ORIGINAL ARTICLE

Risk factors for hand-wrist disorders in repetitive work

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Objectives: To identify the risk of hand-wrist disorders related to repetitive movements, use of hand force and wrist position in repetitive monotonous work.
Methods: Using questionnaires and physical examinations, the prevalence and incidence of hand-wrist pain and possible extensor tendonitis (wrist pain and palpation tenderness) were determined in 3123 employees in 19 industrial settings. With the use of questionnaires and video recordings of homogenous work tasks number of wrist movements, hand force requirements and wrist position were analysed as risk factors for hand-wrist disorders, controlling for potential personal and psychosocial confounders. All participants were re-examined three times during a follow-up period of three years.
Results: Force but not repetition and position was related to hand-wrist pain and possible tendonitis in the baseline analyses showing an exposure-response pattern. Odds ratios for the risk of hand pain was 1.7 (95% CI 1.3 to 2.2) and for possible tendonitis 1.9 (95% CI 1.1 to 3.3). There was no significant interaction between the ergonomic factors. In the follow-up analyses force remained a risk factor for hand pain (OR 1.4, 95% CI 1.1 to 1.8) and for possible tendonitis (OR 2.9, 95% CI 1.3 to 6.8). Repetition was also a risk factor for the onset of hand-wrist pain (OR 1.6, 95% CI 1.2 to 2.3).
Conclusions: Increasing levels of force were associated with prevalent and incident hand-wrist pain and possible extensor tendonitis. The results for repetition were less consistent. Working with the hand in a non-neutral position could not be identified as a risk factor.

Pain in the hand-wrist region may be a sign of an inflammatory or degenerative process involving the tendons and occasionally the tendon sheaths too. Depending on the structures involved the condition is diagnosed as tendonitis, peritendonitis or tenosynovitis. Hand complaints are common among manual workers with self-reported prevalence around 30–45%.[1 2] Symptoms are not always accompanied by clinical findings. Several studies found very low prevalence of clinical tenosynovitis with swelling and/or crepitation but with a considerable variation—from no cases of clinical tenosynovitis at all, up to more than 18%, apparently with more or less the same case definition.[1–5]

Some studies support the hypothesis that mechanical load put on the wrist could be a factor in the development of wrist tendonitis.[1 5–7] According to newer biomechanical models mechanical load is the product of a combination of the intensity of hand use, expressed as the percentage of rest periods, and ergonomic factors (number of wrist movements), force involved in the movements and the position of the wrist.[8] It is, however, quite difficult to get a precise picture of the actual hand load put on a person's hand during the working day because the same person often performs different work tasks with different combinations of possible risk factors. At the same time, personal factors (for example, gender, medical conditions, previous trauma, and leisure time activities) also seem to play an important role in musculoskeletal disorders and therefore should be equally monitored.[9 10 11]

This paper reports results on hand-wrist pain and possible tendonitis from the prospective Danish PRIM health study (Project on Research and Intervention in Monotonous Work). The study involved workers from different industrial settings engaged in different types of monotonous work. This study reports the role of physical factors as a possible cause for hand-wrist disorders.

METHODS

During 1994 and 1995 20 companies throughout Denmark were invited to participate in the study. The companies were recruited through trade unions and occupational health services. One company declined. In the remaining 19 companies all current workers in the company or in specified departments were invited to participate. 3123 out of 4162 workers (75%) participated in the baseline study. They filled out health questionnaires and a company-specific questionnaire about their work tasks, and participated in a physical examination. Companies and departments were selected to ensure that a wide range of ergonomic and psychosocial workloads was represented, including a control group with varied non-repetitive work (26% of the participants). Non-repetitive work included varied office work, internal transportation, driving or supervision. Participation in the different companies varied from 66% to 96%. Industries and the distributions of gender, age and number of referents in each company is given in table 1. The baseline cohort was followed up three times with an interval between each round of 6–12 months. The length of the period between rounds varied because of logistic reasons. The follow-up time from baseline to last follow-up was three years.

