT, USA). The rate of pressure application was approximately 98 kPa/s. The PPT test was given during the workday, approximately 15–20 min after the subject left his or her workstation. The subject was instructed to tell the examiner when a sensation of pressure became painful.

The series of PPT measurements included one taken on the upper thigh at the beginning and then again at the end, as reference values. The protocol specified that if the thigh PPTs differed by more than ±10% between the two trials then a second set of PPTs should be carried out. However, this condition did not occur in any subject, so only one set of PPTs was taken. No participants had any scars or deformities that were judged to interfere with test results.

During the same encounter, a PE determined the presence of muscle/tendon, joint or nerve findings in four upper extremity (UE) sites: neck, shoulder/upper arm, elbow/forearm, or hand/wrist (Punnett 1998). Power grip strength was also measured.

In addition, subjects were administered a questionnaire regarding symptoms during the past year in each of the four UE sites. Specifically, subjects were asked, “During the past 12 months, have you had pain, aching, stiffness, burning, numbness, or tingling (‘pins and needles’)—in the anatomical site... that occurred more than three times or lasted more than 1 week?” Those who answered affirmatively were asked additional questions regarding pain severity, hand/arm numbness frequency, and functional impairment for each symptom site. A pain severity index was constructed as the sum of responses on a visual analog scale to three questions regarding current, previous week, and worst pain during the previous year (index range: 0–30). Functional impairment was the sum of responses to a series of ten questions on task difficulty (from 1—no difficulty at all to 5—cannot do without help) based on the hand/wrist functional status items of Levine et al. (1993) (index range: 0–50). The UE site with maximum pain severity index, functional impairment score or hand/arm numbness frequency was used in each respective analysis. Those with no symptoms were assigned a score of zero for each metric.

Data analysis

The pressure required to elicit pain at the 12 aforementioned UE sites was averaged (avgPPT). The mean of the left and right wrist flexor and extensor PPTs (distal avgPPT) were used in analyses of signs and symptoms of distal UEMSDs, while averages of the remaining sites (proximal avgPPT) were used in the analyses of proximal disorders. In side-specific analyses, the average of the six PPTs of each respective side (left avgPPT and right avgPPT) were employed.

AvgPPT was compared between subgroups defined by a number of potential covariates and indicators of UEMSD morbidity, using t tests for unequal variance. The UEMSD indicators were any UE symptoms during the past year; any PE muscle/tendon findings; and symptoms with muscle/tendon PE findings at the same site. Both symptoms and PE findings were partitioned into proximal (neck, shoulder/upper arm) and distal (elbow/forearm, wrist/hand) regions. Other analyses used side-specific symptoms and/or PE findings in conjunction with side-specific PPTs. Noncases (those with no reported symptoms and no PE findings) served as the reference group for all analyses. An extension of the Wilcoxon rank-sum test (Cuzik 1985) was used to test for trend in examining avgPPT with ordinal variables, such as the number of PE sites with findings (possible range 0–4). Statistical significance was defined as $P \leq 0.05$.

Linear regression models of avgPPT focused on estimating associations with UEMSD indicators and on identifying potential confounders. Age and gender were retained in all models. The criterion for other covariate inclusion was $P \leq 0.05$ or a change of 10% or greater in the remaining variables. Two-factor interaction terms were included in the model to assess effect modification between the UEMSD indicators and other covariates. No significant effect modifiers were found. SAS 8.2 (SAS Institute Inc., Cary, NC, USA) and Stata 6.0 (Stata Corporation, College Station, TX, USA) software packages were used in statistical analysis.

Results

Subjects were removed from the study cohort for the following reasons: complaints of pain during the PPT exam before the instrument indicated that any pressure had been applied ($n = 38$), refusal to participate in the test ($n = 4$), severe obesity ($n = 1$), unreliable PE in the examiner's judgment ($n = 10$), or examiner data errors ($n = 6$). Hence, PPT measurements were available for 460 subjects. Mean age and seniority for these subjects were similar to that of the cohort as a whole at 6-year follow-up, while the percentage of males was slightly higher at 87%.

