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Interindividual variation of physical load in a work task

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Objectives This study analyzed the variation in physical work load among subjects performing an identical work task.

Methods Electromyographs from the trapezius and infraspinatus muscles and wrist movements were recorded bilaterally from 49 women during a highly repetitive industrial work task. An interview and a physical examination were used to define 12 potential explanatory factors, namely, age, anthropometric measures, muscle strength, work stress, and musculoskeletal disorders.

Results For the electromyographs, the means of the 10th percentiles were 2.2% and 2.8% of the maximal voluntary electrical activity (%MVE) for the trapezius and infraspinatus muscles, respectively. However, the interindividual variations were very large [coefficients of variation (CV) 0.75 and 0.62, respectively]. Most of the variance could not be explained; only height, strength, and coactivation of the 2 muscles contributed significantly (R^2_{adj} 0.20—0.52). The variation was still large, though smaller (CV ≤0.63), for values normalized to relative voluntary electrical activity (RVE). For the wrist movements, the median velocity was 29 degrees per second, and the interindividual variations were small (CV ≤0.24). Six factors contributed to the explained variance (R^2_{adj} 0.12—0.55).

Conclusions The interindividual variation is small for wrist movements when the same work tasks are performed. In contrast, the electromyographic variation is large, even though less after RVE normalization, which reduces the influence of strength, than when MVE is used. Because of these variations, several electromyographs are needed to characterize the exposure of a specific work task in terms of muscular load, and individual electromyographs are preferable when the worker's risk of myalgia is being studied.

Key terms electromyography, electromyographic normalization, goniometer, infraspinatus muscle, repetitive, trapezius muscle, wrist, wrist movements.

Detailed information on physical workplace exposure is important for untangling problems involving work-related musculoskeletal disorders. Many studies lack this type of information (1). The relationships between these disorders and work conditions are not yet fully understood. One model explaining musculoskeletal disorders infers that an external exposure causes an internal load that is then modified by individual factors, and may lead to disorders (2). In some occupational settings, the risk of such disorders is pronounced, particularly among women (3—5). However, some persons remain healthy even after long-term exposure. Reasons for this discrepancy may either be differences in susceptibility or differences in individual exposure.

Before valid information can be obtained on individual exposure, the external load has to be quantitatively measured. For this purpose positions and movements of the joints (4, 6, 7) can be determined, or muscular activity can be measured by electromyography (EMG) (8—11). Quantitative data are necessary for estimating dose-response relationships, which in turn enable effective prevention (1).

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In studies of cumulative trauma disorders of the hands and wrists, wrist angles and positions have proved to be associated with the disorders (12, 13). Such associations were also found for the activity of the forearm muscles (13).

As to neck and shoulder disorders, EMG of the trapezius muscle has shown significant associations with work-related disorders (14). In a prospective field study of repetitive industrial work, the muscle activity pattern had predictive value (15). Some studies show no unambiguous associations between EMG data and disorders (16, 17).

Many studies of muscular activity display the problem with very large interindividual variation of the activity levels (14, 16, 18). This variation may be important for understanding the pathogenesis of work-related musculoskeletal disease and can possibly explain the discrepancy in results. However, explanatory factors and the true size of the variation are not fully known.

In assessments of muscular load, the reference used for normalizing the EMG signal is crucial, both for the values and their variation. However, this important aspect has only been studied to a limited extent (19).

Knowledge of variation is essential for estimates of statistical power in the design of epidemiologic studies and, thus, for the optimization of exposure measurements. There is a need for data on this subject.

The objectives of our study were to analyze the interindividual variation in physical work load in an identical work task and also to determine the impact of work performance and individual factors. Furthermore, maximal versus submaximal test contractions for normalizing muscle activity were evaluated.

Subjects and methods

Study group

This study was performed in a laminate industry. It is a substudy of an epidemiologic research program concerning exposure to repetitive work tasks and related health effects on the musculoskeletal system (Hansson et al, to be published). This subgroup comprised 49 women who assembled sheets of paper as the base for the laminate. They were all well experienced in performing the work task. Their median age was 35 (range 19—63) years, height 165 (range 148—175) cm, weight 63 (range 44—90) kg, strength 134 (range 52—226) N, and employment duration 5 (range 1—36) years. Sixteen women scored current problems in the neck and shoulder region on a visual analogue scale (VAS) and 5 scored for elbows or hand complaints. In a physical examination, 15 were diagnosed as having neck or shoulder disorders and 2 were given elbow or hand diagnoses. In an interview their median score for muscle tension was 2.0 (range 0—6), and their median work stress during work was 1.8 (1—4). During maximal voluntary contraction (MVC) their median force was 134 (52—226) N.