EXPOSURE

Work tasks and individual biomechanical exposure

Based on extensive company walk-throughs at baseline, all work tasks were divided into repetitive and non-repetitive work tasks. Workers were classified as exposed to repetitive work if at least one of their tasks involved repetitive hand movements. 425 repetitive work tasks were subsequently collapsed into 103

Abbreviations: BMI, body mass index; PPT, pressure pain threshold; PRIM, Project on Research and Intervention in Monotonous Work

Table 1 Industries, number of participants, number of women, age, number of referents, and mean values of physical exposure variables

Industry	n	Women, n (%)	Age, mean (SD) years	Referents, n (%)	Mean (range, 90th percentile) Repetitions/min	Force, scale 1–5	Position, wrist out of neutral, % of time
Food industry							
Pig slaughtering	211	29 (13.7)	35.6 (9.4)	15 (7.1)	15.7 (6.5–18.0, 18.0)	3.5 (0.5–4.5, 4.0)	21.8 (2.2–32.1, 32.1)
Poultry slaughtering	324	183 (56.5)	34.4 (11.2)	60 (18.5)	27.1 (6.4–44, 36.6)	2.5 (1.0–3.0, 3.0)	33.4 (8.0–64.1, 64.1)
Meat canning	154	27 (17.5)	42.0 (10.1)	46 (29.9)	12.6 (1.0–26.3, 22.4)	1.3 (0.2–2.3, 2.0)	22.1 (0.0–38.6, 37.8)
Cookies production	94	82 (87.2)	38.8 (10.9)	16 (17.0)	16.0 (7.2–25.0, 25.0)	0.8 (0.3–1.0, 1.0)	14.7 (4.6–31.2, 25.1)
Textile production							
Women's underwear	92	89 (96.7)	41.6 (11.0)	15 (16.3)	20.7 (10.3–33.0, 33.0)	1.0 (0.6–1.0, 1.0)	79.4 (52.4–87.4, 83.5)
Children's underwear	126	126 (100)	36.1 (9.6)	8 (7.1)	15.6 (6.8–23.5, 18.3)	1.2 (0.7–2.0, 2.0)	19.2 (0.0–35.0, 24.2)
Women's wear	50	50 (100)	38.2 (10.5)	4 (8.0)	12.0 (10.0–15.0, 15.0)	2.0 (1.0–2.5, 2.5)	29.9 (9.9–36.7, 36.7)
Other manufacturing							
Toy production	291	237 (81.4)	41.1 (9.6)	115 (39.5)	11.8 (3.6–36.0, 15.3)	0.5 (0.2–1.0, 0.7)	19.3 (7.5–33.7, 23.6)
Plastic and paper production	196	112 (57.1)	41.0 (8.9)	78 (39.8)	11.8 (2.4–24.0, 19.5)	1.2 (0.4–2.0, 1.8)	24.0 (0.0–31.2, 31.2)
Plastic containers	62	60 (96.8)	41.3 (10.8)	0 (0)	11.7 (8.0–13.5, 13.5)	1.3 (1.0–2.0, 2.0)	21.0 (0.0–31.1, 31.1)
Electronics	78	44 (56.4)	37.1 (9.9)	34 (43.6)	16.6 (3.3–23.5, 23.5)	1.5 (0.4–2.3, 2.0)	34.1 (6.6–47.6, 47.6)
Life safe equipment	82	50 (61.0)	36.7 (9.0)	9 (11.0)	23.1 (2.5–32.4, 32.4)	2.0 (0.8–3.0, 3.0)	55.9 (0.0–87.6, 87.6)
Cardboard production	156	5 (3.2)	40.6 (9.1)	40 (25.6)	9.6 (1.5–62.0, 17.5)	2.4 (0.5–3.0, 3.0)	3.5 (0.0–34.6, 18.7)
Cardboard production	186	6 (3.2)	43.1 (9.8)	76 (40.9)	10.9 (1.0–34.3, 31.0)	1.4 (0.2–2.0, 2.0)	11.8 (0.0–91.3, 36.5)
Service and commerce							
Postal	149	56 (37.6)	40.0 (9.4)	48 (32.2)	5.2 (0.4–12.8, 9.0)	0.8 (0.1–2.0, 1.4)	7.1 (0.0–52.3, 28.0)
Postal	270	95 (35.2)	32.4 (10.2)	55 (20.4)	6.3 (0.4–14.2, 9.0)	0.8 (0.0–3.0, 1.6)	3.6 (0.0–84.0, 12.2)
Bank	518	518 (100)	42.3 (9.7)	189 (36.5)	11.1 (0.3–23.6, 18.7)	0.8 (0.0–1.9, 1.2)	41.4 (0.0–88.8, 68.5)
Supermarket	42	34 (81.0)	26.1 (12.1)	1 (2.3)	9.0 (3.2–15.0, 15.0)	1.2 (0.4–2.0, 2.0)	13.0 (4.7–21.6, 21.6)
Supermarket	42	20 (47.6)	24.9 (11.1)	4 (9.5)	7.4 (2.2–16.2, 15.0)	1.5 (0.4–3.2, 3.0)	12.3 (3.7–26.7, 24.7)
Total	3123	1823 (58.4)	38.6 (10.7)	813 (26.0)	13.8 (0.3–62.0, 24.0)	1.5 (0.0–4.5, 3.0)	25.3 (0.0–91.3, 64.1)

work task groups with a homogeneous ergonomic exposure—that is, we assumed comparable levels of repetitiveness, postural demands, and force requirements.[12] Before every follow-up round, each company was contacted and new work tasks were evaluated. During the follow-up period 16 new work tasks were introduced.