The 12 PPT values were highly correlated, with pairwise Spearman rank correlation (SRC) coefficients ranging from 70% to 97%. On average, PPTs did not differ by side. Women had a significantly lower threshold than men, and thresholds decreased with age (Table 1). Those with systemic disease and those with grip strength less than the gender-specific mean also had lower avgPPTs. There was no difference in avgPPT with regard to previous UE injury, regular outside activity, cigarette smoking, alcohol use, or ethnicity. All associations observed in the cohort as a whole, except systemic disease, also held with nonsymptomatic subjects ($n = 201$).

PPTs and musculoskeletal morbidity

Those with any UEMSD symptoms had a lower avgPPT than noncases, as did those with any PE findings (Table 2). The majority of PE findings (96%) indicated muscle/tendon problems. These subjects had a lower average PPT than noncases. Side-specific PPTs were similar in magnitude to the avgPPT value for these three UEMSD indicators (data not shown). Those few ($n = 10$) with PE findings other than muscle/tendon (i.e., joint, nerve, or nonspecific findings only) had avgPPTs similar in magnitude to those with muscle/tendon findings.

Table 1 Mean (SD) avgPPT (kPa) in entire cohort and in non-cases in automotive engine plant and stamping plant workers, Detroit, MI, USA, 1998

	Entire cohart			Non-cases		
	n	mean	SD	n	mean	SD
All	460	530	137	201	579	108
Gender*						
Male	399	549	118	184	588	98
Female	59	363	127	17	432	118
Side						
Left	460	530	137	201	579	108
Right	460	530	137	201	579	108
Age**						
20–39	106	549	137	52	588	127
40–49	252	530	137	113	588	108
≥ 50	100	490	137	36	559	108
Previous upper extremity injury						
Yes	145	530	137	54	588	118
No	313	530	137	147	579	108
Systemic disease*						
Yes	107	500	147	37	569	118
No	350	539	137	163	579	108
Regular outside activity						
Yes	281	520	137	112	569	118
No	175	530	137	88	598	98
Cigarette smoking						
Current	179	510	137	78	569	108
Former	131	530	127	51	588	108
Never	147	549	137	72	579	108
Alcohol use						
Current	248	530	137	113	579	108
Former	78	510	127	32	569	118
Never	129	530	147	55	588	118
Ethnicity						
Black	190	520	147	94	569	127
White/non-Hispanic	145	520	127	49	559	98
Right grip strength (lb), (gender-adjusted)*						
< mean (54:m, 30:f)	220	490	147	85	539	127
≥ mean (54:m, 30:f)	238	569	118	116	608	88

avgPPT average of all 12 sites examined (see Appendix for site descriptions)

*$P \leq 0.05$, t test; **$P \leq 0.05$, Wilcoxon rank sum test extension

Those with both symptoms and PE findings in the same site had a somewhat smaller avgPPT.

Among those with any UE symptoms, avgPPT decreased with index of pain severity, with functional impairment index and with presence of hand/arm numbness (Table 3). All three of these indicators were highly correlated with each other: functional impairment and pain severity indices (SRC = 0.95); pain severity index and hand/arm numbness (SRC = 0.69); and hand/arm numbness and functional impairment index (SRC = 0.75). All of those with symptoms of hand/arm numbness also had muscle/tendon PE findings.