Interview

In a structured interview (4) all the women answered questions concerning physical and psychosocial factors or the work environment, type of work tasks, and individual factors such as age, muscle tension (sum of 11 questions with a score of 0, 0.5 or 1), and work stress (mean of 5 questions with a score of 1, 2, 3 or 4).

Standardized work task

A workstation for standardized assembly was designed for a work task. Two women worked together, one on each side of a large adjustable "table". Each woman was experienced in performing the task, which entailed work with elevated arms and both hands. One upper limb (the "take" side) was the most active in that it pulled the sheets over to the table. Only the sheets were pulled, a rapid external rotation of the shoulder (upper arm abducted 70 degrees and forward flexed 30 degrees and lower arm flexed 60 degrees) was needed. The other hand, the "nontake" side, positioned the bundle of sheets, especially when the sheets are to the right. The women were then told to work as they normally did.

The size of the sheets was the same during all the measurements. The work area was fixed and was the same for each person. Before the standardized work task was studied, the work heights were adjusted for each person according to predetermined measures. Since the work pace could not be decided beforehand, the amount of material produced varied. When finished, the quantity of material produced was recorded so that the importance of the work pace could be determined. The data collection period was a minimum of 20 minutes, and the first 20 minutes were used for the analyses.

Electromyography

Because of the arm movements and the localization of the complaints and also the fact that EMG measurements on the trapezius muscle are common in assessments of work load on the shoulder, we chose the trapezius and infraspinatus muscles for our measurements. Bipolar measurements were made from the descending part of the trapezius and the infraspinatus muscles on both the right and left sides. The electrodes were placed in the direction of the muscle. For the trapezius muscle the center of the electrode pair was placed 2 cm laterally of the midpoint of the line drawn from the 7th cervical vertebra to the acromion. For the infraspinatus muscle the electrodes were placed over the muscle belly, which was palpated during an attempted outward rotation in the humeroscapular joint with the upper arm vertical and the forearm horizontal in the sagittal plane as manual resistance was applied to the wrist. The subjects performed sitting push-ups from a chair to ensure that cross-talk from, for example, the trapezius ascendens was not present. A telemetric system, an analogue tape recorder, an analogue-digital converter, and an IBM compatible personal computer were used for the recording and analysis; for details on the electrodes, equipment and signal processing, see the article by Åkesson et al (20).

The EMG signal was converted to the root-mean-square (RMS), and the noise level, recorded during muscular rest with biofeedback, was subtracted before further calculations were made. The EMG for each muscle was normalized to the maximal voluntary EMG (MVE) activity obtained during MVC.

For the trapezius muscle, the MVC was performed with the subject in a standing position, with the arm abducted 90 degrees in the scapular plane and with a strap around the upper arm, proximal to the elbow during an intended abduction (21). The strap was connected to a strain gauge force transducer measuring the exerted force. The tests were performed for one side at a time. The subjects were encouraged to exert 3 maximal voluntary contractions as attempted vertical pull, each lasting 3—5 seconds, and the exerted force shown on a digital display unit was used as the biofeedback for further encouragement. The MVE for the trapezius muscle was calculated as the highest activity recorded during the 3 MVC measurements. The average of the highest force recorded for the right and left sides during the 3 MVC measurements was defined as strength.

In addition to the MVC measurements, submaximal reference voluntary contractions were recorded. They were performed with the subject standing, with one arm at a time abducted in the scapular plane to 90 degrees for 10 seconds, with a 1-kg dumbbell in her hand, and with the back of the hand facing upwards. The relative voluntary electrical (RVE) activity for the trapezius muscle was calculated as the median activity during the test.

For the infraspinatus muscle, the MVC was performed in the same position as described for the palpation of the muscle. These test contractions were made by all the women in a standing position, and by 16 women in a sitting position as well. The MVE was calculated from the activity recorded during either the trapezius tests or the test for the infraspinatus muscle, whichever was highest.

The activity of the infraspinatus muscle during the specific MVC test for the trapezius muscle was defined as the coactivation of the infraspinatus muscle.

For each subject, the 10th, 50th, and 90th percentiles of the APDF (amplitude probability distribution function) were calculated for the 20-minute recording (22). These individual values were used for calculating the group mean values.

