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Relationship between work constraints and the development of musculoskeletal disorders of the wrist: A prospective study

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Abstract

A 2-year prospective study was conducted on 184 workers about the relationship between the development of musculoskeletal wrist disorders (WD) and the occupational constraint parameters at their job (wrist angles, forces, repetitiveness and angular velocities), taking into account personal and occupational confounding factors. The results demonstrate a greater probability of developing WD for the workers suffering from chronic diseases, from psychological disorders, practising a sport involving the upper limbs and judging their work tiring.

All occupational constraint factors are correlated except for the angles. Logistic correlation analyses show that the most significant associations with a greater probability of developing WD are observed for the mean relative EMG value recorded on the finger and hand flexors and the time during which the velocity in flexion–extension is greater than 50°/s. None of the angular parameters shows any association.

Relevance to industry

The study shows that the main factor on which to act in order to reduce the risk of WD is clearly the forces exerted by the hand.

The objective of the control measures should be to reduce the muscular activity of the finger and hand flexors below 15% of the maximum activity corresponding to the maximum voluntary contraction of the finger flexors.

A reduction of these forces appears to be associated with a reduction of the angular velocities of the wrist and of the repetitiveness.

Keywords: Musculoskeletal wrist disorders; Occupational constraint factors; Angles; Forces; Repetitiveness; Velocities; Prospective study

1. Introduction

The present paper deals with the occupational factors in relation with the development of wrist disorders (WD). We adopted for these disorders the definition given by Kroemer (1989) for the upper limb disorders in general: "a collective term for syndromes characterised by discomfort, impairment,

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disability or persistent pain in joints, muscles, tendons and other soft tissues, with or without physical manifestations, including tenosynovitis, ganglionic cysts, carpal tunnel syndromes, ...''.

Although the occupational factors responsible for these WD are largely suspected, Stock (1991) showed that very few studies have in fact scientifically demonstrated the association between WD and forces, repetitiveness and angular postures of the wrist. Even further, very little information is available concerning the correlation between these factors and the relative role they play in the development of WD, while these are essential in order to determine the most appropriate control measures to implement in real work conditions.

Two studies have shown correlations between occupational factors and the development of different types of WD. Silverstein et al. (1986, 1987) showed that the force (OR = 4.4) was a more important risk factor than repetitiveness (OR = 2.9) when considering the wrist disorders in general, while the opposite appeared to be true when considering the carpal tunnel syndrome only (OR = 2.9 for the force and 5.5 for the repetitiveness). This shows clearly that the physiological and biomechanical mechanisms at the basis of different upper limb disorders being not identical, the relative importance of each risk factor might vary accordingly. Marras and Schoenmarklin (1991, 1993) attempted also to determine the hierarchy of the occupational factors responsible of the carpal tunnel syndrome: they found that velocities and accelerations of the wrist in the sagittal plane were the factors the most correlated to the development of this syndrome.

In a preceding paper (Malchaire et al., 1996), we reported a cross sectional study where the prevalence of WD at different workplaces were correlated with the mean values of the occupational factors encountered in these working conditions. The main occupational factor appeared to be the mean force, estimated through the EMG recorded on the finger flexors of the forearm. The second independent factor was the mean relative angle in radial or ulnar deviation. The parameters of repetitiveness and velocities appeared strongly correlated to the mean force.

Following these results, a prospective study was conducted in order to relate the development of WD to the occupational factors to which the subjects were exposed, taking into account, as much as possible, all the confounding non occupational factors. The aim of the study was, in particular, to determine the order of priority in which these occupational factors must be controlled at the job.

2. Material and methods

Fourteen jobs, characterised by different levels of exerted forces, repetitiveness and postures of the wrists, but without exposure to hand–arm vibration, were chosen: 8 occupied by men and 6 by women. High repetitive jobs were defined according to Silverstein et al. (1986) as ''those with a cycle time of less than 30 s or more than 50% of the cycle time involving the same kind of fundamental cycles''. High force jobs were jobs with estimated average hand force requirements of more than 4 kg. These evaluations were made on the basis of a simple survey of the jobs but were rather straightforward in each case. For each job, some 13 subjects were selected after an interview as explained later. The 14 jobs came from ten different companies as follows (with the gender of the workers and the number of wrists included at the beginning and at the end of the study):

(1) the assembling of seats in a car plant (men, 19 and 18 wrists); work is organized in two 8 h shifts with two breaks of 20 min. The workers must assemble everyday the same type and the same number of seats. The workcycle lasts about 12 min.

