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# Work-related Musculoskeletal Problems among Women Workers in the Semiconductor Industry in Peninsular Malaysia

HENG LENG CHEE, PHD, KRISHNA G. RAMPAL, PHD

A cross-sectional study to identify the prevalence of musculoskeletal problems and work-related risk factors was conducted among 906 women semiconductor workers. Highest prevalences were pain in the lower limbs, neck/shoulders, and upper back, and highest exposures were prolonged ( $\geq$  four hours per workshift) hand/wrist movement, standing, and lifting with hands. After logistic regression, lower-limb pain was significantly associated with standing, neck/shoulder pain with sitting and lifting, upper-back pain with climbing steps, low back pain with hand/wrist movement, and hand/wrist pain with lifting. Neck/shoulder pain was significantly higher for workers with shorter working durations, while lower-limb pain was significantly higher for workers with longer working durations. End-of-line assembly workers had significantly higher odds ratios for pain at all sites, while middle-of-line workers had higher odds ratios for pain in neck/shoulders and upper back, and wafer-fabrication workers had higher odds ratios for pain in low back and lower limbs. *Key words:* semiconductor industry; women workers; musculoskeletal problems; ergonomic risk factors.

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**S**emiconductor production begins with wafer fabrication, followed by semiconductor assembly, with the semiconductor, or chip, as the final product. Wafer fabrication is usually carried out in developed countries, but the production processes in semiconductor assembly are located in developing countries, where labor costs are lower. There are many safety and health hazards associated with the semiconductor industry, but the major hazards documented are pri-

marily from intensive chemical usage.<sup>1-3</sup> The large-scale Semiconductor Health Study that encompassed eight manufacturing sites in the United States was largely focussed on the reproductive health hazards associated with chemical exposure,<sup>1</sup> but its cross-sectional component included a study of musculoskeletal symptoms among wafer fabrication and non-wafer-fabrication workers.<sup>4</sup> In Malaysia and Singapore, Lin's study<sup>5</sup> of 903 women workers from five semiconductor factories found that musculoskeletal complaints were among the health complaints of the workers, and the major problems were back and shoulder ache as well as pain in the hand and arm.

In Malaysia, there is a severe lack of studies of the occupational health and safety of semiconductor workers. This is a serious omission considering the central role the semiconductor industry plays in the nation's economy. In 2000, electrical and electronics goods made up 72.5% of the country's total manufactured exports;<sup>6</sup> while the electronics industry is one of the largest employers in the country, employing 343,000 workers, the majority of whom were women, in 1997.<sup>7</sup> Semiconductors are the biggest sector in electronics, accounting for 35-40% of total electronics exports, although the industry is still largely confined to semiconductor assembly and test operations.

With this rationale, a study of occupational health and safety in the semiconductor industry was carried out in Malaysia in 1998-2002. We used data from this study to describe the ergonomic exposures and outcomes of women workers in the semiconductor industry, and to examine the relationships that exist between prolonged exposures to specific postures and movements and outcomes as manifested in pain at specific body sites. Both exposures and outcomes were based on self-reporting.

## METHODS

All semiconductor factories located in two geographic clusters in Peninsular Malaysia were selected from the Malaysian Industrial Development Authority (MIDA) 31 Aug 1998 list, and contact was made by telephone to verify whether or not semiconductors were currently being produced in each factory. A total of 24 factories were identified, and the managements of these factories were invited to participate in the survey through

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invitation letters and information material sent by post, telephone calls, and personal visits by the researchers, as well as a meeting where the questionnaire was discussed, and during which representatives of the state Department of Occupational Safety and Health were present. Nevertheless, representatives of the management of six factories declined to participate, resulting in a total of 18 participating factories and a 75% participation rate.

Data collection was from July 1999 to March 2000. Each factory visit began with a short briefing by human resource and safety and health personnel on work processes, hazards, and health and safety policies, followed by a brief walk-through survey of the plant. The briefings and walk-through surveys varied in duration from factory to factory, but in all cases, they were only sufficient for providing background information about the factories and a cursory understanding of their work processes and working conditions.

The workers' survey was conducted after the initial visit. The managements of the factories did not allow the researchers to carry out selection of the workers directly. The researchers requested the management of each factory to provide a 10% sample of women workers who were Malaysian citizens, had worked for at least a year in the factory, and were direct production line operators. Factories that had fewer than 300 women workers were asked to select at least 30, while those with more than 2,000 workers were asked to select 200 only. The researchers emphasized to the personnel in charge that the selection should be random, and that each work process should be represented.