Wrist positions and movements

The wrist angles of both hands were measured for all the women during the standardized work task. Biaxial electrogoniometers (M110) and data loggers (DL1001; Penny & Giles Biometrics, Blackwood, Gwent, United Kingdom) were used to record flexion and extension, and also the deviation angles of both the right and left wrists (4, 7). The reference position (0 degree of flexion and deviation) was defined as the wrist angles obtained when the subject was standing with arms and hands hanging relaxed beside the body. Positive angles denoted flexion in the palmar direction, deviation in the ulnar. A wrist mobility test was also performed (7). The first 20 minutes of the recordings were analyzed for both the positions and movements (7). The 10th, 50th, and 90th percentiles of the angular distributions, as well as the width of the distribution (95th-5th percentiles), were used to describe the positions. Angular velocities and power spectra were calculated and used to characterize movements.

Neck and upper-limb disorders

A standardized physical examination was made of the neck, shoulders, elbows, and hands. Symptoms and signs were recorded by an examiner. The examiner decided on diagnoses according to a standard set of criteria for symptoms and signs (23). Each subject could be given more than one diagnosis.

In connection with the physical examination, the women were asked about subjective symptoms of the neck and upper limbs (24). The questions concerned the last 12 months and last 7 days. The women were also asked about any inability to work during the last 12 months.

In the beginning of the measurement period, the women were shown a pain drawing and asked to note their current symptoms. They also noted the intensity of the symptoms on a VAS scale (100 mm from no pain at all to maximal pain) (25), one for each anatomic region.

Statistics

The variables (ie, muscular activity and wrist positions and movements) were dichotomized according to the median value of each factor characterizing the workers and their work performance. Student's t-test was used for the univariate comparisons. Furthermore, simple and multiple linear regression analyses were performed for model construction. The data were fairly consistent with the assumptions that underlie the linear regression method (26). A stepwise selection procedure, with $P<0.05$ as the inclusion criterion and $P>0.10$ as the exclusion criterion, was adopted in the multiple regression analyses.

Results

Electromyographic activity

As for the MVE-normalized values for the trapezius muscle, the mean value for the 10th percentile was 2.2% for all the women (table 1). However, the interindividual variation was very large [coefficient of variation (CV) 0.75]. There were no statistically significant differences for any activity level between the "take" and "nontake" sides.

For the RVE-normalized values, the figures were higher, the 10th percentile being 11% (table 1). The CV values were smaller than for the MVE. A statistically significant difference between the "take" and "nontake" sides was seen in only one case, the 90th percentile.

There was a large interindividual variation (range 20—100%) in the coactivation of the infraspinatus muscle (figure 1). The correlation between the right and left sides was weak (Spearman rank correlation coefficient 0.46) (figure 2). Regarding the normalization of the registrations from the infraspinatus muscle, 80 of 97 muscles showed maximal activity during the specific infraspinatus provocation, as compared with 17 during the MVC test for the trapezius muscle. In the present material the mean MVE values for all infraspinatus muscles would have increased to 3.1%, 8.0% and 20% for the 10th, 50th and 90th percentiles, respectively (table 1) if the normalization had been based only on infraspinatus provocation. The RVE:MVE ratio was 20.2 (SD 7.5)% for the right side and 20.5 (SD 7.4)% for the left side.

When the sitting and standing positions during the specific MVC test were compared for the contraction of the infraspinatus muscle, 20 of 32 muscles displayed the highest activity during sitting.

Table 1. Activity of the trapezius and infraspinatus muscles as the percentage of the electromyography during maximal voluntary contraction (%MVE) and for the trapezius muscle as the percentage of the relative voluntary contraction (%RVE) for 49 women during one specific work task for the 10th, 50th and 90th percentiles of the amplitude distribution. (CV = coefficient of variation)

Shoulder	Measurements (N)	Muscle activity																	
		Trapezius muscle												Infraspinatus muscle					
		%MVE						%RVE						%MVE					
		10th		50th		90th		10th		50th		90th		10th		50th		90th	
		Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
"Take"	49	2.1	0.58	6.9	0.51	19	0.46	11	0.60	36	0.50	103*	0.46	3.0	0.55	8.0**		22***	0.46
"Nontake"	48	2.3	0.87	7.7	0.75	18	0.64	11	0.67	37	0.59	88*	0.51	2.6	0.71	6.5**	0.56	15***	0.48
Both combined	96	2.2	0.75	7.3	0.66	19	0.54	11	0.63	37	0.55	95	0.49	2.8	0.62	7.3	0.51	19	0.51

* P<0.05, ** P<0.01, *** P<0.001, comparison between "take" and "nontake" sides, paired t-test.