(2) The sewing of the seat covers in the same company (women, 34 and 33 wrists); the work organization is identical: two 8 h shifts with two breaks for meals. The number of seat covers to sew is imposed and the worker can stop as soon as the quota is reached. The workcycle thus varies between 15 to 20 min.

(3) The handling of car windows in a glass industry (men, 22 and 22); the work is organized in three 8 h shifts with normal breaks for meals. They continuously either lay down car windshields (3 to 5 kg) on a belt at the entrance of an oven (cycle time 10 s), or pick up and place on a rack the same parts at the exit of the oven (cycle time: 20 s).

(4) The work of meatcutter (men, 13 and 12); work is performed only from 7 a.m. to 3 p.m. with normal breaks. It consists in boning and cutting quarters of beef. Depending upon the size of the quarter, the work lasts up to 30 min.

(5) The positioning of ceramic objects on oven racks (men, 14 and 14); the workers continuously have to place or remove from cooking racks, ceramic filters weighing about 1 kg each. They handle about 3600 filters per shift and work in two 8 h shifts with typical breaks. The work remains identical all day long except that filters must be placed at different depths and levels on the racks, involving therefore different levels of constraints for the back and the shoulders. As far as the hands and wrists are concerned, the load varies slightly with the size and the shape of the filters.

(6) The work in a pastry-making industry (men, 29 and 23; women, 26 and 22); work is performed in one 8 h shift with two regular breaks. Although the pastries to prepare vary from one day to another, the work remains essentially the same and is performed by 4 to 6 workers successively on a small production line. The workcycle is shorter than 30 s.

(7) The work of packaging in a pharmaceutical industry (women, 18 and 16); one 8 h shift only with regular breaks. Work consists in picking up from the production line different items of different weights ranging from 30 g to 2.5 kg, placing them in boxes and stacking the boxes in a container. Each operation lasts some 15 s but a whole repetitive cycle is about two minutes long.

(8) Data encoding on a computer using two different techniques (men, 26 and 26; women, 25 and 20); the first technique consists in handling manually with the left hand each money transfer form and encoding all the information (names, addresses, amount, account numbers...) with the right hand. In the second technique, each form is automatically presented in front of the operator who has only to validate the optically read information and encode the amount. They work from 8 a.m. to 5 p.m. with one hour break only. The workcycle is here very short: from 5 to 15 s.

(9) Normal clerical work in an insurance company (men, 30 and 26; women, 32 and 28); this job involves the management of insurance files with telephone calls, form fillings, handling of files. This is a typical administrative work done continuously from 9 a.m. to 5 p.m. (with a one hour break). The mental operations are numerous but the physical constraint is highly homogeneous.

(10) Clerical work in a bank, including some intermittent work on computer (men, 26 and 24; women, 34 and 32); this job involves also the management of files but with more frequent interactions with the computer. Again, the nature of the mental work varies considerably but the hand and wrist operations are about the same all day long. They work according to the same schedule than group 9.

The turnover was almost nil in all cases. There was no financial incentive to increase the production rate. Quota were assigned only after the training phase and could normally and easily be reached. Typically the workers reached their quota faster than theoretically expected and enjoyed a 15 to 30 min rest period at the end of the shift. They never worked more than 8 h per day in any job.

2.1. Protocol of the study

The protocol included an interview at three occasions, at one year interval, and the analysis of the working conditions.

The interviews with the workers were always conducted by the same physiotherapist. A checklist was used to collect information concerning:

- The basic characteristics: age, weight, height, seniority.
- The health status: chronic diseases other than WD, accidents, medications.
- The personal characteristics: smoking habits, hobbies, sports in general and sports involving the upper limbs, psychological profile (more than three symptoms at least once a month among problems of memory, of sleep, headache and irritated temper).
- The working conditions: perception of the physical load and of the fatigue.
- The occurrence of WD in answer to the following question from the Nordic Questionnaire (Kuorinka et al., 1987): "Have you at any time, during the 12 last months, had trouble (ache, pain, discomfort) in the wrists" Yes or No.

Included in the prospective study were all workers answering negatively to this question the first year, providing that they had not had previously any surgery or accident at the wrists.

