Industrial Health 2014, **52**, 461–470

Original Article

Comparative Study of Upper Limb Load Assessment and Occurrence of Musculoskeletal Disorders at Repetitive Task Workstations

Danuta ROMAN-LIU[1]*, Joanna BUGAJSKA[1] and Tomasz TOKARSKI[1]

[1]Laboratory of Biomechanics, Department of Ergonomics, Central Institute for Labour Protection − National Research Institute (CIOP-PIB), Poland

Received December 18, 2013 and accepted May 28, 2014
Published online in J-STAGE June 27, 2014

Abstract: This study explored the relationship between subjectively assessed complaints of pain in the arm, forearm and hand, and musculoskeletal load caused by repetitive tasks. Workers (n=942) were divided into 22 subgroups, according to the type of their workstations. They answered questions on perceived musculoskeletal pain of upper limbs. Basic and aggregate indices from a questionnaire on the prevalence, intensity and frequency of pain were compared with an upper limb load indicator (repetitive task index, RTI) calculated with the recently developed Upper Limb Risk Assessment (ULRA). There was relatively strong correlation of RTI and general intensity and frequency of pain in the arm, and general intensity and frequency of pain in the arm and forearm or prevalence of pain in the arm. Frequency and intensity of pain in the arm were weakly correlated. An aggregate indicator of evaluation of MSDs, which was calculated on the basis of the prevalence, intensity and frequency of pain, was to a higher degree associated with the musculoskeletal load of a task than basic evaluative parameters. Thus, such an aggregate indicator can be an alternative in comparing subjectively assessed MSDs with task-related musculoskeletal load and in establishing limit levels for that load.

Key words: Biomechanics, Occupational, Epidemiology, MSDs, Musculoskeletal load

Introduction

Musculoskeletal disorders (MSDs) are an important issue with increasing personal and socio-economic impact. Prevalence of long-lasting neck/shoulder pain in the general population has been reported to be between 14% and 25%, whereas of short-term pain even as high as 43%[1–4]. The back, neck, the shoulders and the upper limbs are the parts of the body most affected by MSDs[4, 5]. There is an established association between prevalence of pain and work, with noticeable diversification by occupation[6].

In explaining the relationship between work and MSDs, biomechanical load assigned to work tasks performed at workstations is meaningful[7, 8]. An epidemiological study found increased risk of MSDs in high-intensity work[9–11]. Manual tasks, operating a machine and working on a production line in a factory are examples of high-intensity work. Such work imposes an increased number of highly repetitive movements, sometimes requiring significant force, too. According to many researchers repetitive work poses a significant hazard and leads to the development of MSDs[12, 13]. A repetitive task and the resulting workload can be defined with parameters related to posture, exertion

*To whom correspondence should be addressed.
E-mail: daliu@ciop.pl

of external forces and time sequences. Excessive workload causes the development of MSDs[14].

Upper limbs are involved in most tasks, so this part of the worker's body is especially exposed to overload associated with the risk of developing MSDs[11, 15] and it is mostly upper limbs that are affected by similar, repeatedly performed work tasks. MSDs, if not treated properly, could lead to work-related overload symptoms, a significant one of which is carpal tunnel syndrome (CTS). CTS can be observed especially in employees whose work requires repetitive actions, exertion of significant force and awkward posture of the wrist and hand[9, 13].

To avoid MSDs, work-related musculoskeletal load must be at an acceptable level, i.e., a level of load, which should not be exceeded. It can be determined with appropriate methods, which also determine the risk of a work task causing MSDs. Therefore, an established relationship between MSDs and upper limb load for a given type of repetitive task might be crucial in protecting workers against MSDs. A quantitative expression of both musculoskeletal load indicators and MSDs is crucial in comparing them and in establishing criteria for load indicators related to the risk of developing MSDs. MSDs are usually described with a few indicators, e.g., prevalence, intensity and frequency of pain in the past 12 months assessed on a visual scale. However, which of those three indicators is best related to musculoskeletal load at a workstation and can be used in determining risk criteria has to be established. In that respect, it is also important to determine how both musculoskeletal load and the occurrence of MSDs are assessed.

MSDs are mostly evaluated with questionnaires. The Dutch Musculoskeletal Questionnaire is one of the best and most recognized tools[16]. Musculoskeletal symptoms can also be well documented with the Standardized Nordic Questionnaire[6, 17, 18] or the Questionnaire for Subjective Symptoms of Fatigue[19]. Many studies use those questionnaires, either in full or in part, to assess the occurrence of MSDs in specific body parts[20].

Musculoskeletal load associated with a workstation can be assessed with checklists[16, 21, 22]. However, very often are used methods that rely on describing the work process with parameters related to body posture, exerted forces and time sequences. Those methods focus on the work process without considering individual features of workers. The recently developed Upper Limb Risk Assessment (ULRA) method is an example[23].

Exploring the relationship between work-related load and symptoms of MSDs, makes it possible to define that relationship for individual basic indicators (prevalence, intensity and frequency of pain). However, combined prevalence, intensity and frequency of pain may express better actual musculoskeletal load at the workstation and MSDs related to that load. Thus, they will constitute a good general indicator of MSDs. Multiplication or averaging those three indicators of MSDs, i.e., intensity, frequency and prevalence of pain, can create aggregate indicators. Such aggregate indicators could be used to explore the relationship between task-related musculoskeletal load and MSDs and help in establishing limit levels for work load.

