ORIGINAL ARTICLE

The Prevalence of Musculoskeletal Problems and Risk Factors Among Women Assembly Workers in the Semiconductor Industry

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Summary

A cross-sectional study to determine work-related musculoskeletal problems and ergonomic risk factors was conducted among 529 women semiconductor workers. Overall, 83.4% had musculoskeletal symptoms in the last one year. Pain in the back (57.8%), lower leg (48.4%) and shoulder (44.8%) were the three most common musculoskeletal problems. Significant associations were found between prolonged standing and upper and lower leg pain, between prolonged sitting and neck and shoulder pain, and between prolonged bending and shoulder, arm, back and upper leg pain. The study therefore showed a clear association between work-related musculoskeletal pain and prolonged hours spent in particular postures and movements.

Key Words: Musculoskeletal problems, Ergonomic risk factors, Semiconductor industry, Women assembly workers

Introduction

In Malaysia, the electronics industry is the main contributor to the growth of the manufacturing sector, which produces Malaysia's major exports. Within the category of electronics, the semiconductor industry is the leading sub-sector. The two major processes in the semiconductor industry are wafer fabrication and semiconductor assembly. In this country, the wafer fabrication factories do not have the entire line of processes but only wafer preparation, polishing, inspection and packing. The semiconductor assembly factories, however have the entire line of processes which are divided into three main sections, front of line (FOL), middle of line (MOL), and end of line (EOL). In some of the factories, diode and component or parts assembly is also carried out.

The women workers who work in the assembly lines in the semiconductor industry are exposed to various types of occupational hazards, including ergonomic hazards such as static work, sedentary postures, prolonged standing, repetitive movements and awkward postures. In one local electronics factory, for example, the prevalence of work-related musculoskeletal problems was found to be between 3% and 30% in various body sites[1]. The observed risk factors were awkward seated postures, stooping frequently, highly repetitive movements, intermittent bending, constant walking and vibration. In another local study in two electronics factories, more than 40% of the workers reported musculoskeletal problems in the neck and back[2]. A study at an electronics factory manufacturing disk drives in Singapore reported that 44.8% out of 141 workers had complaints of body pain

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and the affected body parts were the hands and shoulders (38%), followed by the back (27%) and legs (26%)[3]. The Semiconductor Health Study in the United States by Pocekay *et al.*[4] that was carried out among 3,175 men and women in eight companies showed musculoskeletal problems to be significantly more prevalent among fabrication workers than non-fabrication workers. However, in Mexico, Harlow *et al.*[5] found that the electronics and other assembly women workers who had worked in the preceding two and half years had a 20% to 35% increased likelihood of reporting lower back, upper back, neck, shoulder and leg pain compared to non-assembly workers.

In this paper, we present the results from a cross-sectional study carried out to determine the prevalence and risk factors for musculoskeletal problems among women workers in the semiconductor industry in Malaysia, and the association between common musculoskeletal problems and prolonged hours (four or more hours) spent in awkward postures, movements, manual handling and repetitive motions.

Materials and Methods

The Malaysian Industrial Development Authority (MIDA) list of electronics factories (31 August 1998) was used for the selection of semiconductor factories. All semiconductor factories in the state of Selangor were selected but out of a total of 11, only six factories agreed to participate in the study. Two factories in the state of Penang were included in order to increase the total number of respondents.

At the beginning of the survey in each factory, a walk-through survey of the production floors was carried out to enable the researcher to understand the processes and tasks as well as to briefly observe the ergonomic risk factors (work postures and movements). The management of each factory was requested to randomly select 10% of the women assembly workers (with a minimum of 30 and a maximum of 200 workers) from all direct production work processes for the study. The inclusion criteria for the selection were women assembly workers (up to the level of line leader) who were directly involved in production, had been working in the factory for at least one year and who were Malaysian citizens. Self-administered questionnaires were filled in by workers in groups in the presence of the researchers who answered questions raised by the respondents.