They were fully informed of the content, the purpose and the length of the study and had to give their free consent in order to participate.

All discrete variables were dichotomized in terms of no or yes, low or high, normal or abnormal.

The work analyses were conducted for about 10 workers at each job (total 146 workers) during the two years, in order to quantify the posture, the forces, the repetitiveness and the movement velocities.

The observation lasted from 30 to 90 min and covered a minimum of three work cycles on a typical working day, as assessed by the worker himself and the hierarchy. Electronic goniometers (Penny and Giles, Blackwood, UK) were placed on both wrists and the angles in the two planes of radial-ulnar deviation and flexion–extension were continuously recorded on a FM recorder (Teac HR-30G, Japan) (frequency response up to 100 Hz and dynamic range 32 dB). Prior to the observation at the job, the maximum active angles were measured in the four directions (radial deviation, ulnar deviation, flexion and extension). The analysis in the laboratory made possible to determine every 0.1 s the instantaneous amplitudes of movement in each direction and, by comparison with the maximum angles, the instantaneous relative amplitudes. Mean values over the observation period were computed for the relative angles in deviations (either ulnar or radial mDr) as well as in flexion or extension (mFr). Similarly, the EMG signal was recorded on both arms, by means of Medicotest N-00-S surface electrodes placed on the medial side of the forearm over the flexor carpi radialis lying superficially above the flexor digitorum superficialis. They were located on an oblique line between the medial epicondyle and the radial styloid. EMG signal was collected using a portable MEGA ME3000 muscle tester (Mega Electronics, Finland) with a frequency response from 20 to 500 Hz. The instrument recorded, at a frequency of 10 Hz, the integrated RMS value of the instantaneous signal.

Each subject performed initially three maximum voluntary grip efforts for each wrist (during ten seconds with a rest period of two minutes between two consecutive trials) with a hand dynamometer Jamar PC 5030G1 (Jamar Camp, UK), and the maximum root mean square (RMS) EMG value was recorded.

The laboratory analysis of the data was conducted on the basis of the mean relative RMS EMG (mEMGr) amplitudes over the observation period.

In addition, the percentages of the time during which the relative angles exceeded 50% in radial or ulnar deviation (pD%) and 60% in flexion or extension (pF%) and during which the relative EMG amplitude exceeded 15% (pEMG%) were computed.

Three indices of repetitiveness were calculated from the recordings of angles (R_{ang}) and forces (R_{emg}) and as the combined repetitiveness in angles or in forces (R_{tot}) and defined as the number of transitions from a 'neutral' to an 'extreme' condition (or vice versa) where the limits mentioned above were exceeded.

Finally, the instantaneous angular signals in both planes were derived according to time and the mean absolute velocities were computed in deviation (mVd) and in flexion or extension (mVf). Again the percentages of the time the velocities exceeded 30°/s in deviations (pVd%) and 50°/s in flexion–extension (pVf%) were computed.

The working conditions were characterised in three different ways:

- Using the mean data for each job, averaged for all the workers from that job.
- By dichotomising, for each job, each of the parameters described hereabove in two classes ('high risk' and 'low risk'). The thresholds used for the mean relative angles, the mean relative EMG amplitude and the mean velocities are those mentioned previously. For the repetitiveness, a limit value of 25 transitions per minute was adopted as suggested by Hammer (in Pelmear et al., 1992). The percentages of the time above limits were taken as 'high' when greater than 25%.
- Using the data from the work analysis for each worker separately: this was possible for the 247 wrists without a past history of WD from the 146 workers for whom work analyses were conducted.

2.2. Study population

201 workers were initially interviewed. Some workers had suffered from WD at one or both wrists during the past year. These wrists were eliminated,

leaving 348 wrists (188 subjects) which underwent the first series of tests. During the first year, a few persons dropped out of the study, leaving 316 wrists for the second interview. 42 wrists had suffered of WD during this first year and are part of the WD group. The other 274 underwent the second series of tests (148 subjects). 32 workers out of these 148 dropped out during the second year: they were included in the study on the basis of the results of the first series of tests (non WD group). The remaining 216 wrists (116 workers) took the final interview at the end of the second year. 31 wrists had suffered of WD during the second year, according to the same criteria than those used the first year. They form with the 42 from the first year the WD group (total 73 wrists, 54 persons). The other 185 wrists remained without complaint and form with the 58 drop outs the non WD group (total 243 wrists, 130 persons). Over the two years, the incidence of WD was therefore 23% or 11.5% per year.