The aim of this study was to (1) evaluate prevalence, intensity and frequency of upper limb pain complaints at various types of repetitive task workstations; (2) explore the relationship between subjectively assessed complaints of pain in the arm, forearm and hand with musculoskeletal load evaluated on repetitive task workstations and (3) propose aggregate indicators of the prevalence, frequency and intensity of pain as alternative indicators of MSD symptoms, which could serve as global MSD indicators in comparing MSDs and task-related musculoskeletal load.

Methods

Types of examined workstations

Analysis covered 22 types of repetitive task workstations characterized by cycle time (CT), the number of cycle phases (k), duration of cycle phases as well as upper limb posture and forces present during each cycle phase. CT was exactly the same for both limbs, whereas the number of phases of cycle could be different for the limbs, which was the case at 11 workstations. For each workstation upper limb load was assessed with ULRA. ULRA evaluates musculoskeletal load and risk of developing MSDs of the upper limbs with the value of the repetitive task indicator (RTI), which is a function of parameters related to cycle time (CT), number of phases (k) and integrated cycle load (ICL; i.e., the sum of k products of relative cycle phase forces multiplied by the duration of cycle phase and divided by cycle time). This method is described in detail in Roman-Liu[23], whereas analysis of the workstations can be found in Roman-Liu *et al*[24].

The 22 workstations can be grouped into assembly tasks, sewing, packing and surveillance, control and packing, installing and using comparably heavy mechanical tools (Table 1).

Table 1 also presents parameters describing work load characteristics obtained with ULRA. It shows values of the integrated cycle load (ICL) and the repetitive task indi-

Table 1. Characteristic parameters of workstations

Workstation		CT	k_R	k_L	ICL_R	ICL_L	RTI_L	RTI_R
Packing and controlling	Manual assembly	22.5	12	12	0.110	0.091	1.54	1.59
	Packing TVs	19.2	5	3	0.010	0.100	0.83	1.04
	Checking appearance	41.1	17	17	0.086	0.088	1.26	1.26
Installing	Programming option 1	22.8	6	5	0.016	0.033	0.75	0.79
	Programming option 2	25.5	7	5	0.052	0.004	0.63	0.9
Packing and surveillance	Unpacking circuit board	22.6	13	12	0.120	0.110	1.59	1.72
	Controller	18.7	4	4	0.029	0.032	0.74	0.74
	Scanning	12.5	8	7	0.121	0.105	1.84	1.9
	Final check	196.2	217	175	0.077	0.135	2.34	2.59
	Packing	23	16	7	0.130	0.060	1.00	2.00
Assembling small elements	Circuit board operator	376.9	168	48	0.072	0.023	0.51	1.26
	Circuit board assembly	11.8	5	6	0.110	0.103	1.45	1.55
	Socket assembly 1	212.4	135	135	0.087	0.088	1.68	1.68
	Electric socket assembly	46.3	33	33	0.091	0.090	1.86	1.86
	Socket assembly 2	171	83	83	0.094	0.078	1.36	1.4
Operating tools	Welder	157	98	28	0.117	0.084	0.77	1.75
	Ironworker	794	128	128	0.176	0.105	0.79	1.03
Sewing	Sewing car seat	87.3	37	37	0.090	0.086	1.26	1.28
	Preliminary sewing	25.6	13	13	0.087	0.052	1.36	1.47
	Sewing armchair backrest	91.9	59	59	0.078	0.102	1.74	1.67
	Sewing − leather	100	57	57	0.183	0.200	1.94	1.88
	Sewing headrest	110.2	64	52	0.100	0.092	1.37	1.6

CT: cycle time in seconds, k: number of phases of a work cycle, L: left upper limb, R: right upper limb, V_R: number of movements during one second for the right limb, V_L: number of movements during one second for the left limb, ICL: Integrated Cycle Load, RTI: Repetitive Task Indicator

cator (RTI) for the left and the right upper limbs.

Subjects

A total of 942 workers participated in the study. They were divided into 22 subgroups according to the type of their workstation (Table 2). Participation in the study was voluntary. Participants signet informed consent. The commission of Scientific Research Ethics at the Central Institute for Labour Protection approved the protocol and methods of the study.

Analyses

The workers answered questions on perceived musculoskeletal pain of the upper limbs. Questions were related to subjective assessment of pain of the upper limbs in the area of arms, forearms and wrists/hands. The questionnaire consisted of two parts: one related to the general diagnosis of upper limb MSDs in arms and forearms, the other to the specific diagnosis of symptoms of CTS.

The part of the questionnaire on MSDs in the arms and forearms consisted of four instructions, with the subjects marking their answers on a 100-mm visual analogue scale (VAS): Please use the scale to indicate the intensity of pain in your arms in the past 12 months. Please use to scale to indicate the frequency of pain in your arms in the past 12 months. Please use the scale to indicate the intensity of pain in your forearms in the past 12 months. Please use to scale to indicate the frequency of pain in your forearms in the past 12 months.

From this part of the questionnaire six basic indicators were obtained: percentage of workers experiencing pain in the arm (Pa), percentage of workers experiencing pain in the forearm (Pf), intensity and frequency of pain in the arm and forearm in the population of workers who experienced pain (Ia, Fa, If, Ff). To simplify and standardize measures of individual indicator, prevalence was expressed as a decimal fraction. Intensity and frequency measures, which correspond to values on VAS, were accepted as dimensionless.