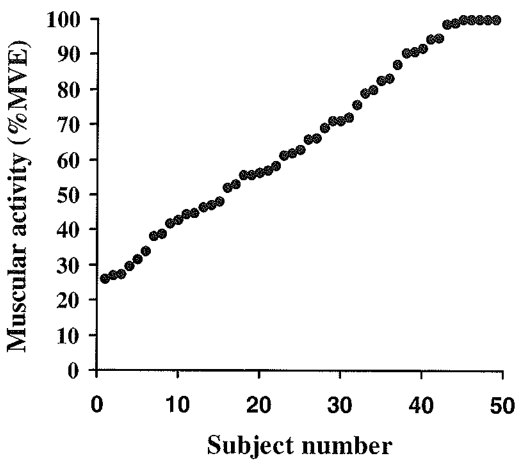

Figure 1. Coactivation of the infraspinatus muscle (% MVE) for 49 subjects during maximal voluntary contraction of the trapezius muscle. The right side is shown, and the subjects have been ranked according to their coactivation level.

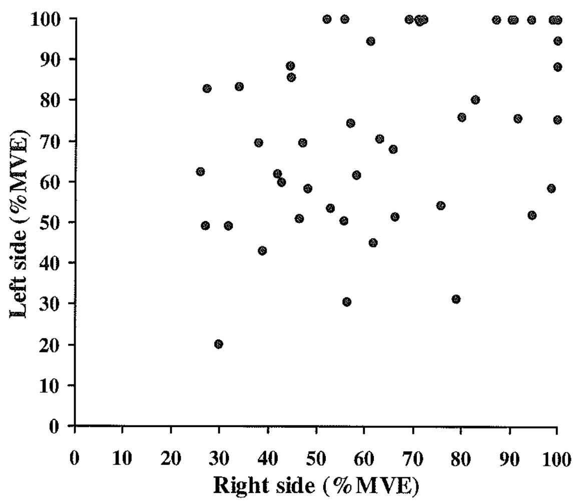

Figure 2. Relation between coactivation for the right and left side of the infraspinatus muscle for 48 subjects. Spearman correlation coefficient = 0.46. Maximum activity (100% MVE) occurred for the infraspinatus muscle for 17 muscles during trapezius provocation.

The CV values for the infraspinatus muscle were smaller than for the trapezius muscle, but they were still relatively high. The activity levels were similar to those of the trapezius muscle; the 10th percentile was 2.8% of the MVE (table 1). There were statistically significant differences between the "take" and "nontake" sides for the 50th and 90th percentiles.

There was a correlation between the "take" and "nontake" sides for both muscles and for all activity levels [correlation coefficient (r) 0.41—0.61]. Moreover, separate uni- and multivariate analyses for the "take" and "nontake" sides revealed no consistent differences. Hence, in the following, the mean of both sides was used in the analyses for the trapezius muscle.

Regarding the trapezius muscle, the only individual factor which had a statistically significant association with muscular activity in the univariate analyses was strength (table 2). Strongness was associated with low muscle activity. This relation was only shown when MVE normalization was used.

For the infraspinatus muscle, the individual factors "high" age, shortness, low strength, "high" coactivation, and immigrantship showed statistically significant associations with high muscle activity in the univariate analyses (table 3).

The median production was 402 (range 252—522) bundles/hour. We found no significant impact of production on muscle activity (tables 2 and 3). Nor did we find any statistically significant differences between "positioning" and "nonpositioning" for either of the 2 muscles.

Since some of the factors in tables 2 and 3 were intercorrelated, they were introduced in a multivariate model. Then, for the trapezius muscle and the MVE-normalized data, low strength was associated with high activity, but the explained variances were lower than 0.20 (not in table). For the RVE-normalized results, no factor gave any significant explanation.

For the infraspinatus muscle, high activities were associated with shortness, with low strength, and with high coactivation (table 4). The explained variances were 0.20—0.52; thus the remaining unexplained variances were still high.