Contrary to our predictions, subjects with PE findings on only one side did not display a lower average PPT on the affected side. In those with findings

Table 2 Mean (SD) avgPPT (kPa) by case status

All	n	Mean	SD
Non-case	201	579	108
ANY symptoms*	124	471	147
ANY PE findings*	238	481	147
PE muscle/tendon findings*	228	481	147
Other PE findings* (no muscle/tendon)	10	490	98
Same site symptom and PE muscle/tendon findings*	88	432	157

*$P \leq 0.05$, t test when compared with noncases

Table 3 Mean (SD) avgPPT (kPa) by symptom or functional impairment status

	n	Mean	SD
Pain severity*			
0 (n = 367)	367	549	127
1–14 (n = 49)	49	481	137
15–30 (n = 44)	44	422	167
Functional impairment*			
0	358	549	127
1–19	75	490	137
20–50	27	382	167
Hand/arm numbness**			
No	397	539	127
Yes	63	441	157

*$P < 0.05$, Wilcoxon rank sum test extension; **$P < 0.05$, t test

exclusively on the left side (n = 77), or on the right side (n = 39), both left avgPPT and right avgPPT were 520 ± 127 kPa. Results were similar in the subset of subjects with both PE findings and symptoms confined to one side only (n = 63: left; n = 34: right).

In noncases, the distal avgPPT was lower than the proximal avgPPT (510 ± 127 vs 618 ± 108 kPa). Those with only proximal PE findings (i.e., exclusive of any distal PE findings) (n = 80) had a 10% reduction in both proximal avgPPT and distal avgPPT, when compared with the corresponding values in noncases (Table 4). However, in those with distal PE findings exclusively (n = 68), the reduction was proportionally twice as large in distal avgPPT than in proximal avgPPT. Results were similar in the subjects with PE findings and symptoms confined either proximally or distally (n = 69: proximal; n = 64: distal).

A decrease in avgPPT was apparent with increasing number of sites with PE findings (Wilcoxon rank sum test extension, $P \leq 0.01$). AvgPPT was approximately 40% less in those with four affected sites than in those with no PE findings (Fig.1).

Linear regression models

Three multivariable regression models were constructed using the three UEMSD indicators mentioned above: any UE symptoms, any PE muscle/tendon findings, and symptoms with PE findings in the same site (Models 1–3, Table 5). AvgPPT was associated with each of these indicators after adjusting for grip strength, pain severity, age, and gender. The coefficient for age {typical value: −1.5 (95%CI: −3 to 0)} was almost identical in all of the models examined. Grip strength was positively associated with avgPPT, while a negative association was found with pain severity across each of the models.

Because they were so highly correlated (SRC = 0.95), it was not possible to include both pain severity and functional impairment in the same model. Regardless of which of these covariates was included, the other coefficients were fairly close in value (Model 4, Table 5).

Discussion

In this cross-sectional study of a population of automobile workers, PPT values in 12 anatomical sites were highly correlated. The correlation between PPTs suggests that there is an overall increased sensitivity in the UE in those with UEMSD signs and symptoms. Additionally, there appears to be a trend toward lower avgPPTs in those with increasing severity of UEMSD signs (as measured by greater number of sites with PE findings) or symptoms (increasing pain severity or functional impairment). However, due to the cross-sectional nature of the study, it is unknown whether this sensitivity preceded or followed the UEMSD morbidity.

In accordance with other studies, we found females to report significantly lower PPTs than males (Gerecz-Simon et al. 1989; Hogeweg et al. 1992; Fransson-Hall and Kilbom 1993; Sterling et al. 2000; Chesterton et al. 2003). After adjusting for other covariates including gender and grip strength, age became only a mild predictor of avgPPT. One study has found a decrease of

Table 4 Mean (SD) anatomic-specific PPT (kPa) in those with exclusive physical examination (PE) findings by anatomical area

	Proximal avgPPT[a]	% Change from non-cases	Distal avgPPT[b]	% Change from non-cases
Non-cases (n = 201)	618 (108)		510 (127)	
Proximal PE findings only (n = 80)	559 (127)	−10	461 (127)	−10
Distal PE findings only (n = 68)	539 (147)	−13	402 (147)	−21

[a] Average of eight points (see text)

[b] Average of four points (see text)