To analyse global complaints, aggregate indicators which express basic indicators jointly, were analysed, too (Fig. 1a).

Table 2. Characteristics of the subjects at each workstation

Workstation	Age (years)		Body Weight (kg)		Body Height (cm)		n	
	M	SD	M	SD	M	SD		
Manual assembly	34.00	5.95	60.14	9.16	165.36	5.87	15	F
Programming option 1	32.81	8.52	64.49	13.26	165.04	7.07	13	F
Controller	27.86	7.95	62.31	12.35	165.02	9.43	52	F
Scanning	32.64	6.38	62.54	8.92	165.63	5.24	47	F
Final check	34.18	9.09	68.51	12.08	168.49	9.14	49	F
Packing	36.19	7.57	62.96	9.62	164.56	5.58	55	F
Circuit board operator	33.92	7.69	66.84	12.41	168.13	8.27	56	F
Circuit board assembly	33.79	6.33	63.21	12.11	166.84	8.30	20	F
Socket assembly 1	35.24	7.80	64.52	11.93	163.00	5.09	58	F
Electric socket assembly	41.39	8.55	61.86	10.81	161.39	5.84	37	F
Socket assembly 2	33.04	8.43	62.33	12.29	163.67	7.57	27	F
Sewing − leather	33.95	7.21	61.62	13.08	169.38	10.7	61	F
Sewing headrest	35.45	7.38	66.14	9.91	167.63	6.32	57	F
Sewing armchair backrest	38.81	9.52	67.49	14.26	170.04	9.07	65	F
Sewing car seat	37.79	9.33	69.21	9.11	169.74	9.30	41	F
Checking appearance	28.57	8.01	60.86	11.55	165.31	8.15	37	F
Checking appearance	25.95	8.07	76.78	18.92	176.96	6.99	23	M
Unpacking circuit board	28.84	8.42	57.80	10.46	164.95	5.97	21	F
Unpacking circuit board	28.09	7.99	81.07	9.26	180.93	7.38	14	M
Programming option 2	36.32	8.96	62.90	10.45	165.57	5.80	29	F
Programming option 2	31.10	9.29	72.62	7.58	177.25	6.30	10	M
Preliminary sewing	42.23	10.54	61.96	9.78	164.33	5.71	39	F
Preliminary sewing	40.08	9.32	72.28	12.56	172.39	9.92	7	M
Packing TVs	32.09	8.11	61.88	9.59	165.54	6.38	34	F
Packing TVs	29.70	8.27	76.03	12.47	175.70	7.80	30	M
Welder	39.42	6.31	86.53	18.12	178.63	9.24	11	M
Ironworker	47.42	8.75	91.54	14.51	182.64	11.43	34	M

M: mean, SD: standard deviation

Aggregate indicators of prevalence of pain (Paf), its intensity (Iaf) and frequency (Faf) were obtained after averaging those indicators for the arm (a) and the forearm (f). Moreover, average intensity and frequency of pain were calculated for the arm (IFa) and the forearm (IFf). Those indicators produced information on the population of only those workers who reported upper limb pain. To obtain data related to the general worker population, those indices were multiplied by the prevalence of pain, expressed as a fraction. In this way, three more aggregate indices were obtained, i.e., severity of pain in the arm (PIFa), in the forearm (PIFf) and in the whole upper limb (PIF). Figure 1b presents sample calculations of aggregate indicators.

The other part of the questionnaire assessed symptoms of CTS. CTS is a specific MSD. In medical examinations, CTS can be diagnosed by the occurrence of increased pain and numbness at night. The workers were asked about pain in the wrist/hand and about increase in pain and numbness at night. There were also questions on relief brought by a change in the position of the wrist. Therefore, the part of the questionnaire on CTS consisted of the following questions: Do you experience increased pain at night? Does a change in the position of the hand/wrist position decrease pain? Do you experience increased numbness at night? Does numbness decrease after you change the position of your wrist?

Indices which relate to CTS symptoms express the percentage of workers who experience an increase in pain at night (IP) and the percentage of workers who found that a change in position decreased pain (CP). Moreover, in the case of numbness there were questions and indices of increased numbness at night (IN) and decreased numbness after a change in the position of the body (CN). The average of those four measures gave an indicator of CTS. Even though those basic indicators express the percentage of workers who answered positively, they are considered

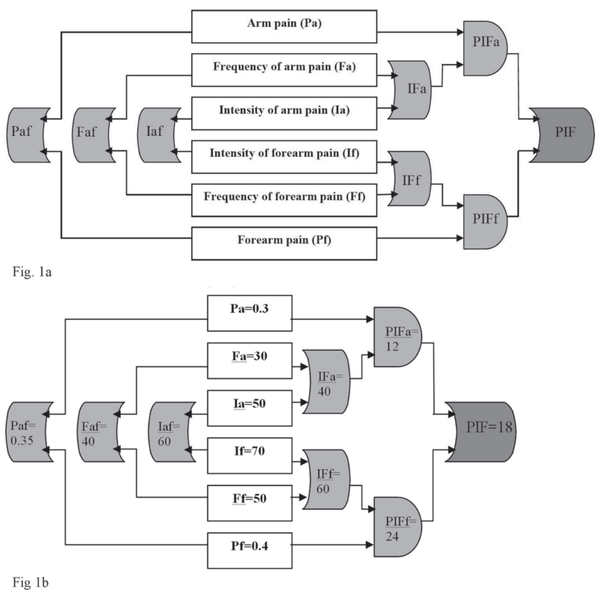

Fig. 1. Diagram of (a) basic (Pa, Pf, Fa, Ff, Ia, If) and aggregated (Paf, Faf, Iaf, IFa, IFf, PIFa, PIFf, PIF) indicators of musculoskeletal disorders; (b) sample calculations of aggregated indicators.