The main causes of the drop outs were job rotations and the vacating of office of the workers. Musculoskeletal disorders were apparently not involved directly or indirectly in any case.

The mean characteristics of the 184 workers who participated effectively in the study are: age 36.5 ± 7.5 years; weight 70.1 ± 14.8 kg; height 169.3 ± 9.1 cm and seniority 14.9 ± 8.0 years. All workers had at least two years of seniority at the job at which they were observed. The statistical analysis showed that there were no differences in age and seniority between men and women. Men were in average taller and heavier than women. There were some differences between the jobs: workers in the bank and insurance companies as well as in the meat cutting and pastry industries were older and had more seniority than the others.

2.3. Statistical analysis

The study compared for each wrist the possible development of disorders after the first or the second year, the personal characteristics recorded during the interview the preceding year and the occupational parameters from the work analyses, in terms of angles, force, repetitiveness and velocities.

All continuous variables were characterized by their mean and standard deviation. Comparisons between the two groups were made using the student *t*-tests for independent samples. In case of inequality of the variances of the two samples (as evidenced by a Fisher test with a probability greater than 5%), preference was given to parametric tests over non parametric tests in view of the high degree of significance of the results but the approximation proposed by Cochran (Snedecor and Cochran, 1967) was used. A linear correlation matrix was computed between all pairs of variables from the job analyses.

Finally, the relationship between the WD incidence and occupational and non occupational factors was studied using a multiple stepwise (backward) logistic regression model.

The level of significance adopted was 5% for the *t*-tests while all the variables with a probability of less than 10%, that the association is due to random factors, were kept in the final model of the logistic regression.

3. Results

Table 1 gives for each parameter of occupational constraint the mean and standard deviation over all job analyses, for the left and right wrists. From the comparison between left and right, it can be concluded that there is a significant difference between the two wrists and, therefore, that the work is not performed symmetrically and that the occupational constraints are significantly different. This justifies the fact that the study is conducted on the basis of two wrists independently, regardless of the side, left or right.

Table 2 gives the correlation matrix between seven occupational factors. The other parameters show the same dependency. Angular parameters are poorly correlated to the other factors. For the EMG, the correlation with repetitiveness and movement velocity is somewhat greater ($R = 0.30–0.50$), while the parameters of repetitiveness and movement velocity are highly correlated ($R = 0.47–0.60$).

A multiple stepwise logistic regression analysis was first performed with the development of WD as dependent variable and all the personal and non-occupational characteristics as independent variables. Table 3 gives for the seven variables in the final model the odds ratio, the 95% confidence interval and the statistical significance. This model shows the greater probability of developing WD for the male workers, for those suffering from chronic diseases or from psychological disorders, practising a sport involving the upper limbs and judging their work tiring. The practice of sport in general as well as the occurrence of accidents in the past are on the contrary negatively associated with the development of WD.

Among the 184 subjects, 29 declared suffering from a chronic disease. In 17 cases, the disease is not known to be related to the development of WDs (cardiac problems, allergies, gastrointestinal problems). In addition, however, one person suffered from diabetes, 7 from high blood pressure and 4 from thyroidic problems. 13 of this group of 29 workers developed WD in the following year and, in particular, 5 out of the 7 with high blood pressure.

To this final model, each of the occupational factors was added, one at a time, in order to determine the relationship between the work conditions and the incidence of WD, taking into account the confounding non occupational factors. Table 4 gives the results for the three types of analyses mentioned previously. Odds ratios and confidence intervals are presented for the parameters significant at the 10% level and for variations by a factor of 10: 10%, 10 transitions per minute, 10°/s according to the parameter.