The selected workers were given time off from their working hours to participate in the study. The management of each factory provided a room where the workers could fill in the questionnaire after being briefed by the researchers. Workers came to the room in staggered batches. During the briefing, the researchers explained the background and rationale for the study and emphasized that it was being conducted by university personnel and funded by the government. The workers were also given the reassurance that individual identification was not required in the questionnaire and that the information they provided would be treated confidentially, as only aggregate data would be used and individual factories would not be identified. The workers generally took about 45 to 60 minutes to fill in the questionnaire.

The instrument used was a self-administered questionnaire containing questions in Malay on sociodemographic and work characteristics, work section, prolonged postures and movements, and body pain. Respondents were asked to circle the sites where they experienced pain on a body map that had been modified from the Nordic Musculoskeletal Questionnaire.<sup>8</sup> The outcome indicators condensed from this were pain experienced in the preceding one year in the neck,

shoulders, arms, hands/wrists, upper back, low back, upper legs (hips, thighs, knees), and lower legs (ankles, feet). Pain felt in the neck and pain felt in the shoulders were combined into one indicator, and pain in the upper and lower legs were also combined (lower limbs), resulting in a total of six indicators.

Exposures were measured by duration in a workday that was spent climbing steps, lifting, standing, sitting, bending, twisting, pushing/pulling, and in doing hand/wrist movements. Responses given in categories of not at all, less than two hours, two to four hours, and four or more hours were collapsed into two categories of less than four hours and four or more hours. Exposure to a particular work posture or movement for four or more hours in a work day was considered to be a risk factor. Work section and duration of working in the present factory were also considered as exposure variables.

The SPSS (Version 11.0) software package was used for statistical analysis. Chi-square and odds ratio were used in bivariate analysis, and the binary logistic regression in multivariate analysis. Six logistic regression models were tested, one for each body pain outcome indicator. The potential confounders tested for their relationships to pain at various body sites were age, work task, work schedule, overtime work, whether or not working environment was too cold, and experienced stress in the preceding one year. Only variables that were statistically significant in the bivariate analysis were included as covariates in each of the models. However, age and number of years worked in present factory were found to be collinear. Therefore, if both of these variables were significantly related to the outcome indicator, only the one with a stronger relationship was included as a covariate in the relevant model.

The study was limited in that objective ergonomic measurements were not carried out, nor were detailed quantitative observations made on postures, movements, and work stations. Furthermore, selection of workers might not have been strictly at random, and could have been biased toward those who were known by management to be healthy and fit. There could also have been a selection bias for workers who could be 'spared' from the production process, leaving out the workers who were under greater time limitations. If it was assumed that workers who were under less time constraint faced fewer health problems, then both these selection biases would lead to an underestimation of health problems.

## RESULTS

Of the 18 participating factories, three were wafer-fabrication factories, and the rest were semiconductor-assembly factories. These wafer-fabrication factories did not carry out all the production processes in wafer fabrication. Instead, semiconductor ingots were imported, and only the wafer-polishing process and the processes

immediately prior to and subsequent to it were carried out. In the semiconductor-assembly factories, the initial processes, from die preparation until die attach, constituted the front-of-line (FOL) work section. These processes were fully automated and carried out in clean rooms. The subsequent steps, in the middle-of-line (MOL) work section, were to mold or encapsulate the exposed die with epoxy resin in order to prevent contamination. Finally, the end-of-line (EOL) work section consisted primarily of processes designed to test the unit in various ways. In a few of the semiconductor assembly factories, assembly of diodes and other electronic components was carried out (collectively termed parts assembly), but these constituted only a minor portion of the production, and were mostly manual operations.

A total of 968 women workers completed the survey, but those who were currently pregnant were not included in the current analysis, making a total of 906 questionnaires. Table 1 shows the background characteristics of the respondents. Only direct-production-line operators were selected for the study, but 7.8% had additional responsibilities as line leaders. All the work sections in the factories were represented by workers in the sample, although it was not known whether they were in proportion to the total numbers of workers in the individual work sections. The majority were in semiconductor assembly EOL (47.9%), while 9.5% were in wafer fabrication, and 5.1% were involved in parts assembly. The majority of the workers had work tasks that were fully automated (57%), where they had to load and unload units into and out of machines, frequently monitoring several machines, fixing the settings and checking when warning buzzers sound. A small percentage (5.6%) were in semi-automated work tasks where they were required to manually handle units in between machine-operated processes. The rest of the workers were performing inspection (19.9%), handling manual tasks (12.3%), and doing supervisory tasks (5.2%), which included maintaining the machines and distributing units.