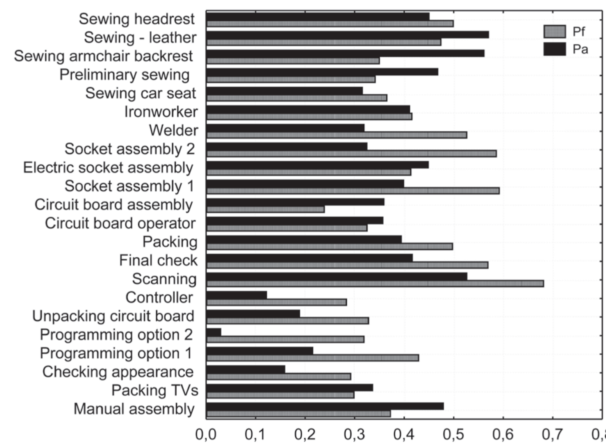

Fig. 2. Prevalence of pain in the forearm (Pf) and pain in the arm (Pa).
Prevalence was expressed as a decimal fraction.

as dimensionless.

Each indicator was compared with an indicator of upper limb load, calculated according to ULRA[24)], separately for left and right upper limb.

Results

Figure 2 shows prevalence of pain in arm and forearm in the workers divided according to their workstations. There was quite a strong variation in the results for workers at individual workstations, from 0.02 (Programming option 2) to 0.56 (Sewing-lather) complaints of pain in the arm, and from 0.03 (Controller) to 0.68 (Scanning) of pain in the forearm. At most workstations the prevalence of pain was 0.30–0.45.

Table 3 shows the intensity and frequency of pain in the arm and forearm experienced in the past 12 months. It also shows significant differences at individual workstations, both in intensity and frequency of pain.

Table 3 presents mean values only of those workers who answered positively to the question regarding pain, i.e., who had experienced pain. The mean values multiplied by the percentage of workers with arm or forearm pain reflect the global indicator related to both the percentage of workers with musculoskeletal problems, and the intensity and frequency of those problems for the arm (PIFa) and for the forearm (PIFf).

Figure 3 presents the percentage of workers who answered positively to the questions related to pain in wrist/hand and numbness increasing at night and if a change in the position of the wrist decreased pain and numbness in the hand/wrist. Those results, too, indicate a diversity among the workstations. At some workstations it was lower than 1 and at others even exceeding 16. Generally, pain was less frequent than numbness. Symptoms of CTS related to workstations were more frequent at those workstations at which MSDs were more frequent, too.

Figure 4 illustrates values of the total index (PIF), CT and average RTI for the left and right upper limbs for all types of workstations. To make comparison possible, PIF and CTS indicators were multiplied by constant value. Figure 4 gives a general overview of the relationship between indicators of musculoskeletal load and MSDs. Generally, for lower RTI, PIF and CTS were lower, too.

Correlation coefficients were calculated for values of RTI and MSD indicators for the 22 workstations (Table 4). The correlations were statistically significant. The strongest correlation of RTI was for general intensity and frequency of pain in the arm (PIFa), in forearm (PIFf), as well as for general intensity and frequency of pain in the arm and forearm (PIF). There was weak correlation in case of frequency of pain in the arm (Fa).

The differences between PIF and the other indicators of MSDs were tested with Friedman ANOVA and post hoc tests. The results showed there were no differences between PIF and PIFa, PIFf, Paf or Pf. There were differences between PIF and all the other indicators.

Table 3. Intensity and frequency of pain in workers reporting pain in the arm and forearm at each workstation

Workstation	Pain in Arm				Pain in Forearm			
	Intensity (Ia)		Frequency (Fa)		Intensity (If)		Frequency (Ff)	
	M	SD	M	SD	M	SD	M	SD
Manual assembly	26.83	16.84	24.83	12.52	66.83	22.52	54.83	22.18
Programming option 1	36.24	25.65	48.82	24.37	46.24	26.23	48.82	25.16
Controller	42.32	8.23	55.26	18.19	42.32	23.81	55.26	26.32
Scanning	67.97	20.76	77.79	29.94	57.97	24.92	47.79	28.83
Final check	79.26	34.83	68.24	25.56	59.26	26.71	78.24	28.76
Packing	40.85	21.86	51.16	20.55	40.85	22.05	51.16	23.84
Circuit board operator	34.98	20.38	43.34	23.23	34.98	13.43	43.34	26.95
Circuit board assembly	44.17	18.92	42.08	14.43	54.17	24.54	52.08	24.81
Socket assembly 1	57.00	18.33	70.30	32.04	57.00	22.36	70.30	24.83
Electric socket assembly	55.36	24.51	51.48	19.47	47.77	29.53	54.36	23.76
Socket assembly 2	47.77	22.65	54.36	28.87	68.17	37.56	58.75	18.98
Sewing - leather	51.56	29.22	64.52	36.57	81.56	44.56	84.52	37.86
Sewing headrest	68.96	23.76	69.72	29.85	68.96	31.23	69.72	32.64
Sewing armchair backrest	66.27	16.32	65.12	27.82	66.27	35.78	65.12	29.76
Sewing car seat	61.85	28.72	61.87	24.55	50.35	27.65	60.71	25.43
Checking appearance	52.12	16.63	65.38	19.50	62.12	19.50	75.38	27.05
Unpacking circuit board	38.17	25.62	51.91	22.83	38.17	25.39	41.91	28.06
Programming option 2	50.35	28.07	60.71	21.36	35.36	26.13	51.48	27.59
Preliminary sewing	35.36	22.02	59.35	28.54	35.36	22.54	59.35	32.85
Packing TVs	45.71	25.21	60.00	15.01	45.71	17.32	60.00	23.39
Welder	68.17	24.32	58.75	22.45	39.16	21.86	51.11	26.91
Ironworker	39.16	29.61	51.11	31.06	61.85	33.87	51.87	29.54