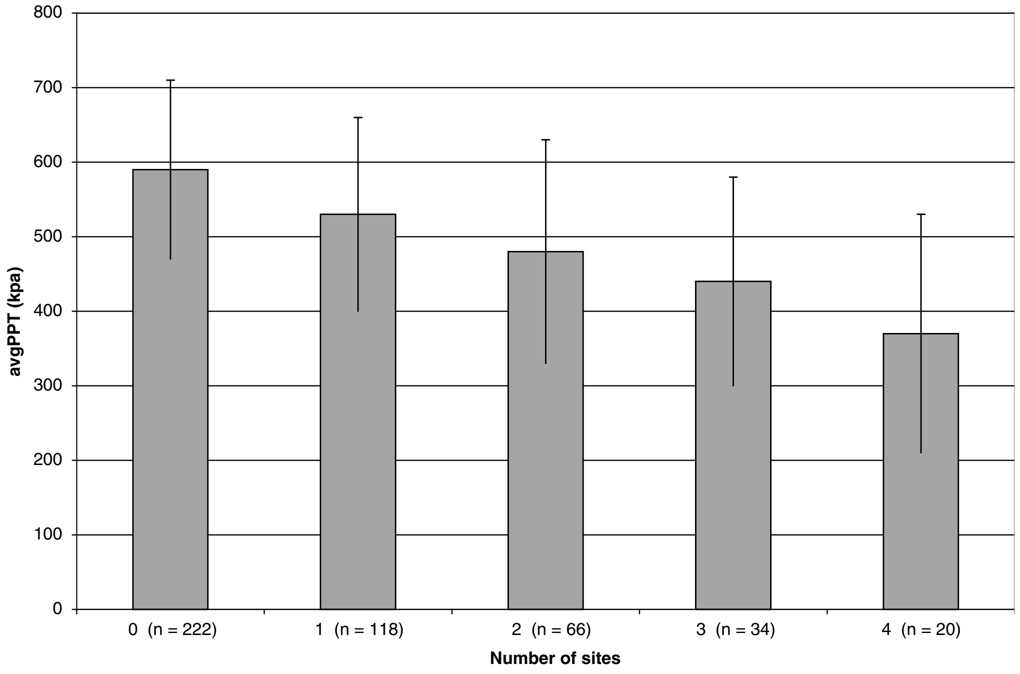

Fig. 1 Mean (SD) avgPPT (kPa) by number of sites with PE findings

PPT with age (Mitchell et al. 2000), while others have found no effect (Fransson-Hall and Kilbom 1993; Byström et al. 1995; Sterling et al. 2000).

We observed an association of avgPPT with grip strength, independent of the associations with gender and age. Fransson-Hall and Kilbom (1993) similarly observed higher PPTs in the hands of healthy subjects with greater grip strength. In a study of several occupational groups (Onishi et al. 1976), there were no associations between trapezius tenderness thresholds and grip strength. However, increased thresholds were correlated with both reduced back muscle and upper arm abduction strength in photographic film rolling workers, and with decreased back muscle and knee extension strength in teachers and nurses for handicapped children. These findings suggest specificity of association, in that strength in a particular anatomic region appears to be associated only with PPTs in the same area (i.e., grip strength with hand PPTs and back strength with trapezius PPTs).

Takala and Viikari-Juntura (1991) reported reduced PPTs in symptomatic compared with asymptomatic bank cashiers. However, the lower PPTs were not accompanied by differences in muscle strength, endurance, or EMG fatigue parameters. This suggests that PPTs are not indicative of muscle function. It is not known why greater grip strength is associated with higher PPTs, even among noncases. Some have speculated that it reflects muscle mass, but this is a topic for further research.