The major ergonomic exposure was moving hands/wrists (68.8%), followed by standing (55.1%) and lifting with hands (51.2%) (Table 2). Nevertheless, pain in hands/wrists (20.3%) was not the foremost ergonomic outcome among the workers, as higher percentages reported pain in shoulders (42.8%), lower legs (41.9%) and upper back (40.2%). A small proportion (7.7%) reported stress as a health problem that they had experienced in the past year, while many complained that the working environment was too cold (27.4%).

In general, odds ratios for body pain were higher for workers with prolonged exposures to awkward postures and movements, with the exception of sitting, which was protective for pain in the arm, low back, and lower limbs, and standing, which was protective for upper-back pain (Table 3). Table 4 presents the adjusted odds ratios from the six logistic regression models. After adjusting for confounding effects, neck/shoulder pain

TABLE 1. Characteristics of the Study Population

	Respondents (n = 906)	
	No.	%
Age (years)		
< 25	293	32.3
25-34	285	31.5
35-44	284	31.3
45-54	44	4.9
Age, mean $\pm$ SD)	30.6 $\pm$ 8.1 years	
Education level		
No formal education	6	0.7
Primary and lower	59	6.5
Lower secondary	248	27.4
Upper secondary and higher	593	65.4
Marital status		
Unmarried	437	48.2
Married	433	47.8
Divorced or widowed	36	4.0
Years worked in present factory		
1-2	216	23.8
> 2-5	229	25.3
> 5-10	144	15.9
> 10-20	233	25.7
> 20	84	9.3
Job designation		
Operator	835	92.2
Line leader	71	7.8
Work section		
Wafer fabrication	86	9.5
Semiconductor assembly		
Front of line	172	19.0
Middle of line	168	18.5
End of line	434	47.9
Parts assembly	46	5.1
Work task		
Automated	517	57.0
Semi-automated	51	5.6
Manual	111	12.3
Inspection	180	19.9
Supervisory	47	5.2
Work schedule		
Fixed shifts	85	9.4
Rotating 8-hour shift	541	59.7
Rotating 12-hour shift	280	30.9
Overtime work		
Yes	482	53.2
No	424	46.8

was significantly associated with sitting (OR 1.6, 95% CI = 1.2-2.1) and lifting (OR 1.6, 95% CI = 1.1-2.0). Lifting was also associated with hand/wrist pain (OR 1.5, 95% CI = 1.1-2.2). Upper-back pain was associated with climbing steps (OR 3.5, 95% CI = 1.6-7.9), and low back pain with hand/wrist movement (OR 1.6, 95% CI = 1.1-2.3). Workers who were exposed to prolonged standing had 2.7 times higher odds (95% CI = 1.9-3.9) of suffering from pain in the lower limbs, while sitting had a protective effect (OR 0.5, 95% CI = 0.4-0.8).

**TABLE 2. Ergonomic Exposures and Outcomes**

	Respondents (n = 906)	
	No.	%
Movement/ position assumed for more than four hours per work shift		
Moving hands and wrists	623	68.8
Standing	499	55.1
Lifting with hands	464	51.2
Sitting	307	33.9
Pushing and pulling	240	26.5
Twisting the body	205	22.6
Bending	145	16.0
Climbing steps	32	3.5
Body pain experienced in the last one year		
Any part of the body	729	80.5
Neck/shoulders*	465	51.3
Neck	231	25.5
Shoulders	388	42.8
Upper limbs*	317	35.0
Arms	246	27.2
Hands/wrists	184	20.3
Back (upper, lower)*	464	51.2
Upper back	364	40.2
Low back	220	24.3
Lower limbs*	471	52.0
Upper legs (hips, thighs, knees)	289	31.9
Lower legs (ankles, feet)	380	41.9
Temperature too cold	248	27.4
Experienced stress in the last one year	70	7.7

\*Respondents indicating pain in a body region would be those who indicate pain in the body part/parts making up the region. For example, respondents indicating pain in "neck/shoulders" will not be the sum of those feeling pain in the neck and of those feeling pain in the shoulders because those who indicate pain in both neck and shoulders will be counted only once.