Wrist positions and movements

The 2-dimensional wrist-angle distributions were wider along the flexion axis than along the deviation one. The mean quotient (the value of the group mean flexion divided by the group mean value of deviation) between the width (95th-5th percentile) of the flexion and deviation distributions was 1.63 (not shown in table). Moreover, the flexion movements dominated over the deviation ones; the quotient between the median flexion and deviation velocities was 1.64. Since cross-talk in the flexion angle measurement is proportional to the deviation angle (and vice versa) (6), the error was, in this study, smallest in the flexion recordings. Thus the flexion data are presented.

The 50th percentile (median) position of the wrist was 21 degrees dorsiflexed (table 5). For 10% of the time, the dorsiflexion was pronounced, exceeding 42 degrees (10th percentile). There was no marked palmar flexion; for 10% of the time, it exceeded only 1 degree (90th percentile). Regarding flexion movements, the work was highly repetitive (MPF 0.54 Hz), with high angular velocities (median 29 degrees/s; 90th percentile (peak velocity) 140 degrees/s); the hand was held still (velocity <1 degree/s) for only 1% of the time. The average

Table 2. Muscular activity of the trapezius muscle as the percentage of the electromyography (EMG) during maximal voluntary contraction (%MVE) and as the percentage of the EMG during relative voluntary contraction (%RVE) for 49 women during one specific work task for the 10th, 50th, and 90th percentiles of the amplitude distribution dichotomized by the median values for different factors. (AU = arbitrary unit)

Factor[a]	Cut-point low-high or no-yes	Mean muscle activity											
		%MVE						%RVE					
		Low or no			High or yes			Low or no			High or yes		
		10th	50th	90th	10th	50th	90th	10th	50th	90th	10th	50th	90th
Age	35 years	1.9	6.4	17	2.5	8.2	20	10	36	94	12	38	97
Height	165 cm	2.3	8.2	21	2.1	6.3	16	11	40	103	11	34	87
Weight	63 kg	2.1	7.1	19	2.4	7.5	18	11	39	104	11	35	87
Strength	134 N	2.6*	8.5*	21*	1.8*	6.0*	16*	12	40	102	10	34	90
Muscle tension	2.0 AU	2.2	7.1	17	2.3	7.7	20	12	37	93	11	37	99
Work stress	1.8 AU	2.5	8.1	19	2.0	6.7	18	12	38	92	10	36	100
Complaints	no-yes	2.3	7.5	18	2.1	7.1	19	12	39	98	10	33	91
Diagnoses	no-yes	2.3	7.8	19	2.0	6.1	17	12	40	100	9	30	86
Production	402/hour	2.2	7.0	18	2.2	7.7	19	11	36	94	11	38	98
Positioning[a]	no-yes	1.9	7.4	17	2.9	8.2	18	10	37	96	12	38	96

[a] Relevant for the "nontake" side only.
* $P < 0.05$, comparison between low-no and high-yes at the 10th, 50th or 90th percentile, t-test.

Table 3. Muscular activity of the infraspinatus muscle of the "take" and "nontake" sides as the percentage of the electromyography during maximal voluntary contraction (%MVE) for 49 women during one specific work task for the 10th, 50th, and 90th percentiles of the amplitude distribution dichotomized by the median values for different factors. (AU = arbitrary unit)

Factor[a]	Mean muscle activity (% MVE)					
	Low or no			High or yes		
	10th	50th	90th	10th	50th	90th
Age (35 years)						
Take	2.3**	6.5**	18*	3.6**	9.4**	25*
Nontake	2.0*	5.3*	13	3.1*	7.6*	17
Height (165 cm)						
Take	3.5*	9.1*	25*	2.4*	7.0*	18*
Nontake	3.1	7.6*	17*	2.0	5.2*	12*
Weight (63 kg)						
Take	3.0	8.1	23	3.0	7.8	21
Nontake	2.5	6.5	16	2.7	6.5	14
Strength (134 N)						
Take	3.6**	9.4**	25**	2.3**	6.6**	18**
Nontake	3.1*	7.7*	17*	2.0*	5.2*	13*
Coactivation (69 %)						
Take	2.2**	6.3**	18**	3.6**	9.4**	25**
Nontake	2.3	5.8	14	3.0	7.3	16
Muscle tension (2.0 AU)						
Take	3.0	7.8	22	3.0	8.1	22
Nontake	2.4	6.1	14	2.8	7.0	16
Work stress (1.8 AU)						
Take	2.8	7.5	21	3.2	8.5	23
Nontake	2.5	6.1	14	2.8	7.0	16
Complaints (no-yes)						
Take	3.1	8.1	22	2.8	7.7	21
Nontake	2.6	6.5	15	2.5	6.5	16
Diagnoses (no-yes)						
Take	3.0	8.3	23	2.8	7.3	20
Nontake	2.6	6.6	15	2.6	6.4	15
Production (402/hour)						
Take	3.1	8.4	21	2.8	7.6	22
Nontake	2.7	6.7	15	2.5	6.4	16
Positioning[b] (no-yes)						
Nontake	2.2	5.9	14	3.2	7.5	17