The questionnaire included questions on socio-demographic background, work processes and work tasks, experience of body pain, and time spent in various postures and movements. A modified version of the body map from the general standardized Nordic Musculoskeletal Questionnaire (NMQ)[6] was used to identify the site of body pain. For this study the body map was pictured with an anterior and a posterior view with seven major sites i.e. neck, shoulder, arm (elbow and forearm), wrist and fingers, upper leg (hips/thighs/knees), lower leg (ankles/feet) and whole back (upper, middle, lower back and buttocks). The respondents were asked to circle the sites of pain on the body map. The identification of ergonomic risk factors was based on duration spent standing, sitting, climbing, bending, twisting, manual lifting, pushing and pulling, and using repetitive hand and wrist movements (categories of less than two hours, two to four hours, four or more hours and not at all). A worker was considered at risk when exposed to a particular work posture or movement for four or more hours in a workday.

The SPSS (Version 9.01) software package was used for statistical analysis. Analysis of the NMQ was simplified by collapsing all reported pain into seven body sites. Anterior, posterior, left or right of a body site was collapsed into one variable. For example, for the shoulder, if one respondent had pain in the anterior (left), anterior (right) and posterior (right) shoulder, it made one case. Another example, if a respondent had pain in the anterior (left) only, it also made one case. For hypothesis testing, duration of exposure to awkward postures and movements was categorized into two groups (less than four hours and four or more hours). The chi-square test was used to determine the odds of developing musculoskeletal problems when specific ergonomic risk factors were reported. The level of significance was set at 0.05. Logistic regression analysis was carried out for each body pain site to adjust for potential confounding variables that were significantly associated with the relevant body pain.

Results

Walk through survey

Eight factories participated in the study, comprising three wafer fabrication and five semiconductor assembly factories. The wafer fabrication factories run only certain parts of the wafer fabrication process and these were wafer preparation, polishing, inspection and packing. In these factories, activities such as lifting,

repetitive work, prolonged standing and working at awkward postures (bending and twisting) were carried out by workers operating the line. In the polishing process, for example, foot control panels were used for operating the machines and workers had to stand for prolonged hours. In the inspection section, the workers had to sit for prolonged hours and inspect wafers continuously. Workers in the semiconductor assembly factories were also exposed to climbing activities, where workers had to climb up three steps to load strips onto the carrier of chip testing.

One of the factories in the study was still using the conventional (semi-automated) molding machines, whereby operators had to manually lift molding metal frames weighing 15 to 20 kilograms. With the new machines where small metal frames were used, the workers only loaded and unloaded the basket with frames containing units and these weighed about four kilograms when filled with units. The fully automated work processes required workers to load and unload machines only and therefore one worker would usually operate several machines which were placed 10 feet apart in one or two parallel rows. Hence workers had to walk from one machine to another most of the time.

Characteristics of the respondents

A total of 529 respondents participated in the study. The mean age of the respondents was 31.2 years (SD $\pm$ 7.4) and the ages ranged between 18 and 54 years old with the majority in the 25 to 34 year age group (36.3%) (Table I). The respondents were largely Malays (75.6%), married (60.7%) and 94.3% had attained a minimum of lower secondary school education. These respondents had been working in the present factory for an average of 10.1 years (SD $\pm$ 7.4) with a range from one to 31 years. The respondents were generally well-experienced as almost half (45.8%) of them had worked for 10 or more years in their respective factories. Majority of the respondents were operators (96.6%) and a small proportion were line leaders (3.4%). Most of them either worked on a rotating eight hour shift for six days per week (51.4%) or a rotating twelve hour shift alternating between a three and a four day week (41.8%).

Nature of work

More than three quarters of the respondents were from semiconductor assembly processes (77.7%) with the rest from wafer fabrication processes (17.6%) and diode and component parts (e.g. camera parts) assembly processes (2.7%) (Table II). Among the semiconductor assembly workers, almost half were from EOL (41.2%). Half of the workers worked in automated processes (52.2%) and only 6.8% of the workers worked in semi-automated processes. These were mostly those who worked with the wafer polishing and conventional molding machines. About 12% of the workers were involved in manual operations, for example, assembly of component parts, rework, assembling diodes and camera parts. Nearly a quarter of the workers (23.6%) carried out inspection using microscopes or magnifying lens but in the wafer fabrication factories, inspection was done by the naked eye. Tasks categorized as 'others' included maintenance of machines, distribution of die and supervisory work, and were carried out by 5.1% of the workers in the study. All work processes present in the factories were represented in the sample.