It is interesting to note that workers with longer durations of working had significantly lower odds ratios for neck/shoulder pain, but higher odds ratios for lower-limb pain (Table 4). Semiconductor assembly EOL workers had significantly higher odds ratios for pain in every body site, but for MOL workers, pain was concentrated in the neck/shoulders and upper back. Wafer-fabrication workers had significantly three times higher odds for pain in the low back (OR 3.0, 95% CI = 1.1–8.0) and lower limbs (OR 3.1, 95% CI = 1.3–7.1).

## DISCUSSION

### Overall Prevalence

The overall prevalence of body pain found in this study (80.5%) was high compared with corresponding rates from other studies, although it is difficult to make comparisons due to the different measurement methods

used and widely varying study populations. Tan had found overall prevalences of 62% and 76% in two electronics factories in Malaysia using a modified version of the Nordic questionnaire.<sup>9</sup> Harlow et al. used a body map similar to ours in a survey of women in Tijuana, Mexico, and found a one-year prevalence of 59% among the 466 women, which included 109 women working in electronics maquiladora factories.<sup>10</sup> A prevalence similar to that in the present study (79.3% with pain in at least one body part in the preceding 12 months), however, was reported from a study that used the Nordic questionnaire to measure body pain among 363 production workers, 85% of whom were women, in two spinning industry factories in Lithuania.<sup>11</sup>

### Major Areas of Body Pain

In the present study, the major areas where pain was experienced were the neck/shoulders, the upper back, and the lower limbs, while pain in the arms, hands/wrists, and low back were less prevalent. This is similar to the experience of the 109 maquiladora electronics workers in Harlow's study, among whom the most prevalent pain was in the upper back, and the least prevalent in the hand or wrist. In Harlow's study, however, low back pain was also high, and neck/shoulder pain relatively less prevalent.<sup>10</sup> Lin's mid-1980s study of 903 women workers in five semiconductor factories in Malaysia and Singapore similarly found that back and shoulder pain was a major musculoskeletal complaint, but unlike the finding in the present study, hand/wrist pain also featured prominently.<sup>5</sup> In contrast to the present study, where low back pain was less prevalent than upper-back pain, even among the parts assembly workers (11.5% low back pain, 38.5% upper-back pain), Tan's case study of 61 assembly workers in an electronics component factory found the highest prevalence of pain in the low back (30%), and a lower rate in the upper back (18%).<sup>12</sup>

Hoozemans et al. studied pushing and pulling in association with low back and shoulder complaints, and the 12-month prevalence rate of 21% high pain intensity in the low back that they found among the highly exposed group is comparable to the 24.3% found in the current study.<sup>13</sup> They also found a 41% prevalence rate of shoulder trouble (ache, pain, discomfort) among the highly exposed group, which is also comparable to the 42.8% prevalence of shoulder pain in the current study. Although different methods were used, and the current study did not differentiate between trouble and pain or distinguish different levels of pain intensities, the comparable prevalence rates suggest that the study population in the current study might also face high levels of exposure to factors that cause low back and shoulder complaints, even though pushing and pulling for more than four hours was recorded for only 26.5% of the sample.