M: mean, SD: standard deviation

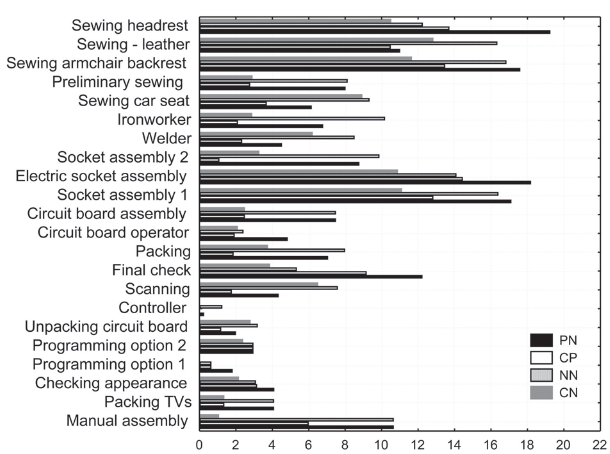

Fig. 3. Percentage of works reporting increased pain in hand/wrist at night (PN), increased numbness at night (NN), a change in position decreased pain (CP) and a change in position decreased numbness (CN).
Those basic indicators are considered as dimensionless

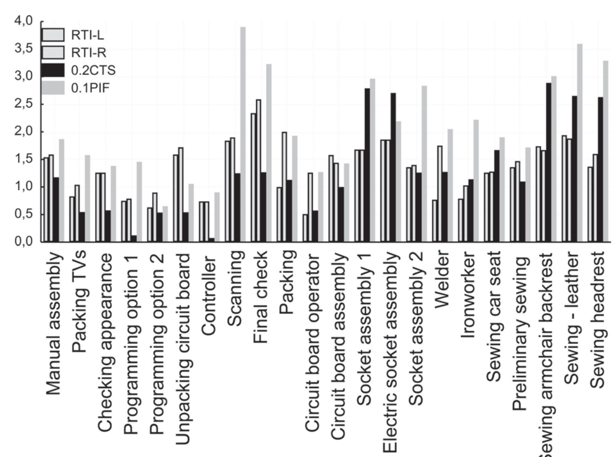

Fig. 4. The total index of musculoskeletal disorders and upper limb load assessed with the repetitive task indicator (RTI) for the right upper limb (RTI-R), for the left upper limb (RTI-L) and for both upper limbs (RTI).
CTS: carpal tunnel syndrome, PIF − aggregate indicator of severity of pain in arm and forearm. The values were multiplied to illustrate the results better CTS by 0.2 and PIF by 0.1.

Table 4. Correlation coefficients for the indicator of upper limb musculoskeletal load (repetitive task indicator, RTI) and evaluative parameters indicating musculoskeletal disorders at each of the 22 workstations

Index	RTI	*p*
Increased pain in wrist/hand at night (IP)	0.555	0.000
Change in position decreases pain in wrist/hand (CP)	0.550	0.000
Increased numbness in wrist/hand at night (IN)	0.498	0.001
Change in position decreases numbness in wrist/hand (CN)	0.503	0.001
Symptoms of CTS (CTS)	0.553	0.000
Prevalence of pain in forearm (Pf)	0.462	0.002
Intensity of pain in forearm (If)	0.446	0.002
Frequency of pain in forearm (Ff)	0.442	0.003
Intensity and frequency of pain in forearm (IFf)	0.480	0.001
General intensity and frequency of pain in forearm (PIFf)	0.542	0.000
Prevalence of pain in arm (Pa)	0.581	0.000
Intensity of pain in arm (Ia)	0.485	0.001
Frequency of pain in arm (Fa)	0.305	0.044
Intensity and frequency of pain in arm (IFa)	0.432	0.003
General intensity and frequency of pain in arm (PIFa)	0.648	0.000
Frequency of pain in arm and forearm (Faf)	0.425	0.004
Pain in arm and forearm (Paf)	0.622	0.000
Intensity of pain in arm and forearm (Iaf)	0.573	0.000
General intensity and frequency of pain in arm and forearm (PIF)	0.649	0.000

Discussion

The results of this study showed that the prevalence of MSDs according to the type of repetitive task workstation ranged broadly from 3 to 61% for pain in the arm and from 3 to 68% for pain in the forearm. Other study on repetitive industrial work reported the prevalence of symptoms among industrial workers of 50% in the neck/shoulders and 22% in the elbows/hands[25]. Assessment of MSDs of supermarket cashiers showed the prevalence of neck and shoulder disorders of 60–70%[26]. In this case the average number of registered items was 0.15 moves per second with the average force of 0.85 kG. This is close to the characteristics of the tasks of the left upper limb at Ironworker, Welder and Packer TVs workstations in the present study. Prevalence of pain at those workstations was about 45% for the first two and about 35% when Packer TVs is considered, too. This is lower than for cashiers in Rissén *et al.*[26] study. The discrepancies suggest that it is not enough to consider repetition of movements and averaged load only to fully characterize work tasks; more detailed parameters are necessary for a full assessment. Work posture as well as the duration and load of each cycle phase are also important for musculoskeletal load. More advanced assessment methods could also consider parameters related to personal characteristics (e.g., gender and age).