When the mean values of the occupational factors are used in the model, the parameters describing the force (through the EMG), the movement velocity in the flexion–extension plane and the repetitiveness

Table 2
Correlation coefficient matrix between occupational constraint parameters

	mDr	mFr	mEMGr	R_{ang}	R_{tot}	mVd	mVf
mDr	1.00						
mFr	0.14	1.00					
mEMGr	0.03	0.21	1.00				
R_{ang}	0.05	0.09	0.30	1.00			
R_{tot}	0.05	0.07	0.48	0.88	1.00		
mVd	0.13	0.44	0.37	0.48	0.57	1.00	
mVf	0.09	0.36	0.50	0.47	0.60	0.79	1.00

Table 1
Means (m) and standard deviations (s) of the occupational constraint parameters (right and left wrists). Significance of the differences between the two wrists

	Symbols	Occupational factors	Right		Left		Significance
			m	s	m	s	
Angles	mDr (%)	mean angle in radial or ulnar deviation	39.5	15.8	44.4	15.9	* *
	mFr (%)	mean angle in flexion or extension	40.1	13.4	36.8	12.6	*
	pD% (% of time)	percentage of the time in 'extreme' radial-ulnar deviation	29.1	21.3	34.4	17.2	*
	pF% (% of time)	percentage of the time in 'extreme' flexion–extension	15.2	16.6	12.4	15.1	N.S.
EMG	mEMGr (%)	relative EMG signal	21.7	16.2	16.0	11.3	* * *
	pEMG% (% of time)	% of the time with the relative EMG greater than 15% (EMGmax)	32.6	27.0	25.0	23.8	* *
Repetitiveness	R_{ang} (#/min)	angular repetitiveness	16.2	6.5	15.6	6.5	N.S.
	R_{EMG} (#/min)	repetitiveness in force	9.5	5.9	8.1	5.9	*
	R_{tot} (#/min)	combined repetitiveness in angles or in force	22.7	8.1	21.1	8.7	N.S.
Velocities	mVd (°/s)	mean velocity in deviation	26.9	5.8	30.2	6.2	* * *
	mVf (°/s)	mean velocity in flexion or extension	44.9	11.0	39.0	11.7	* *
	pVd% (% of time)	% of the time with the velocity in the deviation plane above 30°/s	36.3	5.8	41.3	5.6	* * *
	pVf% (% of time)	% of the time with the velocity in flexion or extension above 50°/s	33.3	6.2	27.5	8.3	* * *

* $p < 5\%$. * * $p < 1\%$. * * * $p < 0.1\%$.

Table 3
Multivariate logistic model for the prediction of the development of WD as a function of non-occupational factors (odds ratio, 95% confidence interval and statistical significance)

Variable	O.R.	95% C.I.	Significance
Gender (men versus women)	2.45	1.32–4.54	* *
Chronic diseases	2.89	1.50–5.55	* *
Accident	0.48	0.27–0.87	*
Sport	0.54	0.27–1.08	#
Sport involving upper limbs	2.82	1.03–7.72	*
Psychological factors	3.17	0.86–11.68	#
Tiring work	2.62	1.34–5.14	##

$p < 10\%$. * $p < 5\%$. * * $p < 1\%$.

are significantly and positively associated with the development of WD; a greater constraint is associated with an increased risk. The most significant associations are observed for the mean relative EMG value and for the time during which the velocity in flexion–extension is above 50°/s. It must be noted that none of the parameters describing the angles of movement provides significant results.

When the analysis is conducted using the dichotomised parameters (high and low), only the two force parameters (mean value and time EMG above 15% of the maximum EMG) provide significant odds ratios.

When individual values of occupational constraints are used, only one parameter of movement velocity appears associated with an increased risk. The probability that this association is due to random factors is however 10%.

Table 4
Logistic models for the prediction of the development of WD as a function of the occupational constraint parameters introduced one by one in the model described in Table 3 (odds ratio, 95% confidence interval and statistical significance)

Variable	O.R.	95% C.I.	Significance
Mean values per workplace			
mEMGr	1.38	1.02–1.86	*
pEMG%	1.15	0.99–1.35	#
R_{EMG}	1.92	0.96–3.86	#
R_{tot}	1.47	0.95–2.28	#
mVf	1.29	0.97–1.73	#
pVf%	1.46	1.01–2.11	*
Mean values classified in 'high' and 'low'			
mEMGr	1.67	0.64–2.91	#
pEMG%	1.74	0.99–3.06	#
Individual values			
pVf%	1.63	0.91–2.92	#

$p < 10\%$. * $p < 5\%$.