Musculoskeletal symptoms and ergonomic risk factors

The prevalence of musculoskeletal symptoms in the last 12 months among the women assembly workers was highest for the back (57.8%), followed by lower leg (48.4%), shoulder (44.8%), upper leg (38.8%) and neck (29.7%) (Table III). The work postures and movements that were predominant were repetitive hand and wrist movements (77.9% were doing this for four or more hours), standing (61.2%), manual lifting (55.6%), sitting (34.0%) and pushing and pulling (31.4%) as shown in Table IV.

The relationship between the duration spent at work postures and movements and musculoskeletal pain at different body sites

Table V shows the association between pain in each body site and the time spent at various work postures and movements. Each of the body pain site was related to at least one work posture or movement. However, stepping and repetitive hand and wrist movement were not significantly associated with any of the body pains. Potential confounders were tested for their association to each body pain site (Table VI). Stress at work was found to be significantly associated to all the body pain sites. After adjusting for the significant potential confounders for each body pain site, the significant risk factors are shown in Table VII.

The highest odds ratio was 4.8 (95% CI 3.3 - 7.1) for lower leg and standing, reflecting a ratio of almost five

times the odds of developing lower leg pain among those who spent four or more hours compared with those who spent less than four hours at standing operations (Table V). The odds of developing lower leg pain was also increased for climbing (OR 3.1, 95% CI 1.1 - 8.7), lifting (OR 1.8, 95% CI 1.3 - 2.5), twisting (OR 2.1, 95% CI 1.4 - 3.1) and pushing and pulling (OR 2.0, 95% CI 1.4 - 2.9) (Table V). After adjusting for confounders, however, only those who stand for four or more hours in a day had a significant increase in the odds of lower leg pain by more than three times (adjusted OR 3.3, 95% CI 2.1 - 5.3) (Table VII). Standing for four or more hours also showed a significantly higher chance of developing upper leg pain with an odds ratio of 3.1 (95% CI 2.1 - 4.5) (Table V). The odds of developing upper leg pain was also raised for bending, twisting and pushing and pulling, but after adjusting for confounders, it was only significantly higher for bending (adjusted OR 2.7, 95% CI 1.4 - 5.1) and standing (adjusted OR 1.8, 95% CI 1.1 - 2.9) (Table VII).

The chance of developing neck pain was independently associated with sitting, bending and twisting, but after adjusting for confounders, it was only significantly higher by about two times (adjusted OR 2.1, 95% CI 1.3 - 3.2) when sitting for four or more hours. Bending and sitting were both significantly associated with shoulder pain, before and after adjusting for confounders, arm pain was significantly associated with bending only (adjusted OR 1.9, 95% CI 1.2 - 3.2) and wrist pain was not significantly associated with any work postures and movements.

Bending (OR 2.3, 95% CI 1.4 - 3.6) and twisting (OR 1.6, 95% CI 1.1 - 2.3) for four or more hours were significant risk factors for developing back pain (Table V), but after adjusting for confounders, the chance of developing back pain increased significantly by two times (adjusted OR 2.0, 95% CI 1.2 - 3.5) for those who bend for four or more hours (Table VII).

Table I: Socio-demographic characteristics and work profile of the respondents

		Distribution of respondents (N = 529)	
		N	%
Age (years old)	- < 25	137	25.9
	- 25 - 34	192	36.3
	- 35 - 44	177	33.6
	- 45 - 54	23	4.2
Ethnicity	- Malay	400	75.6
	- Chinese	56	10.6
	- Indian	72	13.6
	- Bidayuh	1	0.2
Educational level	- No formal education	3	0.6
	- Primary	27	5.1
	- Lower secondary	137	25.9
	- Upper secondary	327	61.8
	- Sixth form / college / university	35	6.6
Marital status	- Single	186	35.2
	- Married	321	60.6
	- Divorced/widowed	22	4.2
Number of years working in the present factory			
	- 1 - < 2	30	5.7
	- 2 - 4.9	161	30.4
	- 5 - 9.9	96	18.1
	- 10 - 19.9	168	31.8
	- ≥ 20	74	14.0
Work schedule	- Fixed working schedule	36	6.8
	- Rotating eight hour shift	272	51.4
	- Rotating twelve hour shift	221	41.8