[a] Cut-point for low-high or no-yes in parentheses.
[b] Relevant for the "nontake" side only.
* $P<0.05$, ** $P<0.01$, comparison between low-no and high-yes at the 10th, 50th or 90th percentile, t-test.

Table 4. Regression coefficient, P-value, and explained variance (R^2_{adj}) from the multivariate analysis of muscular activity for the 10th, 50th, and 90th percentiles for the infraspinatus muscle of the "take" and "nontake" sides for the statistically significant ($P<0.05$ for inclusion and $P>0.1$ for exclusion) factors. The muscular activity was normalized to maximal voluntary contraction (%MVE). The factors age, weight, muscle tension, complaints, diagnoses, production and "positioning" (relevant for the "nontake" side only) were not statistically significant.

Factor	Infraspinatus muscle (%MVE)					
	10th		50th		90th	
	Sign	P-value	Sign	P-value	Sign	P-value
Height						
Take			-0.23	0.09		
Nontake	-0.47	0.001	-0.52	<0.001	-0.57	<0.001
Strength						
Take	-0.55	<0.001	-0.43	0.002	-0.55	<0.001
Nontake						
Coactivation						
Take	+0.57	<0.001	+0.48	<0.001	+0.51	<0.001
Nontake						
Work stress						
Take	+0.22	0.042				
Nontake						
Explained variance (R^2_{adj})						
Take	0.52	0.50	0.43			
Nontake	0.20	0.25	0.30			

flexion wrist mobility for the women was 145 degrees (SD 15°).

The CV values were low (<0.22) for both the positions and the movements, except for velocity <1 degree/second (CV 0.89) (table 5). The latter variable also had a skewed distribution, with occasional high values.

There were statistically significant differences, both regarding positions and movements, for the "nontake" side as opposed to the "take" one (less dorsiflexion, but higher in both repetitiveness and — in particular — peak velocities) (table 5). Thus, in the presentation, these sides were separated.

As to the potential explanatory factors, the univariate analysis showed no significant association with the wrist positions (not in table). However, concerning movements, high productivity, for both the "take" and "nontake" sides, was associated with higher repetitiveness and wrist velocity, and the hands were held still for a lower fraction of the time (table 6). Between "positioning" and "nonpositioning" there were significant differences, with a wider angular distribution (95th-5th percentile) (not in table), but lower repetitiveness, for "positioning". The younger women had higher wrist velocities than the older ones. Those with elbow or hand diagnoses had lower repetitiveness, held their hands still for a longer time, and showed a tendency towards lower velocity.

In the multivariate approach, high production showed, as expected, a consistent association with both high velocity and high repetitiveness (table 7). Furthermore, high wrist mobility was associated with high velocities, but with low repetitiveness. In addition, the subjects with diagnosed elbow or hand disorders held their hands still a higher fraction of the time, and they displayed lower repetitiveness.

The explained variances were generally rather low (table 7). However, they were considerably higher for movements (0.12—0.55) than for positions (0.00—0.33).

Table 5. Wrist positions and movements of the "take" and "nontake" sides for flexion during one specific work task of 49 women. Positive values denote flexion in the palmar direction. (CV = coefficient of variation, SD = standard deviation)

Wrist	Measurements (N)	Positions (percentile; degree)								Movements (velocities)						Repetitiveness (MPF, Hz)	
		Distribution								<1 degree/s		Distribution (percentile; degree/s)				Mean	CV or SD
		10th		50th		90th		95th-5th		Mean	CV or SD	50th		90th			
		Mean	CV or SD	Mean	CV or SD	Mean	CV or SD	Mean	CV or SD			Mean	CV or SD	Mean	CV or SD		
Take	49	-45**	8	-24***	9	- 2***	10	54	0.13	0.9***	0.91	29	0.18	124***	0.17	0.50***	0.18
Nontake	46	-40**	11	-17***	8	5***	8	57	0.18	1.3***	0.83	29	0.24	158***	0.18	0.58***	0.24
Both combined	95	-42	10	-21	9	1	10	55	0.15	1.0	0.89	29	0.21	140	0.21	0.54	0.22

* P<0.05, ** P<0.01, *** P<0.001, comparison between "take" and "nontake" sides, paired t-test.