Differences among the examined workstations were also noticed in the CTS indicator. Hand and wrist symptoms and signs were prevalent in a car factory where Zetterberg and Öfverholm[27] studied subjective complaints in 564 car assembly workers: 57% of the females and 37% of the males reported them. Assembly work was repetitive, with a cycle time of up to two minutes. Sewing − leather and Sewing headrest in the present study had a similar cycle time. CTS symptoms at those workstations were at the level of about 12%, which was more similar to Leclerc *et al.*[13] results. According to Leclerc *et al.* in different companies with repetitive industrial work (assembly line, clothing and shoe industry, food industry) 11.8% of workers had CTS associated with repetitive work. The differences in the prevalence of MSDs in various studies can result from the fact that the repetitive tasks at the workstations varied in time sequences, forces and upper limb postures. Quintana and Hernandez-Masser proved the relationship between MSDs and those factors[14].

The present study showed a statistically significant correlation between workload and basic and aggregated indicators of MSDs. When the aggregate indicators of pain in the arm (PIFa) or forearm (PIFf), and in the arm and forearm (PIF) were compared with RTI, the correlation coefficient was higher than when basic indicators were compared. The basic parameters referred to prevalence, intensity and frequency separately. Since assessment was subjective, it could have been associated with inaccuracies. The responses were subjectively biased; however, assessment was less subjective when a combination of all three indicators was used. The differences related to workstations multiplied when aggregated indicators were considered. That can be why correlation was better between RTI and the aggregate PIF indicator with the greatest correlation coefficient. This suggests that the approach in this study can be useful in comparing task-related musculoskeletal load with MSDs. In this way, it can help in establishing limit levels of load.

However, it is important that all correlation coefficients were between 0.40 and 0.65 and all of them were significant. That means the differences in correlation coefficients between basic and aggregate indicators are not high. That cannot strongly support the supposition that the aggregate indicators proposed in this paper, especially the general intensity and frequency of pain in the arm and forearm (PIF), give a much better overview of the existing severity of upper limb load associated with work tasks. Even if the correlation coefficient in the case of PIF is not much higher than in the case of the basic indicators, this is one global indicator, which can be recommended as suitable in comparing work-related musculoskeletal load and for the risk of developing MSDs.

The study effect consists in the result which shows a correlation between the occurrence of MSDs and the upper limb load indicator (RTI). This means that the occurrence of MSDs can be predicted by assessing musculoskeletal load involved in performing work tasks. That means that assessing musculoskeletal load on the basis of characteristics of work tasks with a method like ULRA can prevent injury. If the assessed musculoskeletal load carries a high risk of MSDs, the workstation, the work process or both can be modified to decrease that risk.

However, not in all cases was full agreement between MSDs indicators and RTI. The differences between RTI and MSDs, as well as the differences between various studies on the development of MSDs at various repetitive task workstation may have causes.

Firstly, MSDs were subjectively assessed. Therefore, the results were strongly influenced by the subjective component. Engstrom *et al*.[28] study proved that, in general, self-reported physical exposure showed only a few significant associations with musculoskeletal symptoms. A questionnaire shows about 50% higher prevalence of pain in various areas of the body than a physical examination[15].

Secondly, MSDs are multifactorial and although in explaining the relationship between work and MSDs biomechanical load has been assigned the main role[7, 8], other factors are meaningful, too. Thus, there is no full convergence between RTI and MSD indicators. For example, numerous studies have shown psychosocial aspects to be risk factors for the development of MSDs[29–31] with a poor psychosocial situation resulting in higher reports of MSDs[26, 32, 33].

Psychosocial factors are subjective; their assessment is not included in methods that rely on parameters that define tasks. Monitoring musculoskeletal load during work tasks is possible with so-called external and internal load assessment methods. The external load assessment method used in the present study relies on parameters related to body posture, exerted forces and time sequences. It considers the work process only, not factors such as age, gender or psychosocial characteristics. Mental demands as well as individual factors are reflected in internal load assessment methods, which register the reaction of the worker's body to external load. Heart rate, blood pressure or muscle activity registration (electromyography) register not only work-related load, but also individual characteristics of a worker's body and mental load[34–36]. Psychosocial and individual factors could have also influenced the occurrence of MSDs at the workstations examined in the present study. However, workers' internal load, which would take into account also those factors, was not assessed in the present study. Therefore, only strictly biomechanical parameters the same for each worker, were considered in assessing musculoskeletal load. This may account for the differences obtained when comparing MSDs and musculoskeletal load at the workstations.