Table II: Work processes and tasks of respondents

	Distribution of respondents (N = 529)	
	N	%
Work processes		
Wafer fabrication	***93***	***17.6***
Wafer preparation	22	4.2
Wafer polishing	13	2.5
Wafer inspection and packing	58	10.9
Semiconductor assembly	***411***	***77.7***
Front of line	(98)	(18.5)
Die preparation	34	6.4
Die attach	40	7.6
Wire bonding	24	4.5
Middle of line	(95)	(18.0)
Molding	38	7.2
Forming and trimming	21	4.0
Soldering	36	6.8
End of line	(218)	(41.2)
Die marking and curing	36	6.8
Chip testing	83	15.7
Chip burn-in	15	2.8
Chip inspection	54	10.2
Chip packing	30	5.7
Diode and other assemblies	***25***	***4.7***
Tasks		
Automated	276	52.2
Semi-automated	36	6.8
Manual operation	65	12.3
Inspection	125	23.6
Others	27	5.1

Table III: Prevalence of musculoskeletal symptoms in the last 12 months among women assembly workers (N = 529)

Body sites	Distribution of respondents (N = 529)	
	No.[a]	%
Neck	**157**	**29.7**
Anterior	121	22.9
Posterior	132	25.0
Shoulder	**237**	**44.8**
Anterior (L)	131	24.8
Anterior (R)	158	29.9
Posterior (L)	158	29.9
Posterior (R)	156	29.5
Arm (elbow and forearm)	**154**	**29.1**
Anterior (L)	85	16.1
Anterior (R)	109	20.6
Posterior (L)	80	15.1
Posterior (R)	93	17.6
Wrist and fingers	**117**	**22.1**
Anterior (L)	70	13.2
Anterior (R)	95	18.0
Posterior (L)	59	11.2
Posterior (R)	62	11.7
Upper leg (hips / thighs / knees)	**205**	**38.8**
Anterior (L)	148	28.0
Anterior (R)	150	28.4
Posterior (L)	143	27.0
Posterior (R)	132	25.0
Lower leg (ankles / feet)	256	48.4
Anterior (L)	212	40.1
Anterior (R)	208	39.3
Posterior (L)	214	40.5
Posterior (R)	181	34.2
Back	**306**	**57.8**
Upper back	147	27.8
Middle back	184	34.8
Lower back	151	28.5
Buttock	54	10.2

[a] A respondent can report more than one site of pain.

Table IV: Percentage distribution of respondents at various work postures and movements based on duration per working day (N=529)

Various postures and movements	Duration per working day			
	Not at all	Less than two hours	Two to four hours	Four or more hours
Repetitive hand and wrist movement	0.4	10.5	11.2	77.9
Standing	2.3	23.6	12.9	61.2
Manual lifting	3.0	26.1	15.3	55.6
Sitting	2.6	44.6	18.8	34.0
Pushing and pulling	12.9	42.5	13.2	31.4
Twisting	16.1	33.5	19.8	30.6
Bending	12.5	47.6	20.4	19.5
Climbing	81.7	11.7	3.0	3.6

Table V: Association between pain experienced at various body sites and the time spent at various work postures and movements