**TABLE 3. Odds Ratios for Body Pain of Respondents with Prolonged Exposures to Awkward Postures and Movements**

	Neck/Shoulder Pain		Arm Pain		Hand/Wrist Pain		Upper-back Pain		Low Back Pain		Lower-limb Pain	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Climbing steps	1.6	0.8-3.3	1.9	0.9-3.9	2.1	1.0-4.5	3.4	1.6-7.3	1.0	0.5-2.4	2.1	1.0-4.5
Lifting	1.6	1.2-2.0	1.5	1.1-2.1	1.8	1.3-2.6	1.2	0.9-1.5	1.1	0.8-1.5	1.5	1.1-1.9
Standing	1.1	0.9-1.5	1.4	1.0-1.8*	1.4	1.0-1.9	1.0	0.7-1.3	1.2	0.9-1.6	4.1	3.1-5.4
Sitting	1.5	1.2-2.0	0.9	0.6-1.2	1.2	0.8-1.6	1.2	0.9-1.6	0.9	0.7-1.3	0.4	0.3-0.5
Bending	2.0	1.4-2.9	2.3	1.6-3.4	2.4	1.6-3.5	1.8	1.2-2.5	1.5	1.0-2.2*	1.8	1.3-2.6
Twisting	1.8	1.3-2.5	1.8	1.3-2.6	2.1	1.5-3.0	1.7	1.2-2.3	1.6	1.1-2.2	2.2	1.6-3.1
Pushing/pulling	1.4	1.1-1.9	1.9	1.4-2.6	1.6	1.1-2.3	1.1	0.8-1.5	1.3	0.9-1.8	1.5	1.1-2.0
Hand-wrist movement	1.4	1.0-1.8*	1.5	1.1-2.1	1.5	1.0-2.1*	1.5	1.1-2.0	1.8	1.3-2.6	1.4	1.1-1.9
Years worked												
1-2	2.1	1.2-3.5	1.5	0.8-2.7	1.3	0.7-2.6	1.6	0.9-2.7	1.3	0.7-2.5	1.0	—
> 2-5	2.2	1.3-3.8	1.5	0.8-2.8	1.4	0.7-2.7	2.0	1.1-3.4	1.9	1.0-3.5	1.4	0.9-2.0
> 5-10	1.8	1.0-3.1*	1.4	0.7-2.7	1.8	0.9-3.7	1.9	1.1-3.4	1.5	0.7-3.0	1.5	1.0-2.4*
> 10-20	1.9	1.1-3.2	1.6	0.9-3.0	1.4	0.7-2.7	1.7	1.0-2.9	2.0	1.1-3.8	2.4	1.6-3.5
> 20	1.0	—	1.0	—	1.0	—	1.0	—	1.0	—	2.5	1.5-4.2
Work section												
Wafer fabrication	1.4	0.8-2.3	1.0	—	1.2	0.6-2.4	1.0	—	3.2	1.2-8.5	3.0	1.4-6.4
Front of line	1.0	—	1.6	0.8-3.1	1.0	—	1.1	0.6-1.9	1.5	0.6-3.9	1.7	0.9-3.4
Middle of line	1.8	1.2-2.8	1.8	0.9-3.5	1.6	0.9-2.8	1.7	1.0-2.9	1.9	0.7-4.8	2.0	1.0-3.91
End of line	1.8	1.3-2.6	2.3	1.3-4.3	2.1	1.3-3.4	1.7	1.0-2.8*	2.5	1.0-5.9*	1.8	1.0-3.3
Parts assembly	1.5	0.8-2.9	2.3	1.0-5.3	1.8	0.8-4.1	1.2	0.5-2.5	1.0	—	1.0	—

\*Considered marginally significant because 95% CI was above 1.00 but lower than 1.05.

*Neck/Shoulder Pain*

In the logistic regression model for neck/shoulder pain, the adjusted odds ratios were significantly higher for sitting and the EOL work section. Among the EOL workers, many were chip inspection workers who would be seated with their necks and shoulders in a bent-forward position when doing inspection work. Association between neck/shoulder pain and sitting was also found in a study of workers from seven manufacturing industries in South Africa.<sup>14</sup>

The odds ratio for neck/shoulder pain was also higher for MOL workers and for lifting. In the MOL work section, molding workers, particularly those using the older machines, would be exposed when lifting the molding metal frames. The metal frames handled by those using the newer machines were smaller and the loads lifted lighter, but the repetitive nature of the task could increase the exposure risk.

Lifting had been associated with shoulder pain in previous studies. For example, shoulder pain among newly employed workers was associated with carrying on one shoulder, lifting at least 25 lb with one hand or at least 50 lb with both hands, lifting at or above shoulder level, pulling, and bending forwards in an uncomfortable position.<sup>15</sup> Gamperiene and Stigum had found that spinning workers who lifted small weights had more problems of the neck or arms than did those who seldom or never lifted.<sup>11</sup>

Previous researchers also had associated neck and shoulder pain with repetitive tasks. Shoulder-girdle

(neck, shoulder, upper arms) pain was significantly higher among workers in the fish-processing industry who performed tasks with repetitive movements, as well as sustained forceful movements, of their upper limbs.<sup>16</sup> In a longitudinal study that included over 6,000 women in France, the incidence of neck and shoulder pain was found to be significantly related to repetitive work under time constraints and high job demand, after controlling for age and other exposures.<sup>17</sup> One previous study had found shoulder complaints to be consistently related to a high exposure of pushing and pulling,<sup>13</sup> but this relationship was not observed in the current study.