All work tasks (including those introduced during the follow-up period) were observed using a video-based, computer-assisted technique.[12 13] Random samples of workers were selected from each of the 103 work tasks and a medium of three recordings per work task was conducted (range 1–7). The intention was to obtain 3–4 recordings per task, but this was not always possible because few performed the task at the same time. Sometimes some variation in performing the task was observed and then the number of recordings was increased. At least 10 work cycles, or a time period of at least 10–15 min for work tasks with long work cycles, were recorded using three camera angles (rear, side and close-up of the dominant hand). A total of 349 recordings were analysed. Wrist position was recorded as the percentage of time with wrist flexion and extension 15–45° and >45°, ulnar deviation 10–20° and >20°, and radial deviation 5–15° and >15°. The extreme positions were hardly represented. Thus, flexion or extension of the wrist >45° was performed less than 1% of the work time among the participants with repetitive work tasks. Ulnar deviation >20° was performed 5% of the time and radial deviation >15° was not represented at all. It was therefore decided to create a variable—the percentage of time with the wrist out of neutral position—as the percentage of time with the wrist position in either >15° flexion or extension, or ulnar deviation >10° or radial deviation >5°. Repetition was recorded as number of wrist movements per minute. Force was subjectively assessed by the observers (physiotherapists) using a five-point scale relating to maximal voluntary contraction, as described by Moore and Garg.[14] This method was validated using electromyographic technique for some task groups and showed good agreement.[15] The methods are described in more detail by Fallentin *et al*.[12] The 349 video films were analysed by three experienced occupational physiotherapists trained in using the method. Interobserver reliability expressed as the intraclass correlation coefficient was 0.83 for ulnar deviation 10–20°, 0.52 for radial deviation 5–15°, 0.71 for neutral position (two observers, 20 video recordings). Interobserver reliability was not determined for extension/flexion.[12] The distributions of number of hand repetitions, force and position for each company are shown in table 1.

A few repetitive work tasks were not observed because they only encompassed a few workers. Exposure characteristics of non-repetitive work tasks (control work) were not observed for ergonomic exposures.

In every follow-up round each participant filled out a questionnaire on the proportion of work time or weekly hours spent in specific work tasks identified from company walk-throughs, including new work tasks introduced during the follow-up period. For each person the proportion of time per week that was spent in any of the observed or non-observed work task groups in the company was calculated as the proportion of a working week of 37 h.

For each observed exposure variable, an individual exposure estimate was calculated as

$$\sum_{i=1}^{5} m_i \, p_i$$

where m_i is the median value of the observed exposure variable in the i'th work task group, and p_i is the proportion of time that the subject worked in this work task group. Up to five different work task groups were considered for each person, accounting for 99% of all work hours.

Control work was assigned values for the ergonomic exposure variables indicating no exposure (for example, neutral hand positions all of the time, zero velocity, zero force, no exertions, etc). Non-observed repetitive work tasks were assigned missing values, and if summed with other exposures the sum was considered as missing (n = 182).

Psychosocial exposure, personality traits, and stress

Psychosocial exposure was assessed using the Whitehall II version of Karasek's job content questionnaire.[16] The participants answered questions on job demand (3 items, Cronbach's α 0.53), job control (14 items, Cronbach's α 0.72) and social support from colleagues and supervisors (6 items, Cronbach's α 0.53) on a four-point scale from "often" to "never/almost never". Each item response was dichotomised into high and low aspects of the item content. High job demand was defined as a high score on at least two of the three items on job demand, low job control as a low score on at least five of the 14 items on job control, and low social support as a low score on at least three of the six items on social support. These cut-off levels were based on the 75th percentile of the distribution of the dichotomised item responses of the three work characteristics. Psychological strain was defined as present if the participant complained of both high demands and low control. Personality traits included type A behaviour based on four items about competitiveness from Siegrist's effort-reward model.[17] Type A behaviour was defined as present if the 75th percentile of the sum of item scores was exceeded. Loneliness was defined as present if contact with family or friends was rare or non-existent, if you had no-one to speak to about personal matters, or if you were alone on a daily basis but would rather be with other people. A measure of stress symptoms was based on 18 questions from Setterlind's stress profile questionnaire.[18] A standardised scale ranging from 0–12 was constructed. Details of the construction of this scale have previously been reported.[19] Based on tertile values, three levels were created: no distress (<0.5 on the scale from 0–12), minor distress (0.5–2) and high level of distress (>2), treated as dummy variables in the analyses.