4. Discussion

The studied population included at the beginning 201 workers (402 wrists). 54 wrists were eliminated on the basis of the history of WD. The prevalence was therefore 13.5%. This is quite low compared to what is reported in literature for specific occupational groups. Ohlsson et al. (1989), for instance, reported prevalence of WD in general equal to 43% in a plastic component assembly plant and 32% in a reference group of administrative workers. However, in a previous study conducted on 1496 workers from several industrial sectors (Brusco and Malchaire, 1993), the prevalence of WD at one of the two wrists was 17.1%. It can therefore be expected that our sample is representative for the general population of active workers, rather than for specifically exposed workers.

The study concerns 184 subjects from 14 different jobs. Occupational constraints of the left and right wrists have been shown to be rather different and both wrists were considered independently. Among the 316 wrists, 73 developed WD after one or two years. The number of workers per job is too small to present results in terms of incidence per working condition. However, globally, the incidence is about 12% per year. This cannot be compared with other studies, which report exclusively on prevalence rates.

The occupational constraints were defined in terms of mean values of the relative angles and forces (through the EMG) as well as in terms of percentage of the time during which limit values were exceeded. According to Byström (1991); Dahalan and Fernandez (1993); Mathiassen and Winkel (1991); Kilböm (1994), 15% of maximum voluntary contraction (MVC) is the mean acceptable contraction intensity during work over an extended period of time. The same figure was used in the present study, and not restricted to static exercises.

Few methods are available to evaluate the force required for a job. In some instances, it is possible to measure the loads moved by the worker and the duration of these handlings. This however gives only an idea of the external stress and not of the internal constraint for the muscles. Besides, this approach would not have been possible in many of the jobs investigated, as, typically, for the car seat assembly job the workers had mainly to push and pull to stretch the material over the frame.

Physiologists, in controlled environments, might envisage to implant needles in the relevant fibres of the relevant muscle and calibrate statically and dynamically the EMG signal. This is of course unworkable in practice in the field and furthermore would probably not provide the most interesting information, as we will discuss later.

One has therefore to rely on the recording of the EMG signal from surface electrodes located as accurately as possible on the appropriate muscles.

The limitations of this technique are numerous: the signal might vary according to the position of the electrodes for a fixed position of the arms and additionally with the sliding of the skin on the muscles as the forearm rotates. As described before, we fixed the electrodes exactly at the third of the distance on the oblique line between the medial epicondyle and the radial styloid, as recommended by Moore et al. (1991). In this position, the electrodes are located above the flexor carpi radialis under which are located the finger flexors. Therefore the EMG signal will be influenced more by the wrist efforts than by the finger exertions.

Even with the wrist externally held in a given posture (flexion or extension), it was shown (Duque et al., 1995) that the relation between the RMS EMG value and the finger static forces vary greatly with this posture and is not linear. Static calibration of this relationship should therefore ideally be performed, as mentioned but not described by Armstrong et al. (1982); Silverstein et al. (1987) for several postures of the wrist. This is extremely difficult to perform and does not appear to solve the problem as all postures of the wrist are encountered, that wrist exertions are in some cases predominant and efforts are essentially performed dynamically instead of statically.

We choose to 'calibrate' the EMG signals recorded on the subjects during their work by comparison with the maximum RMS EMG value recorded during a maximum voluntary isometric contraction of the fingers with the forearm in neutral position.

This 'calibration' is clearly unvalid for the interpretation of the RMS EMG values in terms of wrist or hand forces, and due to the prominent role played by the flexor carpi radialis, in some cases, as again in the seat assembly job, relative RMS EMG values greater than 100% were observed which is theoretically meaningless and unacceptable. Such a calibration however was necessary, i.e. to eliminate the effects of the electrodes and the conductance of the skin.

This method therefore appears to be the only one applicable in the field and in the context of studies like the one reported here. Clearly, it does not provide an accurate estimation of the forces exerted by the wrist and the hand. It must therefore be considered as a parameter of exertion by itself, reflecting perhaps more than simply the forces, the total constraint of the wrist and therefore the risk encountered.

Several authors have shown that stressful postures are a major cause of disease and some attempted to determine categories of angular postures. Armstrong (1986) defined simply five zones of movement in flexion–extension: more than 45° in extension, 15°–45° in extension, 15° extension–15° flexion, 15°–45° in flexion and more than 45° in flexion. Punnett and Keyserling (1987) qualified these zones in terms of severity as mild (15° to 45°) or severe (more than 45° both in extension or flexion). Stetson et al. (1991) went one step further in concluding that wrist movements become a risk factor for wrist extension angles greater than 45° and wrist flexion angles greater than 30°. We decided to follow the considerations by Punnett and Keyserling (1987) and adopted 45° as the borderline angles for extreme postures in flexion as well as in extension.