*Arm Pain*

In previous studies, arm pain, along with shoulder pain, had been associated with lifting light loads and repetitive movements of the upper limbs.<sup>11,16,18</sup> Increased risks were also found for exposures measured by a combination of postures and movements, such as strained posture among spinning workers, which referred to workers who were simultaneously bending, working with hands raised above shoulder level, and performing repetitive movements with their fingers.<sup>11</sup> Women trailer-assembly workers exposed to at least two of high repetitive movements, forceful exertions, or frequent wrist bending had been found to have high risk for arm pain.<sup>18</sup> In the current study, arm pain was marginally associated with bending, but not with other movements. It may be that bending was

**TABLE 4. Adjusted Odds Ratios for Body Pain of Respondents with Prolonged Exposures to Awkward Postures and Movements**

	Neck/Shoulder Pain		Arm Pain		Hand/Wrist Pain		Upper-back Pain		Low Back Pain		Lower-limb Pain	
	Adj OR	95% CI	Adj OR	95% CI	Adj OR	95% CI	Adj OR	95% CI	Adj OR	95% CI	Adj OR	95% CI
Climbing steps	—	—	—	—	—	—	3.5	1.6–7.9	—	—	—	—
Lifting	1.6	1.1–2.0	1.2	0.9–1.7	1.5	1.1–2.2	—	—	—	—	0.8	0.6–1.2
Standing	—	—	1.0	0.7–1.5	—	—	—	—	—	—	2.7	1.9–3.9
Sitting	1.6	1.2–2.1	—	—	—	—	—	—	—	—	0.5	0.4–0.8
Bending	1.3	0.8–1.9	1.6	1.0–2.5*	1.5	1.0–2.4	1.2	0.8–1.8	1.1	0.7–1.7	1.4	0.9–2.3
Twisting	1.4	1.0–2.1	1.2	0.8–1.9	1.6	1.0–2.4*	1.3	0.9–1.9	1.3	0.8–1.9	1.3	0.8–1.9
Pushing/pulling	1.1	0.8–1.5	1.4	0.9–2.0	1.0	0.7–1.5	—	—	—	—	0.9	0.6–1.3
Hand-wrist movement	0.9	0.7–1.3	1.2	0.8–1.7	1.1	0.7–1.6	1.3	0.9–1.8	1.6	1.1–2.3	1.2	0.9–1.7
Years worked			—	—	—	—						
1–2	2.0	1.9–3.5					1.4	0.8–2.5	1.2	0.6–2.5	1.0	—
> 2–5	2.0	1.2–3.5					1.8	1.0–3.1*	1.7	0.9–3.3	1.3	0.9–2.0
> 5–10	1.7	1.0–3.0					1.7	0.9–3.0	1.4	0.7–2.9	1.8	1.1–2.8
> 10–20	1.8	1.0–3.1*					1.5	0.8–2.6	2.0	1.0–3.8*	2.0	1.3–3.0
> 20	1.0	—					1.0	—	1.0	—	2.2	1.2–4.0
Work section												
Wafer fabrication	1.2	0.7–2.2	1.0	—	1.0	0.5–2.1	1.0	—	3.0	1.1–8.0	3.1	1.3–7.1
Front of line	1.0	—	1.8	0.9–3.6	1.0	—	1.5	0.8–2.7	1.8	0.7–4.7	1.5	0.7–3.2
Middle of line	1.7	1.1–2.7	1.9	1.0–3.8	1.4	0.8–2.5	2.2	1.2–4.0	1.9	0.7–5.2	1.7	0.8–3.7
End of line	1.8	1.3–2.7	2.7	1.4–5.1	2.1	1.3–3.4	2.1	1.2–3.5	2.7	1.1–6.8	2.1	1.0–4.3*
Parts assembly	1.5	0.8–3.0	2.5	1.0–6.0*	1.8	0.8–4.2	1.2	0.5–2.7	1.0	—	1.0	—

\*Considered marginally significant because 95% CI was above 1.00 but lower than 1.05.