Table 6. Wrist movements of the "take" and "nontake" sides for flexion during one specific work task of 49 women — mean values for different factors, dichotomized by the median values for each factor. (AU = arbitrary unit)

Factor[a]	Velocity (degree/s)						Repetitiveness (MPF; Hz)	
	Low or no			High or yes			Low or no	High or yes
	<1 degree/s (% of time)	Distribution (percentile)		<1 degree/s (% of time)	Distribution (percentile)			
		50th	90th		50th	90th		
Age (35 years)								
Take	0.9	31*	128	0.8	27*	120	0.50	0.50
Nontake	1.2	30	161	1.4	27	155	0.58	0.59
Height (165 cm)								
Take	0.8	29	125	0.9	28	122	0.50	0.50
Nontake	1.5	28	156	1.0	30	160	0.60	0.56
Weight (63 kg)								
Take	0.8	30	125	0.9	28	123	0.51	0.49
Nontake	1.3	28	160	1.3	29	155	0.59	0.58
Strength (134 N)								
Take	1.0	29	126	0.7	29	121	0.51	0.49
Nontake	1.7**	26**	151	0.8**	31**	163	0.57	0.60
Wrist mobility (145 degrees)								
Take	1.1	27	120	0.7	30	127	0.51	0.49
Nontake	1.4	28	161	1.2	29	154	0.64**	0.52**
Muscle tension (2.0 AU)								
Take	0.8	28	121	0.8	30	128	0.51	0.50
Nontake	1.4	28	154	1.0	29	161	0.59	0.57
Work stress (1.8 AU)								
Take	09	28	122	07	30	127	0.49	0.52
Nontake	1.4	30	161	1.1	27	153	0.57	0.59
Complaints[b] (No-yes)								
Take	0.8	29	123	0.9	30	127	0.50	0.47
Nontake	1.3	29	160	1.3	25	141	0.59	0.53
Diagnoses[b] (No-yes)								
Take	0.8*	29	124	2.1*	25	113	0.51*	0.38*
Nontake	1.2	29	159	2.7	20	132	0.59	0.45
Production (402/hour)								
Take	1.2***	26***	115**	0.5***	32***	132**	0.47**	0.53**
Nontake	1.5	26***	148*	1.0	31**	167*	0.54*	0.63*
Positioning[c] (no-yes)								
Nontake	1.2	29	155	1.3	28	161	0.62*	0.54*

[a] Cut-point low-high or no-yes in parentheses.
[b] For the elbows or hands or both.
[c] Relevant for the "nontake" side only.
* P < 0.05, ** P < 0.01, *** P < 0.001, comparison between low-no and high-yes; t-test.

Table 7. Regression coefficient, P-value, and explained variance from the multivariate analysis of wrist positions and movements for the "take" and "nontake" sides for statistically significant (P<0.05) factors — diagnoses for elbow or hands. The factors age, height, muscle tension, work stress, and complaints were not statistically significant.

Factor	Positions (percentile; degree)								Movements (velocities)						Repetitiveness (MPF; Hz)	
	10th		50th		90th		95th-5th		<1 degree/s (% of time)		Distribution (percentile; degree/s)				Sign	P-value
											50th		90th			
	Sign	P-value	Sign	P-value	Sign	P-value	Sign	P-value	Sign	P-value	Sign	P-value	Sign	P-value		
Weight																
Take	-0.30	0.04	-0.29	0.04	-0.29	0.04	.	.	.	.	.	.	.	.	.	.
Nontake	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Strenght																
Take	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Nontake	.	.	.	.	+0.34	0.02	.	.	-0.45	0.001	+0.26	0.02	.	.	.	.
Wrist mobility																
Take	.	.	.	.	.	.	.	.	.	.	.	.	.	.	-0.29	0.03
Nontake	.	.	.	.	.	.	+0.42	0.002	.	.	+0.29	0.01	.		-0.27	0.04
Diagnoses																
Take	.	.	.	.	.	.	.	.	+0.34	0.01	.	.	.	.	-0.28	0.04
Nontake	.	.	.	.	.	.	.	.	+0.32	0.02	-0.22	0.04	.	.	.	.
Production																
Take	.	.	.	.	.	.	.	.	-0.34	0.01	+0.48	0.001	+0.37	0.01	+0.31	0.02
Nontake	.	.	.	.	.	.	+0.28	0.04	.	.	+0.58	0.001	+0.51	<0.001	+0.44	0.002
Positioning																
Nontake	-0.33	0.03	.	.	.	.	+0.42	0.002	.	.	.	.	.	.	.	.
Explained variance (R^2_{adj})																
Take	0.07	.	0.07	.	0.07	.	0.00	.	0.23	.	0.22	.	0.12	.	0.24	.
Nontake	0.09	.	0.00	.	0.10	.	0.33	.	0.26	.	0.55	.	0.24	.	0.28	.