Even when considering external load assessment methods only, the selection of a method of assessing upper limb load is important. In the present study, ULRA was chosen. SI (Strain Index)[37] and OCRA (Occupational Repetitive Actions)[38] are two other methods for assessing upper limb load musculoskeletal load. OCRA is the best known method for evaluating the musculoskeletal load of upper limbs caused by repetitive tasks, and the risk of developing MSDs. It only considers movements of the arms below shoulder level and focuses on movements of the forearms without differentiating load caused by the position of the arms. Both SI and OCRA refer to parameters describing repetitive task with codes, which assign a given measure one value for a range of values. This means the load indicator changes in steps. ULRA gives analogue results, which produce better comparisons than methods which assess musculoskeletal load with digitalized codes. Reliability of the assessment of upper limb musculoskeletal load presented in this study has been confirmed by another study that reported convergence of OCRA and ULRA[24].

External load assessment methods do not distinguish musculoskeletal load and risk of developing MSDs in relation to the gender or age of the working population. Because gender and age influence the development of MSDs, that fact could have influenced the results presented in this paper. Eighty-six percent of the population covered by the study were female, which means that the obtained relationship refers mostly to women.

Even though convergence between MSDs and RTI has been documented and the proposed MSD indicator proves the best convergence with upper limb load, this study has some limitations: in assessing upper limb load only biomechanical factors are considered, not psychosocial and individual ones. However, if RTI considered individual factors, e.g., gender and age, this method would analyse not only external but also to some extent internal load, which could result in better convergence between upper limb load and MSD indicators. Another limitation can result from the questionnaire, which considered MSD and CTS symptoms averaged for both upper limbs, and not the left and the right ones individually. However, as repetitive work usually engages both upper limbs and as a comparison of RTI for the left and right upper limbs showed very small differences only, this limitation can probably be disregarded as not very relevant to study results.

Conclusion

This study proved the relationship between upper limb musculoskeletal load, assessed on the basis of factors describing repetitive tasks with parameters related to upper limb posture, force and time sequences, with the occurrence of MSDs. A relationship was found both when prevalence of pain in the arm and forearm was considered and when intensity and frequency of pain were analysed. However, the aggregate indicators proposed in this study, especially that of general intensity and frequency of pain in the arm and forearm (PIF), may provide a good overview of existing MSDs. As global indicators, they can be a good alternative in comparing subjectively assessed MSDs with task-related musculoskeletal load and in establishing limit levels of that load.

Acknowledgement

This paper was prepared on the basis of the results of a research task carried out within the scope of the first stage of the National Programme “Improvement of safety and working conditions” partly supported by the Ministry of Labour and Social Policy. The Central Institute for Labour Protection − National Research Institute was the Programme’s co-ordinator. The authors would like to thank Anna Groborz for her help in musculoskeletal load analysis at the work stands being the subject of the paper.

References

1) Guez M, Hildingsson C, Nilsson M, Toolanen G (2002) The prevalence of neck pain: a population-based study from northern Sweden. Acta Orthop Scand **73**, 455–9.
2) Gummesson C, Isacsson SO, Isacsson AH, Andersson HI, Ektor-Andersen J, Ostergren PO, Hanson B, Malmö Shoulder-Neck Study group (2006) The transition of reported pain in different body regions—a one-year follow-up study. BMC Musculoskelet Disord **7**, 17.
3) Mehlum IS, Kjuus H, Veiersted KB, Wergeland E (2006) Self-reported work-related health problems from the Oslo Health Study. Occup Med (Lond) **56**, 371–9.
4) Aström C, Lindkvist M, Burström L, Sundelin G, Karlsson JS (2009) Changes in EMG activity in the upper trapezius muscle due to local vibration exposure. J Electromyogr Kinesiol **19**, 407–15.
5) Côté P, Cassidy JD, Carroll LJ, Kristman V (2004) The annual incidence and course of neck pain in the general population: a population-based cohort study. Pain **112**, 267–73.
6) Roquelaure Y, Ha C, Leclerc A, Touranchet A, Sauteron M, Melchior M, Imbernon E, Goldberg M (2006) Epidemiologic surveillance of upper-extremity musculoskeletal disorders in the working population. Arthritis Rheum **55**, 765–78.
7) Christensen JO, Knardahl S (2010) Work and neck pain: a prospective study of psychological, social, and mechanical risk factors. Pain **151**, 162–73.
8) Aptel M, Aublet-Cuvelier A, Cnockaert JC (2002) Work-related musculoskeletal disorders of the upper limb. Joint Bone Spine **69**, 546–55.
9) Bugajska J, Jedryka-Góral A, Sudoł-Szopińska I, Tomczykiewicz K (2007) Carpal tunnel syndrome in occupational medicine practice. Int J Occup Saf Ergon **13**, 29–38.
10) Bongers PM, Ijmker S, van den Heuvel S, Blatter BM (2006) Epidemiology of work related neck and upper limb problems: psychosocial and personal risk factors (part I) and effective interventions from a bio behavioural perspective (part II). J Occup Rehabil **16**, 279–302.
11) Bernaards CM, Ariëns GAM, Knol DL, Hildebrandt VH (2007) The effectiveness of a work style intervention and a lifestyle physical activity intervention on the recovery from neck and upper limb symptoms in computer workers. Pain **132**, 142–53.
12) Muggleton JM, Allen R, Chappell PH (1999) Hand and arm injuries associated with repetitive manual work in industry: a review of disorders, risk factors and preventive measures. Ergonomics **42**, 714–39.
13) Leclerc A, Franchi P, Cristofari MF, Delemotte B, Mereau P, Teyssier-Cotte C, Touranchet A, Study Group on Repetitive Work (1998) Carpal tunnel syndrome and work organisation in repetitive work: a cross sectional study in France. Occup Environ Med **55**, 180–7.
14) Quintana R, Hernandez-Masser V (2003) Limiting design criteria framework for manual electronics assembly. Hum Factors Ergon Manuf **13**, 165–79.
15) Zetterberg C, Forsberg A, Hansson E, Johansson H, Nielsen P, Danielsson B, Inge G, Olsson BM (1997) Neck and upper extremity problems in car assembly workers: a comparison of subjective complaints, work satisfaction,