Health assessment

Questionnaires

Hand-wrist complaints (pain or discomfort) were recorded by a self-administered short questionnaire about (1) worst complaints, (2) average complaints, (3) complaint-related impairment of daily activities during the last three months, and (4) complaints during the last seven days. Each of the four questions was answered on a 10-point scale (0 = no discomfort at all, and 9 = pain as bad as could be). A hand-wrist pain score was calculated as the sum of the four scales. The questionnaire was developed for the PRIM study to be a short and easily-filled questionnaire on pain intensity and impairment of some duration (three months) and present pain (seven days). Reliability and validity aspects of the PRIM questionnaire have been dealt with previously.[20,21] The reliability of the PRIM pain questionnaire was tested and found to be good in a test-retest trial. Furthermore, weekly scores were compared to the three-month retrospective score in the PRIM questionnaire. For average pain scores there was complete agreement in 80% of the answers and the agreement within one score was 92%, strongly indicating that it is reliable to use retrospectively—even for a period as long as three months.[20] A separate baseline questionnaire was used to investigate hand injury and surgery, and about leisure time physical activities (hours and intensity), and about sports (h/week), including hand-wrist demanding sports (badminton/tennis and ball games). The participants were further asked about medical conditions including connective tissue disorders and rheumatoid arthritis.

At each follow-up round all participants answered the complaint questionnaire. If the hand-wrist complaint score was 12 or more (on a scale spanning 0–36) in the follow-up questionnaire then the participant was invited to a physical examination.

Physical examination

At baseline, all participants went through a physical examination. On site, three teams of 2–3 physicians performed physical examination of signs of neck and upper extremity disorders according to a detailed protocol. The physical examinations were performed without knowledge of the complaint and exposure status of the examinee. The wrist extensor side was palpated and inspected with respect to direct tenderness, swelling and crepitation, and indirect tenderness was examined by wrist extension against resistance. Palpation was performed with a mild pressure with the thumb, trained regularly to be about 4 kg.

The physical examination further included measurements of weight (kg), height (cm), and shoulder width (twice the distance (cm) between the 7th cervical spine prominence and the lateral acromion edge on the right side). From these measurements the body mass index (weight/(height/100)^2), and a body build index (shoulder width in percentage of height), were calculated. Handgrip force for each hand was measured as the maximum of three trials using Martin's vigorimeter. This device has been tested and was found very precise.[22] We used the average pressure pain threshold (PPT) from three pressure points of the lower extremities (the right and left medial vastus muscle, 15 cm above the knee, and the tibia on the right side, 10 cm below the knee) as a measure of a general pain threshold, assumed to be independent of any work-related upper extremity disorders. PPTs were measured with an Algometer (Somedic, Stockholm, Sweden) with a circular rubber-coated pressure head, area 1 cm^2, using a pressure rate increase of 50 kPa per second.[23]

No diagnoses were specified at the physical examination. Diagnoses were subsequently established from algorithms based on recorded symptoms and findings. Hand-wrist pain was considered to be present if the hand-wrist pain score was $\geqslant$12 points. A diagnosis of *possible extensor tendonitis* was made if pain was present and if there was wrist extensor tendon tenderness on palpation. A diagnosis of *definite extensor tendonitis* further required that there was indirect tenderness. These criteria for diagnosing wrist tendonitis in epidemiological studies are in accordance with recent recommendations.[24,25]

An incident symptom case was defined by a symptom score of less than 12 at baseline and an increase of 12 score points from the hand-wrist during follow-up. An incident clinical case (possible extensor tendonitis) was defined as an incident symptom case with extensor tendon tenderness on palpation.

Analysis

Cases with definite extensor tendonitis were very few (6 in the control group and 10 in the repetitive group, baseline data) and were not further analysed as a separate clinical entity.