For each logistic regression model, the covariates were the variables with values presented in the respective column. In addition, confounding variables included as covariates were 1) temperature too cold and experienced stress in the last one year for neck/shoulder pain, 2) experienced stress in the last one year for arm pain, 3) experienced stress in the last one year for hand/wrist pain, 4) work task, temperature too cold and experienced stress in the last one year for upper back pain, 5) work task, overtime, and temperature too cold for low back pain, and 6) work task, work schedule, overtime, temperature too cold and experienced stress in the last one year for lower-limb pain.

done simultaneously with other movements, that together, as a composite, would account for the arm pain. If that were so, a combination of movements would have been a better measure of exposure.

#### Hand/Wrist Pain

Considering the high proportion (68.8%) of workers having prolonged exposure to hand/wrist movements in the current study, the prevalence of hand/wrist pain was lower than expected (20.3%). Furthermore, hand/wrist pain was not higher among workers exposed to prolonged hand/wrist movements, although it was associated with lifting. This could be because of particular movements in the work tasks that may not be concentrating the movements in the wrists but distributing them over the shoulders and arms. The current results therefore contrast with those of previous studies that show associations between repetitive wrist movements and wrist or forearm pain.<sup>21</sup> In the Semiconductor Health Study, increased risk of musculoskeletal symptoms in distal upper extremities was associated with frequency of lifting, and use of vacuum wands and projection aligners.<sup>4</sup>

#### Upper-back Pain

Climbing steps was significantly related to upper-back pain, but only 32 workers (3.5%) reported prolonged exposure to this movement. This was in the EOL section where the worker had to climb three steps up to load the strips of chips onto the carrier for testing. Upper-back pain was significantly higher for MOL and EOL work sections, and for workers in inspection and semi-automated work tasks. The chip-inspection workers at the EOL who suffered from neck/shoulder pain due to the bent-forward position of the head and neck could also face higher risk of upper back pain from the prolonged sitting, particularly when chairs did not have back support and tables were too high. In the MOL, many of the workers performed lifting tasks, which could be a cause for the upper back pain.

Most studies in the literature focus on pain in either the low back or the whole back, rather than on upper-back pain. Back disorders among production workers in an automobile assembly plant were related to bending and twisting of the trunk.<sup>19</sup> Repeated strenuous physical activity such as lifting, pushing or pulling

heavy objects, and repeated bending, twisting, or reaching were the risk factors identified for back pain among 30,074 workers who were surveyed in the United States National Health Interview Survey.<sup>20</sup> In the current study, bending and twisting had higher odds ratios for upper-back pain as well as low back pain, but these relationships were not significant.

### *Low Back Pain*

In the literature, low back pain is associated with lifting heavy loads, twisting, and bending.<sup>21</sup> Besides shoulder pain, increased odds ratios for low back pain were also found for carrying on one shoulder, lifting at least 25 lb with one hand, and lifting at least 50 lb with both hands among newly employed workers.<sup>15</sup> In a random sample of 5,185 Danish employees, low back pain was significantly associated with physically hard work, twisting or bending, and lifting heavy loads.<sup>22</sup>

In the current study, lifting, twisting, and bending were not significantly associated with low back pain. However, low back pain was significantly higher in wafer fabrication. There were work processes in wafer fabrication where workers were lifting ingots that were heavier than 30 kilograms and racks that were heavier than 1 kilogram. Low back pain was also significantly more prevalent in the EOL workers. One work process at the EOL that could have a high risk for workers was the chip burn-in process, which involves loading chips manually onto burn-in boards with highly repetitive movements, stacking the boards onto a trolley, and loading and unloading boards into and out of ovens, which might require bending.

Sitting was not significantly related to low back pain. This is different from Jin's review of two studies where prevalences of back pain among sedentary workers in electric-component factories were higher in both instances than those in standing and free-posture workers.<sup>21</sup> On the other hand, low back pain among Danish employees was associated with standing, but not with sitting.<sup>22</sup> Hand/wrist movement was inexplicably found to be significantly associated with low back pain in the current study. It might be that workers doing hand/wrist movements were involved in different tasks that required various combinations of other body movements that caused low back pain.