Decreased PPTs have been associated with frequency of symptoms in the forearm and shoulder (Takala et al. 1992) and with perceived musculoskeletal discomfort (Nakata et al. 1993). Similarly, we found a reduced avgPPT in those reporting increasing pain severity. The three available metrics for characterizing UEMSD

Table 5 Multivariable regression models of mean pressure pain threshold (kPa) ($n = 447$), adjusted for age

Covariate	Model 1		Model 2		Model 3		Model 4	
	Coefficient	95% CI	Coefficient	95% CI	Coefficient	95% CI	Coefficient	95% CI
Gender (0 male, 1 female)	−167	−205, −129	−162	−203, −122	−179	−210, −148	−182	−213, −151
Right grip strength	57	33, 82	65	38, 91	65	45, 86	63	42, 84
Pain severity score (0–30)	−4	−6, −1	−3	−5, −0	−4	−5, −2		
Functional impairment score (0–50)							−4	−6, −3
Any symptom (0/1)	−51	−85, −18						
PE m/t finding (0/1)						−58	−81, −36	−51	−74, −28
Same-side symptom and PE m/t finding (0/1)			−79	−120, −38				

95% *CI* 95 percent confidence interval; *PE* physical examination; *m*/*t* muscle/tendon
Grip strength standardized to gender-specific means (54 lb, male; 30 lb, female): 0 if < mean, 1 if ≥ mean

symptoms (pain severity, functional impairment, and hand/arm numbness) were too strongly correlated to permit comparison of their associations in a single model. The multivariable models suggest that there is a baseline effect of reduced PPTs in those with any UE symptoms or PE muscle/tendon findings. This baseline PPT is further reduced in those with greater symptom severity—whether characterized by pain intensity, functional impairment or presumably hand/arm numbness frequency.

Left and right average PPTs were similar in those with PE findings on one side only. Neither have differences been found in PPT between affected and contralateral sides in patients with chronic trapezius myalgia (Leffler et al. 2003) or lateral epicondylalgia (Leffler et al. 2000). In a small longitudinal study of initially asymptomatic industrial workers ($n=12$), Madeleine et al. (2003) found that lower PPTs at the start of employment predicted shoulder/neck pain after 6 months. This reduced PPT was present bilaterally and even somewhat distally. A mechanism for the spread of muscle pain in UEMSDs through sensitization of secondary muscle spindle afferents (MSAs) has been suggested by Johansson and Sojka (1991). In a rat model of a unilateral repetitive reaching and grasping task, an elevation of immunoreactive macrophages was observed in both the involved and uninvolved limbs (Barbe et al. 2003), again suggesting the bilateral spread of a physiological effect. Central sensitization presents another potential mechanism (Woolf and King 1990). Whether the uniformity of PPTs across side in those with symptoms (or symptoms and signs) confined to one side actually reflects any of these proposed mechanisms is unknown.

We found that the distal arm avgPPT was lower than the proximal arm avgPPT by approximately 17% in normal subjects. PPT testing points are not standardized with regard to anatomical locations. Furthermore, previous studies of PPT norms (Fischer 1987; Takala 1990; Hogeweg et al. 1992; Fransson-Hall and Kilbom 1993; Kosek et al. 1993) do not enumerate the identical points as those in the current analysis. PPTs are known to vary in normal subjects, depending on the anatomical testing site. In particular, the lower back is less sensitive than the upper back (Fischer 1987; Hogeweg et al. 1992). It is not possible to determine whether the proximal limb was less sensitive than the distal limb in the aforementioned studies.

Conclusions

PPTs were associated with signs and symptoms of UEMSDs, after adjusting for gender, age, grip strength, and pain severity or functional impairment. The utility of this noninvasive testing modality should be assessed on the basis of prospective large cohort studies to determine if low PPTs are predictive of UEMSDs in asymptomatic individuals or of progression and spread of UEMSDs from localized to more diffuse disorders.

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Appendix

Definition of points for PPT measurements

1. Trapezius: find largest cervical vertebrae (C7 or T1 depending on individual) and move laterally three fingers.
2. Rhomboids: find medial border of scapula below spine of scapula. Pressure point is located midway between medial border and thoracic spine (about T3).
3. Teres major: find inferior angle of scapula and drop off laterally. Resist humoral external rotation to locate muscle.
4. Deltoid: find lateral edge of acromium and drop off three fingers onto deltoid muscle.
5. Wrist extensors: with forearm supported, have subject extend wrist and locate muscle mass in proximal and lateral forearm. Apply resistance if needed.
6. Wrist flexors: with forearm supported, have subject flex wrist and locate muscle mass in proximal and medial forearm. Apply resistance if needed.