These absolute limits were converted in relative values of 60% in average, the average maximum angles reported by Hoppenfeld and Hutton (1984) being 80° and 70° respectively in flexion and extension. On the basis of the present knowledge, it appeared unjustified to make a distinction between the two directions.

Concerning the deviation plane, Armstrong (1986) divided the 57° of average range of wrist motion into three zones defined as ulnar deviation, neutral and radial deviation. Border values were proposed by Punnett and Keyserling (1987) as angles of 15° in ulnar deviation and 5° in radial deviation. These were not justified in terms of risk factors. Without any definite bases for estimation, Stetson et al. (1991) assumed that the risk increased when the angle in deviation exceeded 50% of the maximum value. Although their reasoning appeared to be restricted to ulnar deviation, the same hypothesis was formulated for both ulnar and radial deviations.

Repetitiveness was defined in terms of angles, of force and angles or force combined, by the number of transitions from a condition below the borderline values described above to a situation above these values. This definition was preferred to the one adopted by Loslever et al. (1992); Ranaivosoa et al. (1992), that is, the number of peaks of force per minute, and to the method developed by Aptel (1993) who recorded the number of variations in the direction of the movement. The three methods are defendable and should be compared concerning their discriminating power in order to reach a consensus on the definition.

Concerning the movement velocities, Marras and Schoenmarklin (1991) reported that the velocities in deviations and in flexion–extension were in average 77.3°/s and 121.2°/s respectively at workplaces with low incidence of WD and 115.7°/s and 174.2°/s respectively at workplaces with high incidence of WD. We adopted initially the mean values of their two groups as cut points, 90°/s and 150°/s respectively. However, these figures appeared to be of a greater order of magnitude than we observed and borderline values were arbitrarily set at one-third of these cut point values. Our values were about identical, in average, to those reported by Ranaivosoa et al. (1992) in a study conducted on several workplaces in industry.

The regression analyses between all the occupational factors indicate that the angular parameters are slightly correlated with the others, suggesting that they bring a specific information about the working conditions, complementary to the other factors. On the contrary, repetitiveness and movement velocities are highly correlated, indicating that a greater repetitiveness, that is, a greater number of motions per minute, is usually obtained with an increase in movement velocity.

Globally, the results in Table 4, which will be discussed later, show that the two approaches used to characterise the occupational constraint, based on the mean values and based on the percentages of the time during which extreme values are exceeded, provide approximately the same relationships with the development of WD.

The non occupational factors significantly associated with the development of WD are: gender, chronical diseases, practice of sport involving the upper limbs, work judged as tiring, psychological factors, sport in general and previous accidents. Most of these associations were observed in previous epidemiological studies concerning the general population (Hagberg et al., 1992; Kroemer, 1989; Turner and Buckle, 1987; Pujol, 1993).

In studies on the industrial environment, however, these factors have very rarely been taken into account (Silverstein et al., 1987; Cannon et al., 1981). Discrepancies between gender can still be due to differences in the working conditions between men and women as, in our study, the two effects are not distinguishable. In the literature review done by Hagberg et al. (1992), results vary between different studies. These authors mention that a gender effect is no longer observed when working conditions are taken into account. This is in agreement with the observation by Silverstein et al. (1987); Nathan et al. (1992) who did not observe any gender effect. This is also our conclusion since the parameter gender was no longer significant in all the logistical analyses reported hereunder, once the occupational factors were included, while the odds ratios for the other parameters reported in Table 3 remained significant.

The relationship between the occupational constraint parameters and the development of WD was studied by adding one by one, after removal of the gender, each parameter in the multivariate logistic model is given in Table 3.

Another statistical approach followed was the introduction, at the same time, of all the occupational factors and their interactions in the logistic model. This was done using the parameters based on the mean values on the one hand and the percentages of the time borderline values are exceeded on the other hand. For both sets of parameters, the analyses led to a unusable model including 14 main and interaction effects. These were impossible to interpret and the analysis was abandoned.