### *Lower-limb Pain*

Workers exposed to prolonged standing faced a 2.7 times significantly higher risk of pain in the lower limbs. As many as 55% of the workers reported having to stand for more than four hours in a work shift. Wafer-fabrication workers faced more than three times significantly higher risk of lower-limb pain. This might be accounted for by the wafer preparation and wafer-polishing workers, who lifted racks and did other tasks

while standing, sometimes intermittently walking short distances. Emphasis on lower-limb pain appears less in the literature, although high prevalences have been recorded among electronics-assembly workers.<sup>9,10</sup> The protective effect of sitting observed in the current study had also been recorded among workers in the spinning industry in another country.<sup>11</sup>

### *Work Section and Work Task*

On the whole, EOL workers had significantly higher risks for pain in all body parts. This is supported by Lin, who found that semiconductor workers at the EOL and test sections were more likely to experience musculoskeletal pains (Lin's classification of "end of line" is equivalent to the current study's "MOL," while "test sections" in Lin is similar to "EOL" in the current study).<sup>5</sup>

The high level of lower-limb pain in the current study was concentrated among the workers in wafer fabrication, which was not a work section included in Lin's study. In the United States, wafer-fabrication workers had a higher risk of musculoskeletal symptoms than did non-wafer-fabrication workers,<sup>4</sup> but this could not be applied to the current study, where the wafer fabrication work processes were not all present. Nonetheless, there is also a possibility that the higher representation of EOL workers in the current study rendered statistical relationships between variables more visible.

The MOL workers suffered primarily from pain in the neck/shoulders and the upper back, most likely attributable to frequent lifting. Parts-assembly workers had a significantly higher risk of arm pain, but also registered a relatively higher prevalence of pain in the neck/shoulders and hand/wrist. The lack of statistical association could be due to the small number of parts-assembly workers in the current sample. The FOL workers had relatively lower risks of body pain. Workers here did more walking around, as they operated several machines at a time, although they worked in clean rooms and were exposed to cold temperatures.

### *Number of Years Worked*

Workers with shorter working durations faced higher risks of neck/shoulder pain. This could be indicative of a healthy-worker effect, where those with serious problems would have left employment earlier, leaving behind in the workforce workers with lesser problems. Health selection has been shown in previous studies for back complaints,<sup>23</sup> musculoskeletal disorders of the neck and shoulders,<sup>24</sup> and fingers,<sup>25</sup> and disorders of the upper limbs.<sup>18</sup> In contrast to neck/shoulder pain, health selection was not observed for lower-limb pain, which was significantly more prevalent among workers with longer working durations in the current study. This was most likely an effect of age, which was



correlated with working duration. It is possible that aging has a greater impact on an outcome (in this case, lower-limb pain) that has not been subjected to health selection.

## CONCLUSION

The strength of the current study lies in its relatively large sample size, which was constituted by workers from a fair representation of the semiconductor factories located in two large clusters. Insofar as selection could have favored less busy and healthier workers, it would have led to an underestimation of symptom prevalences. A healthy-worker effect, if present, would also work in the same direction of bias.

One of the limitations of the study was that it relied on self-reporting for measurement of exposures and outcomes. The study was primarily focussed on work-related factors, and other potential confounders, such as leisure-time activities, history of back disorders, anthropometric measurements, and demographic factors such as taking care of young children, were not taken into consideration.

Psychosocial factors could have been important confounders, but were not within the scope of the study. Recent studies in the literature emphasize the effect of psychosocial factors in increasing the risk of musculoskeletal problems such as chronic neck and shoulder pain,<sup>17,24</sup> upper-limb disorders, particularly hand and wrist pain,<sup>26</sup> back disorders,<sup>27</sup> and low back complaints.<sup>13,28</sup> Stress was very crudely measured in the current study. More nuanced measurements of stress and the effects of psychosocial factors should be incorporated into future studies.

One major finding was that large proportions of the semiconductor workforce were exposed to prolonged standing (55%) and experienced pain in the lower limbs (52%), and there was a clear association between them. The shoulders and upper back were the regions where pain prevalence was dominant among the semiconductor workers. The risk factors for these, however, were not so clearly defined by the study, and require further investigation.

The apparent anomaly seen in the high level of exposures to prolonged hand/wrist movements and relatively low prevalence of hand/wrist and arm pain also needs to be further investigated. It could be that risk factors would be more realistically and accurately represented by composites of working postures and movements. Likewise, further investigation is needed for the relatively higher levels of pain in the neck/shoulders, upper extremities, and upper back reported by workers in the EOL section, and the increased pain in the neck/shoulders and upper back among workers at the MOL. Working processes and postures of workers in parts assembly should be investigated for an association with back pain.

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