References

Antonaci F, Sand T, Lucas G (1998) Pressure algometry in healthy subjects: inter-examiner variability. Scand J Rehabil Med 30:3–8

Barbe MF, Barr AE, Gorzelany I, Amin M, Gaughan JP, Safadi FF (2003) Chronic repetitive reaching and grasping results in decreased motor performance and widespread tissue responses in a rat model of MSD. J Orthop Res 21:167–176

Buchbinder R (1992) The classification of soft tissue disorders of the neck and upper limb for epidemiological research. Doctoral thesis, Department of Community Health. Toronto, ON, University of Toronto

Byström S, Hall C, Welander T, Kilbom Å (1995) Clinical disorders and pressure-pain threshold of the forearm and hand among automobile assembly line workers. J Hand Surg [Br] 20B:782–790

Chesterton LS, Barlas P, Foster NE, Baxter GD, Wright CC (2003) Gender differences in pressure pain threshold in healthy humans. Pain 101:259–266

Cuzik J (1985) A Wilcoxon-type test for trend. Stat Med 4:87–90

Fahs M, Kantos N, Berliner H, Alcalá M, Herbert R, Plattus R, Job L (2000) Detection, disease management, and compensation: health and economic outcomes of upper extremity work-related musculoskeletal disorders among garment workers in New York City. American Public Health Association, Boston

Fischer AA (1987) Pressure algometry over normal muscles. Standard values, validity and reproducibility of pressure threshold. Pain 30:115–126

Fransson-Hall C, Kilbom Å (1993) Sensitivity of the hand to surface pressure. Appl Ergon 24:181–189

Fricton J (1990) Myofascial pain syndrome: characteristics and epidemiology. In: Fricton J, Awad E (eds) Advances in pain research and therapy. Raven Press, New York, pp 107–127

Gerecz-Simon E, Tunks E, Heale J-A, Kean W, Buchanan W (1989) Measurement of pain threshold in patients with rheumatoid arthritis, osteoarthritis, ankylosing spondylitis, and healthy controls. Clin Rheumatol 8:467–474

Gerr F, Marcus M, Ensor C, Kleinbaum D, Cohen S, Edwards A, Gentry E, Ortiz DJ, Monteilh C (2002) Prospective study of computer users: 1. Study design and incidence of musculoskeletal symptoms and disorders. Am J Ind Med 41:221–235

Hägg GM, Åström A (1997) Load pattern and pressure pain threshold in the upper trapezius muscle and psychosocial factors in medical secretaries with and without shoulder/neck disorders. Int Arch Occup Environ Health 69:423–432

Hall T, Quintner JL (1996) Responses to mechanical stimulation of the upper limb in painful cervical radiculopathy. Aust J Physiother 42:277–285

Han S, Harrison P (1997) Myofascial pain syndrome and trigger-point management. Reg Anaesth 22:89–101

Hogeweg J, Langereis M, Bernards A, Faber J, Helders P (1992) Algometry: measuring pain threshold, method and characteristics in healthy subjects. Scand J Rehabil Med 24:99–103

Hong C-Z, Simons DG (1998) Pathophysiologic and electrophysiologic mechanisms of myofascial trigger points. Arch Phys Med Rehabil 79:863–872

Johansson H, Sojka P (1991) Pathophysiological mechanisms involved in genesis and spread of muscular tension in occupational muscle pain and in chronic musculoskeletal pain syndromes: a hypothesis. Med Hypothesis 35:196–203

Kosek E, Ekholm J, Nordemar R (1993) A comparison of pressure pain thresholds in different tissues and body regions. Scand J Rehabil Med 25:117–124