Using baseline data, hand-wrist pain and possible extensor tendonitis were analysed in logistic regression analyses with one ergonomic variable at a time (repetition, force, position). The exposure effects were examined as continuous variables within the group with repetitive exposure. The continuous exposure variables were standardised to have a range from 0–3 by division with the maximum value and multiplying with 3. Thus a one-unit increase reflects an increase of one third of the maximum. Additionally, the exposure variables were dichotomised into high and low exposure by their approximate medians, and analysed as dummy covariates with non-repetitive work as the reference. The effects of low and high exposure for each ergonomic variable were tested controlling for high exposure of the other ergonomic variables in three analyses, one for each exposure variable, with the unexposed group as the reference. Interaction between the ergonomic variables (repetition, force and position) was tested within the repetitive group. The following interaction terms were constructed: high force × high repetition, high repetition × high position, and high force × high position. The effect of these interaction terms was tested in a model including the main effects and the interaction term.

The following fixed set of potential confounders were included as covariates in the model: age, age squared, examining centre, gender, private physical activity (⩽4 h vs >4 h light physical activity per week), possible wrist/hand straining sport (<1 h/⩾1 h per week), previous hand injury (yes/no), previous hand surgery (yes/no), self-reported rheumatoid arthritis (yes/no), self-reported connective tissue disease (yes/no), shoulder width/height below the lower quartile. Body mass index (BMI) and PPT were categorised as below the approximate lower quartile (yes/no) or above the higher quartile (yes/no). The PPT quartiles were calculated for each sex. Psychosocial covariates were demands, control, social support and strain. Personality traits included type A behaviour and loneliness. Stress was categorised as minor distress (yes/no) and high level of distress (yes/no).

The risk of developing hand-wrist pain and possible wrist tendonitis during follow-up was calculated with a logistic regression technique equivalent to discrete survival analysis with the number of follow-up round entered as dummy variables.[26] Observations were right censored when the criterion for outcome became positive. In the analyses we used the value from the preceding round for both the physical and psychosocial variables.

All of the potential confounders were kept in the models whether their effects on the outcome were statistically significant or not, and irrespective of their effects on the relation between exposure and outcome.

T tests were used to compare the continuous exposure variables in dropouts versus individuals staying in the cohort and χ^2 tests for the dichotomous variables. We performed the analyses in SAS, version 8.e for Windows.

RESULTS

Baseline data

The prevalence of hand-wrist pain was 7.8% in the control group and 15.7% among subjects with repetitive work. The prevalence of possible wrist extensor tendonitis in the two groups was 1.5% and 3.8%, and of definite wrist extensor tendonitis 0.76% and 0.51%, respectively. No cases with swelling or crepitation over the extensor tendons were observed.

Table 2 shows the distribution characteristics for the hand exposure variables in the 349 recordings of the 103 work tasks and for each summed and time-weighted variable for the 2033 participants with repetitive work. As was intended in the selection of the study population, most exposures were appropriately represented by the work tasks.

Also shown in table 2 is the ratio of the within work task variation divided by the between work task variation based on the same recordings. For exposure variables with a low ratio the contrasts between work task groups are more reliable than for exposure variables with a high ratio. In this respect, force was a more reliable exposure variable than repetitions per minute. In the PRIM study a ratio of 0.75 was arbitrarily chosen as the cut point for an acceptable value.[12]

The results of the logistic regression analyses for the baseline data are shown in table 3.

All ORs for the continuous exposure variables were above unity, indicating a positive exposure-response relation but this was only significant for force. The effect of the continuous exposure variables was also analysed with repetition, force and position simultaneously in the model. The significant effect of force remained for both hand pain and possible tendonitis. The effect of repetition and position remained insignificant (data not shown). In the analyses with categorical exposure variables a positive exposure-response relation was seen for force (hand pain). There were no significant findings for position and repetition and no significant effects of the interaction terms.

For the other covariates, the most consistent findings were significant effects of former hand accidents with ORs around 2 and an effect of not having support from family or colleagues with OR around 1.3. Reporting distress, both minor and high level, had significant effects with ORs around 1.8 and 2.5, respectively. There were no significant effects of low control, high demands or the combined factor strain. In almost all of the analyses we saw a significant protective effect of increasing hand grip force.

Follow-up analyses

3123 participated at baseline, 2368 in the first follow-up, 2013 in the second, and 1546 in the third. Thus, the cohort was reduced by 50.5%. We compared those who remained in the cohort with those who left on different parameters at baseline. The mean age was 43.1 years for those who stayed in the cohort and 36.8 years for the dropouts (p<0.001), 53.3% and 63.4% were females (p<0.001), 12.7% and 14.3% had wrist pain (p = 0.19), and 67.3% and 75.6% had repetitive work (p<0.001) respectively. The mean number of repetitive hand movements was 7.7 for those who stayed in the cohort and 11.3 for dropouts (p<0.001), force level was 0.9 versus 1.2 (p<0.001) and percentage of time with the hand out of neutral was 16.5 versus 20.8 (p<0.001). In the follow up period, the three sewing companies with highly repetitive work and only women moved their production to Eastern Europe.