Work postures and movements (four or more hours)	Odds ratio (95% CI)						
	Neck	Shoulder	Arm	Wrist	Back	Upper leg	Lower leg
Climbing	1.1	1.1	1.4	1.7	1.3	1.8	3.1*
	(0.4-2.9)	(0.5-2.8)	(0.6-3.7)	(0.6-4.5)	(0.5-3.3)	(0.7-4.5)	(1.1-8.7)
Lifting	1.2	1.1	1.2	1.7*	1.0	1.2	1.8*
	(0.8-1.7)	(1.0-2.0)	(0.8-1.8)	(1.1-2.7)	(0.7-1.5)	(0.8-1.7)	(1.3-2.5)
Standing	0.8	0.9	1.0	1.2	1.1	3.1*	4.8*
	(0.5-1.1)	(0.6-1.3)	(0.7-1.4)	(0.8-1.9)	(0.7-1.5)	(2.1-4.5)	(3.3-7.1)
Sitting	1.8*	1.7*	1.0	1.2	1.0	0.5	0.4
	(1.2-2.6)	(1.2-2.4)	(0.6-1.5)	(0.8-1.9)	(0.7-1.4)	(0.3-0.7)	(0.3-0.6)
Bending	1.9*	2.1*	2.5*	2.7*	2.3*	2.5*	1.5
	(1.2-2.9)	(1.3-3.2)	(1.6-3.9)	(1.7-4.4)	(1.4-3.6)	(1.6-3.8)	(1.0-2.3)
Twisting	1.9*	1.5	1.7*	2.5*	1.6*	1.8*	2.1*
	(1.3-2.9)	(1.0-2.2)	(1.2-2.5)	(1.7-3.8)	(1.1-2.3)	(1.2-2.6)	(1.4-3.1)
Pushing and pulling	1.2	1.5	1.8*	1.9*	1.3	1.5*	2.0*
	(0.8-1.8)	(0.7-1.5)	(1.2-2.7)	(1.3-2.9)	(0.9-1.8)	(1.1-2.2)	(1.4-2.9)
Repetitive hand and wrist movements	1.3	1.1	1.3	1.5			
	(0.8-2.1)	(0.7-1.7)	(0.8-2.0)	(0.9-2.5)			
Stepping	0.6	0.8	-		2.9	1.1	1.6
	(0.1-5.3)	(0.1-5.0)			(0.3-26.5)	(0.2-6.4)	(0.3-9.7)

* Significant

Table VI: Association between potential confounders and body pain by site

Confounders	Chi-square values						
	Neck	Shoulder	Arm	Wrist	Whole back	Upper leg	Lower leg
Stress at work	26.7*	16.1*	12.6*	8.2*	20.0*	11.5*	37.6*
Temperature too cold	3.9*	1.6	0.0	0.0	1.4	8.7*	4.4*
Work schedule#	0.9	0.7	1.0	0.2	0.2	0.1	4.5*
Pregnant during the time of the study	0.0	0.5	2.3	5.3*	1.7	0.8	3.1
Age	35.5*	6.9	10.6*	13.5*	2.8	14.7*	3.9
Number of years working in the present factory	31.1*	9.7*	10.9*	6.9	5.4	4.9	2.2

* $p < 0.05$

Rotating shift work vs. fixed working schedule

Table VII: Association between pain experienced at various body sites and the time spent at various work postures and movements after adjusting for possible confounders

Various work postures and movements (four or more hours)	Adjusted odds ratio (95% CI)						
	Neck	Shoulder	Arm	Wrist	Back	Upper leg	Lower leg
Climbing							1.6 (0.5-4.6)
Lifting				1.3 (0.8-2.2)			1.2 (0.8-1.8)
Standing						1.8* (1.1-2.9)	3.3* (2.1-5.3)
Sitting	2.1* (1.3-3.2)	1.7* (1.2-2.5)				0.6 (0.3-1.0)	0.6 (0.4-1.0)
Bending	1.1 (0.6-1.9)	1.7* (1.1-2.7)	1.9* (1.2-3.2)	1.6 (0.9-2.9)	2.0* (1.2-3.5)	2.7* (1.4-5.1)	
Twisting	1.7 (1.0-2.7)		1.1 (0.7-1.8)	1.6 (0.9-2.7)	1.2 (0.7-1.8)	1.0 (0.6-1.6)	1.0 (0.7-1.6)
Pushing and pulling			1.4 (0.9-2.2)	1.2 (0.7-2.1)		1.0 (0.6-1.7)	1.3 (0.8-2.1)

*Significant

Discussion

In this study, the one-year prevalence of having any musculoskeletal ache or pain ranged from 7% to 48% for different body sites. These prevalence rates are generally higher compared to the study done by Tan[1] among 61 electronics assembly workers from the first seal loading, marking and soldering lines. Only 10% of the respondents in Tan's study had lower leg pain and 20% in the lower back and buttocks. The difference between the two studies could be due to the younger sample in Tan's study (49% of the respondents worked less than two years compared to 5.7% in the present study). Tan's study also had differences in gender composition (inclusion of a male sample), work process and screening methods (one-to-one interview in Tan's study compared to self-reporting in the present study). Ho and Phoon[3] also reported a lower prevalence rate for leg pain (26%) and a higher rate for hands and shoulder pain (38%) among electronics workers.