physical examination and gender. Int J Ind Ergon **19**, 277–89.
16) Kemper HCG, Hildebrandt VH, Bongers PM, van Dijk FJH, Dul J (2001) Dutch Musculoskeletal Questionnaire: description and basic qualities. Taylor & Francis, London.
17) Kuorinka I, Jonsson B, Kilbom A, Vinterberg H, Biering-Sørensen F, Andersson G, Jørgensen K (1987) Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. Appl Ergon **18**, 233–7.
18) Luttmann A, Schmidt KH, Jäger M (2010) Working conditions, muscular activity and complaints of office workers. Int J Ind Ergon **40**, 549–59.
19) Khaleque A (1981) Performance and strain in short-cycled repetitive work. Int Arch Occup Environ Health **48**, 309–17.
20) Lei L, Dempsey PG, Xu JG, Ge LN, Liang YX (2005) Risk factors for the prevalence of musculoskeletal disorders among Chinese foundry workers. Int J Ind Ergon **35**, 197–204.
21) Kemmlert K (1995) A method assigned for the identification of ergonomic hazards - PLIBEL. Appl Ergon **26**, 199–211.
22) Ketola R, Toivonen R, Häkkänen M, Luukkonen R, Takala EP, Viikari-Juntura E, Expert Group in Ergonomics (2002) Effects of ergonomic intervention in work with video display units. Scand J Work Environ Health **28**, 18–24.
23) Roman-Liu D (2007) Repetitive task indicator as a tool for assessment of upper limb musculoskeletal load induced by repetitive task. Ergonomics **50**, 1740–60.
24) Roman-Liu D, Groborz A, Tokarski T (2013) Comparison of risk assessment procedures used in OCRA and ULRA methods. Ergonomics **56**, 1584–98.
25) Ohlsson K, Attewell RG, Pålsson B, Karlsson B, Balogh I, Johnsson B, Ahlm A, Skerfving S (1995) Repetitive industrial work and neck and upper limb disorders in females. Am J Ind Med **27**, 731–47.
26) Rissén D, Melin B, Sandsjö L, Dohns I, Lundberg U (2000) Surface EMG and psychophysiological stress reactions in women during repetitive work. Eur J Appl Physiol **83**, 215–22.
27) Zetterberg C, Ofverholm T (1999) Carpal tunnel syndrome and other wrist/hand symptoms and signs in male and female car assembly workers. Int J Ind Ergon **23**, 193–204.
28) Engström T, Hanse JJ, Kadefors R (1999) Musculoskeletal symptoms due to technical preconditions in long cycle time work in an automobile assembly plant: a study of prevalence and relation to psychosocial factors and physical exposure. Appl Ergon **30**, 443–53.
29) Bongers PM, Kremer AM, ter Laak J (2002) Are psychosocial factors, risk factors for symptoms and signs of the shoulder, elbow, or hand/wrist?: a review of the epidemiological literature. Am J Ind Med **41**, 315–42.
30) Byström P, Hanse JJ, Kjellberg A (2004) Appraised psychological workload, musculoskeletal symptoms, and the mediating effect of fatigue: a structural equation modeling approach. Scand J Psychol **45**, 331–41.
31) van der Windt DAWM, Thomas E, Pope DP, de Winter AF, Macfarlane GJ, Bouter LM, Silman AJ (2000) Occupational risk factors for shoulder pain: a systematic review. Occup Environ Med **57**, 433–42.
32) Ariëns GAM, Bongers PM, Hoogendoorn WE, van der Wal G, van Mechelen W (2002) High physical and psychosocial load at work and sickness absence due to neck pain. Scand J Work Environ Health **28**, 222–31.
33) Wahlstedt K, Norbäck D, Wieslander G, Skoglund L, Runeson R (2010) Psychosocial and ergonomic factors, and their relation to musculoskeletal complaints in the Swedish workforce. Int J Occup Saf Ergon **16**, 311–21.
34) Leino PI, Hänninen V (1995) Psychosocial factors at work in relation to back and limb disorders. Scand J Work Environ Health **21**, 134–42.
35) Vasseljen O Jr, Westgaard RH (1996) Can stress-related shoulder and neck pain develop independently of muscle activity? Pain **64**, 221–30.
36) Waersted M, Westgaard RH (1996) Attention-related muscle activity in different body regions during VDU work with minimal physical activity. Ergonomics **39**, 661–76.
37) Moore JS, Garg A (1995) The Strain Index: a proposed method to analyze jobs for risk of distal upper extremity disorders. Am Ind Hyg Assoc J **56**, 443–58.
38) Occhipinti E (1998) OCRA: a concise index for the assessment of exposure to repetitive movements of the upper limbs. Ergonomics **41**, 1290–311.