Force analysed as a continuous variable was a significant risk factor for the onset of hand pain and for possible tendonitis. Repetition was a risk factor for the onset of hand pain. There were no significant findings for position (table 4).

Table 2 Exposure distributions in 103 observed work task groups and in 2033 subjects with repetitive work

	Distribution characteristics of observed work tasks (n = 103)			Distribution of the time weighted and summed exposure variables for subjects with repetitive work (n = 2033)		
Exposure variable	Mean of medians (SD)	Min-max	Within vs between variation*	Number with no exposure, n (%)	Median	90th percentile
Position, % of cycle time						
Non-neutral position (>15° flexion or extension, >5° radial or >10° ulnar deviation)	73.7 (8.8)	0.8–100	0.37	396 (20)	21.7	64.1
Repetitions, n/min						
Wrist movements	16.0 (5.0)	2.3–62.0	0.64	0 (0)	12.5	24.1
Force, rating units 1–5	2.0 (0.0)	1.0–4.5	0.29	0 (0)	1	3

*Within work task variation (estimated as the mean of work task specific standard deviations) divided by between work task variation (standard deviation of the medians of work tasks).

Table 3 Prevalent hand-wrist pain and possible tendonitis by physical exposures

		Pain		Possible tendonitis	
Physical exposure factor	**n**	**n (%)**	**$OR_{adj.}$ (95% CI)**	**n (%)**	**$OR_{adj.}$ (95% CI)**
Number of repetitions/min					
Continuous variable, repetitive group	1720	264 (15.4)	1.3 (0.9 to 1.8)	64 (3.7)	1.6 (0.8 to 3.2)
Grouped exposure					
Reference	795	62 (7.8)	1	12 (1.5)	1
Low (1–12)	982	133 (13.5)	1.4 (1.0 to 2.1)	29 (3.0)	1.3 (0.6 to 2.9)
High (>12)	987	177 (17.9)	1.4 (0.9 to 2.3)	46 (4.7)	1.6 (0.6 to 4.3)
			Test: p = 1.00*		Test: p = 0.41*
Force (scale 1–5)					
Continuous variable, repetitive group	1720	264 (15.4)	**1.7 (1.3 to 2.2)**	64 (3.7)	**1.9 (1.1 to 3.3)**
Grouped exposure					
Reference	795	62 (7.8)	1	12 (1.5)	1
Low (0–1)	1055	150 (14.2)	1.4 (1.0 to 2.1)	42 (4.0)	1.3 (0.6 to 2.9)
High (>1)	914	160 (17.5)	**2.0 (1.3 to 3.0)**	33 (3.6)	1.7 (0.7 to 4.1)
			Test: p = 0.03*		Test: p = 0.34*
Position (wrist out of neutral), % of time					
Continuous variable, repetitive group	1720	264 (15.4)	1.1 (0.9 to 1.3)	64 (3.7)	1.4 (1.0 to 2.0)
Grouped exposure					
Reference	795	62 (7.8)	1	12 (1.5)	1
Low (1–21.7)	959	128 (13.4)	1.1 (0.7 to 1.7)	23 (2.4)	1.4 (0.6 to 3.1)
High (>21.7)	1010	182 (18.0)	1.4 (1.0 to 2.1)	52 (5.2)	1.8 (0.8 to 3.8)
			Test: p = 0.18*		Test: p = 0.51*

*p value of no difference between the estimates in the groups ''low'' and ''high''.
All analyses were adjusted for the following fixed set of potential confounders: age, age^2, examining centre, gender private physical activity, hand straining sport, hand injury, hand surgery, rheumatoid arthritis, connective tissue disease, shoulder width/height, BMI, pressure pain threshold, psychosocial covariates (demand, control, strain, social support), type A behaviour, loneliness, stress.
In the analyses of the effect of the continuous variables, the odds ratio expresses the risk for hand pain or possible tendonitis with an increase of one third of the range of the variable.
Significant findings are in bold.