Leffler A-S, Hansson P, Kosek E (2003) Somatosensory perception in patients suffering from long-term trapezius myalgia at the site overlying the most painful part of the muscle and in an area of pain referrel. Eur J Pain 7:267–276

Leffler A-S, Kosek E, Hansson P (2000) The influence of pain intensity on somatosensory perception in patients suffering from subacute/chronic lateral epicondylalgia. Eur J Pain 4:57–71

Levine DW, Simmons BP, Koris MJ, Daltroy LH, Hohl GG, Fossel AH, Katz JN (1993) A self-administered questionnaire for the assessment of severity of symptoms and functional status in carpal tunnel syndrome. J Bone Joint Surg Am 75-A:1585–1592

Madeleine P, Lundager B, Voigt M, Arendt-Nielsen L (2003) The effects of neck-shoulder pain development on sensory-motor interactions among female workers in the poultry and fish industries. A prospective study. Int Arch Occup Environ Health 76:39–49

Mitchell S, Reading I, Walker-Bone K, Palmer KT, Cooper C, Coggon D (2000) Pain tolerance in upper limb disorders: findings from a community survey. Occup Environ Med 60(3):217–221

Nakata M, Hagner I-M, Jonsson B (1993) Trapezius muscle pressure pain threshold and strain in the neck and shoulder regions during repetitive light work. Scand J Rehabil Med 25:131–137

Nussbaum EL, Downes L (1998) Reliability of clinical pressure-pain algometric measurements obtained on consecutive days. Phys Ther 78:160–169

Onishi N, Nomura H, Sakai K, Yamamoto T, Hirayama K, Itani T (1976) Shoulder muscle tenderness and physical features of female industrial workers. J Hum Ergol (Tokyo) 5:87–102

Punnett L (1998) Ergonomic stressors and upper extremity disorders in vehicle manufacturing: cross sectional exposure-response trends. Occup Environ Med 55:414–420

Punnett L, Gold JE (2003) Work-related upper extremity disorders: epidemiologic findings and unresolved questions. In: Johansson H, Djupsjöbacka M, Windhorst U, Passatore M (eds) Chronic work-related myalgia: neuromuscular mechanisms behind work-related chronic muscle pain syndromes. Gävle University Press, Gävle, pp 47–56

Silverstein BA, Kalat J, Fan ZJ (2003) Work-related musculoskeletal disorders of the neck, back, and upper extremity in Washingon State, state fund and self insured workers' compensation claims. Safety & Health Assessment and Research for Prevention (SHARP), Olympia

Sluiter JK, Rest KM, Frings-Dresen MH (2000) Criteria document for evaluation of the work-relatedness of upper extremity musculoskeletal disorders, Coronel Institute for occupational and environmental health. University of Amsterdam, The Netherlands

Sterling M, Treleaven J, Edwards S, Jull G (2000) Pressure pain thresholds of upper limb peripheral nerve trunks in asymptomatic subjects. Physiother Res Int 5:220–229

Takala E-P (1990) Pressure pain threshold on upper trapezius and levator scapulae muscles. Scand J Rehabil Med 22:63–68

Takala E-P, Viikari-Juntura E (1991) Muscle force, endurance and neck-shoulder symptoms of sedentary workers. An experimental study on bank cashiers with and without symptoms. Int J Ind Ergon 7:123–132

Takala E, Viikari-Juntura E, Häkkänen M (1992) Pressure pain threshold on forearm—an indicator of work load? In: International Scientific Conference on Prevention of Work-related Musculoskeletal Disorders PREMUS, Sweden

Viikari-Juntura E (1999) New avenues in research on musculoskeletal disorders. Scand J Work Environ Health 26:564–568

Woolf CJ, King AE (1990) Dynamic alterations in the cutaneous mechanoreceptive fields of dorsal horn neurons in the rat spinal cord. J Neurosci 10:2717–2726