Discussion

The interindividual variations in the EMG of the shoulder muscles were large among the subjects performing the same work; the wrist movements varied far less. High EMG variations have also been reported in earlier, though smaller and less well-standardized studies (20, 27, 28, 17).

One possible explanation for the large variation is methodological. We paid particular attention to the electrode placement; they were not placed over the end-plate region (29). Thus the risk for cross-talk from signals originating in adjacent muscles was small. Moreover, we performed a detailed quality control of the raw EMG, and, if necessary, artifacts from disturbed telemetric transmission, or electrodes and cables, were excluded from the calculations. Furthermore, the method used for normalizing the EMG affects the activity value. When RVE-normalized values were used, the interindividual differences were smaller than for MVE. This difference is an advantage of the RVE normalization, since the influence of strength is reduced. Furthermore, submaximal isometric contractions are more reliable (30). Hence the methodological explanations only account for a part of the total variation.

Thus most of the variation must be due to other factors. When we tested a series of possible causes, neck-shoulder disorders did not have any significant impact on the variance; this result indicates that muscular load does not change when the disorder appears. In contrast, such an effect has been observed in dentists (20), probably due to their possibilities to adapt their work. As for stress tendency, the lack of consistent associations is also in contrast to the findings of other studies (31). This difference may be due to a low range in our material. Interestingly, we found an association between activities in the trapezius and infraspinatus muscles. Thus general motor-control factors may be of significance. Such factors could be overstabilization of the shoulder (32, 33), contralateral coactivation (34), and decreased ability to relax (35).

For the subjects with diagnosed elbow or hand disorders, the velocities and repetitiveness were high, but still lower than for the persons without such conditions. Thus it seems that subjects with pain try to lower their activity. There were, however, only a few elbow or hand disorders diagnosed.

The total variances in the EMG results and the movements explained by the individual factors were unexpectedly low. Our intention was to study identical work.

However, it turned out that there were some differences. Therefore, production rate was adjusted for in the statistical model. However, it did not explain any significant fraction of the variation in muscular load. On the contrary, wrist movements were, to some extent, impacted by production, because of a low degree of "freedom" in work performance. Other unknown factors must be also of explanatory importance.

Furthermore, the muscular load could not be predicted from the work and individual factors studied. Since musculoskeletal disorders involve various structures and different pathomechanisms may be involved, there is a demand for assessing several dimensions of physical exposure (eg, for the muscles, the pattern of activity and, for the joints, position and movements).

Complaints are mostly described for the neck-shoulder region. Hence the load on the muscles involved in the stabilization of the shoulder as, for example, the trapezius muscle, are of great interest in dose-response relationships, but it seems not to be affected by the complaints.

It is reasonable to assume that the work load of a muscle is a risk factor for work-related myalgia. Thus it is of interest to measure EMG. However, the interindividual variation in EMG poses a problem in epidemiologic studies. Hence an accurate estimate of the average load in a particular work task requires a large number of readings. For example, with the present CV of 0.58, it is necessary to measure 130 subjects to achieve a mean with a relative standard error of 10%. Furthermore, when 2 work tasks are compared, it is possible to detect a true difference of 66% (P=0.05 and a statistical power of 80%) in studies with 25 subjects each.

Even if a correct estimate of the group mean is obtained for the work task, the assignment of this estimate to a subject may cause a major misclassification of the exposure of that person. Thus, ideally, each subject should be measured.

Furthermore, in order to make cost-effect estimates of differences in work load between different work tasks (eg, at intervention), the same person should be measured in the various situations. With a CV of 0.20, which is a reasonable assumption for repeated measurements (36), a group size of 7 is sufficient to detect a difference of the above size.

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