DISCUSSION

Hand-wrist disorders defined as self-reported symptoms with or without palpation tenderness were associated with observational measures of repetition and force. This was consistent in both the baseline and the follow-up analyses for force as a risk factor. High repetition was a risk factor for developing hand pain but no associations between repetition and hand disorders were seen in the baseline analyses. Furthermore, no significant associations were found for wrist position. The correlation coefficients were moderately high between repetition and force

Table 4 Incident wrist pain and possible tendonitis by physical exposures

	Pain			Possible tendinitis		
Physical exposure factor	**n**	**n (%)**	**$OR_{adj.}$ (95% CI)**	**n**	**n (%)**	**$OR_{adj.}$ (95%CI)**
Number of repetitions/min						
Continuous variable, repetitive group	3014	284 (9.4)	**1.6 (1.2 to 2.3)**	3247	33 (1.0)	1.4 (0.5 to 4.0)†
Grouped exposure						
Reference	1526	87 (5.7)	1	1596	11 (0.7)	1
Low (⩽10.8)	1453	108 (7.4)	1.2 (0.8 to 1.7)	1543	13 (0.8)	0.6 (0.2 to 1.7)
High (>10.8)	1561	176 (11.3)	**1.7 (1.1 to 2.7)**	1704	20 (1.2)	1.1 (0.2 to 4.2)
			Test: p = 0.02*			Test: p = 0.35*
Force (scale 1–5)						
Continuous variable, repetitive group	3014	284 (9.4)	**1.4 (1.1 to 1.8)**	3247	33 (1.0)	**2.9 (1.3 to 6.8)†**
Grouped exposure						
Reference	1526	87 (5.7)	1	1596	11 (0.7)	1
Low (⩽1)	1243	107 (8.6)	1.2 (0.8 to 1.7)	1309	17 (1.3)	0.6 (0.2 to 1.8)
High (>1)	1771	177 (10.0)	1.3 (0.9 to 1.9)	1938	16 (0.8)	0.5 (0.1 to 1.8)
			Test: p = 0.38*			Test: p = 0.82*
Position (wrist out of neutral), % of time						
Continuous variable, repetitive group	3014	284 (9.4)	1.2 (1.0 to 1.4)	3247	33 (1.0)	1.0 (0.6 to 1.6)†
Grouped variable						
Reference	1526	87 (5.7)	1	1596	11 (0.7)	1
Low (<19.8)	1404	116 (8.3)	1.2 (0.8 to 1.7)	1477	13 (0.9)	0.6 (0.2 to 1.7)
High (>19.8)	1610	168 (10.4)	1.2 (0.8 to 1.8)	1770	20 (1.1)	0.5 (0.1 to 1.6)
			Test: p = 0.83*			Test: p = 0.70*

*p value of no difference between estimates in the groups ''low'' and ''high''.
All analyses were adjusted for the following fixed set of potential confounders: age, age^2, examining centre, gender private physical activity, hand straining sport, hand injury, hand surgery, rheumatoid arthritis, connective tissue disease, shoulder width/height, BMI, pressure pain threshold, psychosocial covariates (demand, control, strain, social support), type A behaviour, loneliness, stress.
†No cases of incident possible tendonitis among individuals with former hand surgery. This variable was left out in the analyses.
In the analyses of the effect of the continuous variables, odds ratio (OR) expresses the risk for hand pain or possible tendonitis with an increase of one third of the range of the variable.
Significant findings are in bold.

(0.45) and between repetition and position (0.57) but low between position and force (0.05). This could affect the ability to reach significant results for the separate effects of repetition and force and thus explain some of the inconsistency in the results. The dropout rate in the study was considerable. Furthermore, those who dropped out had a higher level of repetition, force and non-neutral hand position (but not of hand pain at baseline). This could also have reduced the incidence rates and the power to detect true associations.

The variables for repetition and force showed a very favourable distribution with many people exposed to both low and high levels. In this study, we have recorded other position variables than the non-neutral position variable reported. However, these other position variables were not satisfactorily distributed because very few worked with their hands in assumed hazardous positions. We used non-neutral wrist position as the position exposure variable in this study as a consequence of the lack of representation of more extreme positions. Maybe a more pronounced pattern for the position variables would have emerged if the extreme positions had been more common. As this material represents a broad spectrum of monotonous work in the Danish industry it must be concluded that such exposure is rare. In former recommendations,[27 28] flexion-extension beyond 40–50°, ulnar deviation more than 25° and radial deviation more than 0° have been regarded as hazardous. In the study by Marras and Schoenmärklin of ''high risk'' and ''low risk'' workers defined as such based on frequency of injury claims, the hand movements measured with electrogoniometers ranged from 29° extension to 7° flexion among the ''high risk'' workers and from 24° to 4° among ''low risk'' workers. Thus, a significant overlap existed and threshold limits could not be suggested.[28] Even though in the present study there is some consistency in the results, especially for force, it does not allow any distinct threshold suggestions for repetition, force or position.