A similar attempt was made using only the main effects of angles, force, repetitiveness and velocities, for the two sets of parameters. The two final models included the two identical parameters, namely, mEMGr (OR = 1.86) and mVd (OR = 0.48) or pEMG% (OR = 1.34) and pVd% (OR = 0.56). As shown in Table 2, these parameters are correlated and therefore the odds ratios remain difficult to interpret.

Three different approaches were followed to study the relationship between occupational constraints and the development of WD.

The first one classified the working conditions for each parameter in 'high' and 'low' as done by Silverstein et al. (1986); Silverstein et al. (1987). According to these authors, the repetitiveness and force parameters would be the most significant. However, the relative importance of these two factors appeared to depend on the nature of the WD considered: repetitiveness was a greater risk factor for the carpal tunnel syndrome, while, for all WD globally, the association with force was stronger. Our results confirm this latter tendency, although the criteria for the classification of the parameters in 'high' and 'low' were quite different in the two studies.

The approach used by Marras and Schoenmarklin (1991); Marras and Schoenmarklin (1993); Ranaivosoa et al. (1992); Loslever et al. (1992) was to define the occupational constraint by the means of the parameters recorded on a few workers. When using this approach, the present study shows that the parameters of force, repetitiveness and movement velocity are associated with the development of WD. The same conclusion was reached by Silverstein et al. (1987); Thouvenin et al. (1990); Armstrong (1987). This last author reported that repetitive and forceful work was leading to prevalence of tenosynovitis 29 times more frequently than non stressful work.

According to Marras and Schoenmarklin (1991); Marras and Schoenmarklin (1993) as well as Ranaivosoa et al. (1992), the movement velocity would be the most pertinent parameter for the prediction of the WD risk. The parameters characterizing the EMG activity on the forearm flexors and the velocity of movement in the flexion–extension plane appear also in our study the most significant factors when taken independently. However, these two sets of parameters are highly correlated and do not add up when taken together in a multiple logistic correlation.

Finally, our results are in agreement with those of the researchers mentioned above in finding no association between the development of WD and the angular parameters of the wrists.

It is logical to think that the individual risk would be best correlated with the exposure constraint experienced by each individual. The logistic regression analysis shows however that this is not the case. The likely explanation is that the data collected at a given workplace on a given individual and at a given time, are not representative of the mean exposure of that individual, even if the duration of observation, ranging from 30 to 90 min, lasted at least 3 cycles. At each job, the type of work could vary from day to day, depending upon the seats or windows that were assembled or handled, the product that was conditioned, the pastry that were prepared, the number of documents to encode, etc. Many papers have recently underlined the large interindividual differences in the exposure to any factor (Rappaport et al., 1993). They have also emphasized the large intraindividual differences in the working procedures and in the exposure from morning to afternoon, from day to day, etc. (Burdorf, 1992). It is reasonable therefore to conclude that an individual measurement is not representative of the whole exposure of the subject and the mean of the different observations made at random at each workplace, on several workers is probably more representative of the mean exposure.

5. Conclusion

This study concerns the association between the risk factors recorded at the job and the development of wrist disorders, taking into account an ensemble of potential confounding factors. A multiple logistic regression model made possible to identify the occupational risk factors on which to act in order to reduce the risk of musculoskeletal disorders at the wrist; the factors identified are, in order of priority, the forces exerted by the wrist and the hand, the velocity of movement in flexion–extension and the repetitiveness.

The most significant parameter is clearly the force exerted by the wrist and the hand and the objective is to reduce the muscular activity below 15% of the maximum activity corresponding to the maximum voluntary contraction of the finger flexors. We arrived at a comparable result in the cross-sectional study reported earlier (Malchaire et al., 1996); the predicted prevalence of WD increased by 18.7% for an increase of the mean relative EMG amplitude by 10%. In this previous study, we reported an additional effect of the mean angle in deviation: greater mean angles were associated with greater prevalence. This is contradictory to the results of the present prospective study since, in the multivariate logistic model reported above, the velocity — and not the angle — in the deviation plane was significant. This needs clarification but it is, in any case, very likely the angle is not the main factor. This lack of relationship between the WD incidence and the wrist angles does not mean however that specific disorders, such as the de Quervain tenosynovitis, could not be related to extreme angles. Therefore, attempts should continue to be made to reduce the wrist angles in the two planes by a better position of the grip point or more adapted shapes of the tools.

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