A large number of the respondents had upper and lower leg pain and this could be because almost two-thirds of the respondents (61.2%) reported standing for four or more hours in a day, while about half of them (52.2%) reported working with automated machines that required the workers to move from one machine to another. In general, the results in this study were in accordance with Harlow *et al.* among electronics assembly women workers in Tijuana, Mexico in 1993, where the prevalence rate for wrist pain was low and prevalence rates for back, neck, shoulder and leg pain (except for ankle or foot sites) were high[5].

The risk factors found in this study were similar to the study by Pocekay *et al.*[4], who found frequent lifting, awkward posture, repetitive work and prolonged activities associated with musculoskeletal problems in the wafer fabrication factories in the United States. The risk factors assessed by Tan[1] in an electronics factory were highly repetitive movements, constant walking, prolonged sitting and intermittent bending as these were also major risk factors found in this study.

Neck and shoulder pain were significantly associated with sitting rather than standing work and this is in accordance with the study by Shierhout *et al.*[7] among workers from seven manufacturing industries in South Africa. This could be because the neck would have been in a bent forward position most of the time when the workers were seated and carrying out tasks like inspection or manual assembly work and the excessive use of the hands at seated jobs cause shoulder pain. In this study there were no significant associations between shoulder pain and repetitive work or forceful movements (lifting, pushing and pulling), but Chiang *et al's* study[8] among fish processing workers in Taiwan showed such associations.

Nevertheless, the prevalence of wrist pain was lower than expected, particularly as a very high number of the workers spent long hours in a day at repetitive hand and wrist movements. The results did not reflect a high prevalence of wrist pain but this could be because the movements were not concentrated in the wrists but distributed over the shoulders, elbows and arms. There was also no significant association between arm and shoulder pain and repetitive hand and wrist movement. The stepping movement was not significantly related to any of the body pain as only about 20% of respondents were involved in tasks that involved stepping and only a very small number (0.9%) did the task for four or more hours.

The study by Punnett *et al.*[9] also found an increased risk of back disorders among production workers in an automobile assembly plant when they were exposed to mild flexion (bending) and twisting of the trunk. The study showed that it was roughly five times more likely to develop back disorders when working with the trunk in mild flexion for any length of time and about six times more likely to develop back disorders when working with the trunk either in severe flexion or twisted or bent sideways. The risk increased with a combination of trunk postures.

This study showed no association between lower back pain and prolonged sitting, while Thorbjörnsson *et al.*[10] did show an association between low back pain and prolonged sitting. Nevertheless, this study showed an association between whole back pain and bending. This could be due to the difference in the type of work where Thorbjörnsson *et al.*[10] covered a general population who were involved in various types of work, while this study was restricted to assembly workers in the semiconductor industry only.

There were some significant associations between work postures and movements and certain body sites that were not directly involved in those particular work postures and movements. For example, bending was significantly related to arm pain, where bending did not directly involve arm movement. This could be because when the worker bends, she also uses her arms to lift

a load like carriers with compartments which were below her waist level.

One of the limitations of this study was the selection of respondents that was left to the supervisors, as the factory managements did not permit researchers to freely carry out random selection. Although it was emphasized to the supervisors that workers should be selected at random from all work processes, nevertheless bias might have existed in the selection of respondents because the supervisor needed to ensure that the production flow was not interrupted by the absence of the workers. Therefore workers with fewer responsibilities and duties might have been selected. Furthermore, workers who were unwell due to musculoskeletal problems might have left employment or were on medical leave thus reducing the apparent prevalence of musculoskeletal problems among women assembly workers in this industry. These two selection biases would, however, lead to an under-estimation rather than an over-estimation of ergonomic problems. Besides this, the study could be improved with a quantifiable observation method to assess the risk factors among the workers.

Conclusion

The prevalence rate of musculoskeletal problems among semiconductor women workers was high and a clear relationship between work-related musculoskeletal pain and exposures to prolonged hours spent in particular postures and movements was demonstrated. It is recommended that employers conduct ergonomic risk assessments in order to reduce the prevalence of musculoskeletal problems in their workplace.

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