Outcome

The PRIM health study was primarily interested in studying non-trivial musculoskeletal discomfort and pain and associated clinical disorders.[9 10] We therefore wanted a pain measure instrument that reliably reflected the intensity of pain and functional impairment resulting from pain of some duration in the period just before the physical examination.

The PRIM hand-wrist pain score was highly correlated with duration of pain, professional examination or treatment for pain, and sick leave because of pain within the last 12 months. These associations were quite monotonous and did not indicate a certain cut-off level for definite pain in the PRIM pain score. The same was true for palpation tenderness. However, hand grip force was similar in subjects with no pain and ''mild'' pain (hand-wrist pain score 1–11 points) and significantly different from subjects with definite pain (104 kPa, 103 kPa and 91 kPa, respectively).

Our criterion for definite pain may have been somewhat conservative, but the data did not indicate any lower more relevant cut-off scores. We could have considered any discomfort or pain as relevant. However, 40% of the study population had a hand-wrist pain score above zero, which is obviously meaningless from a clinical point of view. Thus, we used a continuous scale which was dichotomised. In this way some ''near-cases'' may have been missed but this procedure is actually identical to dichotomising questionnaire responses by collapsing the response categories. In such a procedure, ''near-cases'' will also be missed.

The physical examination procedures were designed to minimise differences between the clinical examiners. Palpation pressure was designed to be approximately 4 kg.

Main messages

- Force seems to be the main ergonomic risk factor for hand disorders in monotonous industrial work, but high levels of repetition may also play a role.
- Working with the hands out of neutral position was not identified as a risk factor.
- Threshold limits for force, repetition and position could not be established.
- Almost 20 different production facilities all over Denmark with more than 400 repetitive work task groups were studied. The levels of repetition and force varied considerably whereas extreme wrist positions were not common.

Policy implications

- High levels of repetition and especially force should be reduced.

However, the prevalence of hand-wrist palpation tenderness was higher at one centre (Glostrup) than at the other two centres, controlling for the level of hand-wrist pain, but the difference was only found for women, and it was not related to the degree of repetitive work. This difference between centres was not found for other anatomical regions, and we therefore believe that it is a random effect rather than a systematic bias (data not shown). Finally, in analyses of the relations between outcomes and ergonomic exposures we controlled for the effect of centre.

Exposure

One of the strengths of the study was the way the exposure information was obtained. Homogenous work tasks were characterised by objective measurements or observations and an individual exposure value was calculated by multiplying this value with the self-reported individual number of hours per week. The exposure values, however, reflect a combination of intensity and weekly duration for a range of ergonomic exposures but actually we do not know whether a very short but intense exposure is better, worse or equal to less intense exposure for a longer period. The low exposure group of all exposure variables had exposure values equal or close to zero. At this level of the exposure variables, or for a value of zero in the continuous exposure variables, one would expect no excess risk compared to the control group—that is, an odds ratio close to unity. The increased prevalence of wrist-hand pain and possible wrist extensor tendonitis was therefore not fully explained by the ergonomic exposure variables and the potential confounders included in the models (tables 3 and 4). No observations were performed on the control group. It would have been very resource-intensive to observe all the different work tasks in this group and also very difficult to assign individually-based time periods to this group. The control group also constitutes a spectrum of ergonomic ''exposures'' and perhaps some of the unexplained excess risk in the low exposure group could be levelled out if we had these measurements.

There may be some misclassification of the exposure. The original 425 repetitive work tasks were collapsed into 103 groups. Thus, in this process a lack of homogeneity was introduced. This is reflected in the variation in the exposure measurements within the task groups (table 2). However, for most variables the exposure contrasts between the task groups were considerable, reducing the effect of the within-group variation. More measurements within the task groups would have determined the exposure more precisely. Exposure classification also relied on questionnaire information because number of working hours in each task was self-reported. Actual health status may induce either over- or underestimation of the actual exposure leading to false positive or negative associations.

The main conclusions of the study were that observational measures of repetition and particularly force were related to hand-wrist pain and mild clinical signs of tendonitis. Extreme wrist postures were not common. Hand pain and mild signs of tendonitis are common but the fully developed clinical entity of wrist tendonitis is not a common finding in a working population when examined at time points separated by approximately 6–12 months. This may be due to temporary or permanent selection out of work because of tendonitis, or because the indirect tenderness criterion is not present for very long during tendonitis.

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