Effects of ergonomics-based wafer handling training on reduction in musculoskeletal disorders among wafer handlers

Hsin-Chieh Wu\textsuperscript{a}\*, Hsieh-Ching Chen\textsuperscript{a}, Toly Chen\textsuperscript{b}

\textsuperscript{a}Department of Industrial Engineering and Management, Chaoyang University of Technology, No.168, Jifong East Road, Wufong Township, Taichung County, 41349, Taiwan, R.O.C.

\textsuperscript{b}Department of Industrial Engineering and System Management, Feng Chia University, Taichung, 407, Taiwan, ROC

\*Corresponding author. Tel.: 886-4-2332-3000 ext.4537; fax: 886-4-2374-2327.

\textit{E-mail address:} hcwul@cyut.edu.tw (H.-C. Wu)

\textit{Postal address:} Department of Industrial Engineering and Management, Chaoyang University of Technology, No.168, Jifong East Road, Wufong Township, Taichung County, 41349, Taiwan, R.O.C.
Abstract

This study was aimed at better understanding the effects of ergonomics-based wafer handling training in a semiconductor fab. The 400 female wafer handlers were given two hours of the ergonomics-based wafer handling training course. The identified risk factor ratio (IRFR) in the workplace and workers’ musculoskeletal disorders (MSDs) were collected before and after the training. The qualitative efficacy of the training was also obtained through a questionnaire. The responses to the questionnaire reflect the generally positive attitude of the workers towards the training. The results of the IRFR from pre- to immediately post-training proved that the implementation of the training significantly increased safe behavior in work practices. One year after training, no significant decreases in the prevalence of MSDs were found for any body parts except the legs. This ergonomics-based training intervention is considered as a success to reduce risk factors associated with improper work methods and postures, but little data could validate its effectiveness on prevention of all the MSD problems.

Relevance to industry

This study demonstrates a systematic approach for examining effects of ergonomics-based wafer handling training tailored for female fab workers on reductions
in work-related risk factors and their musculoskeletal disorders. Although the training course and effect evaluation methods are developed for the semiconductor industry, other similar industries can refer to this paper to design their own ergonomic training courses and evaluate the effects of the training interventions in practice.

*Keywords:* Musculoskeletal disorders; Employee training; Clean room health; Occupational safety and health; Work-related risk factors
1. Introduction

The semiconductor manufacturing industry is one of the important industrial sectors in Taiwan. Some studies have already reported the prevalence of musculoskeletal disorders (MSDs) in semiconductor workers (Pocekay et al., 1995; IOSH, 1996; Yu, et al., 2003; Chee and Rampal, 2004). The work-related risk factors in the semiconductor wafer fabrication might include awkward postures and long working hours (Chee and Rampal, 2004), prolonged standing and frequent walking (Yu, et al., 2003), and high production demands, inadequate equipment design and repetitive wafer handling activities (Pocekay et al., 1995; Chee and Rampal, 2004). In particular, Wang et al. (2004) indicated that 300mm wafer handlers exposed to more musculoskeletal risk factors, as compared to 200mm wafer handlers. This is due to that both the weight and the size of a 300mm wafer markedly increase physical load on the wafer handlers.

Several ergonomic interventions, such as employee training, redesign of process tools or workstations, and improvement of work conditions, were suggested to tackle musculoskeletal problems in industries (Wang et al., 2003; Weestgard and Winkel, 1997). However, a semiconductor manufacturer still needs to know actual effects of a proposed ergonomic intervention to judge whether this MSD preventive measure is worth doing or not. In fact, several ergonomists had proved that ergonomically
redesigned workstations or the introduction of new tools and equipments could reduce musculoskeletal discomfort or injuries for the semiconductor workers (Chung and Wang, 2001 and 2002; Lin and Chan, 2007), but relatively few attempts were made to evaluate the training effects for tackling MSDs in practice (Whysall, et al., 2006; Whysall, et al., 2004).

This paper presents an empirical study that examines the effects of the ergonomics-based wafer handling training on the wafer handlers in a 300mm semiconductor fab. Firstly, the participants and their work activities were introduced. Then, the development and implementation of the training intervention were mentioned. Subsequently, the qualitative and quantitative measures for examining the effects of the training course were expressed. Finally, the impacts of the training intervention on the reductions in identified risk factor ratio (IRFR) and prevalence of MSDs were presented and discussed.

2. Methods

Information was collected from the semiconductor workers via a questionnaire, interviews, and field observation using the MSDs checklist.
2.1 Participants and their jobs

Potential participants in this study were full-time workers in a 300mm wafer fab in Taiwan. A total of 400 workers were asked to attend the ergonomics-based wafer handling training course. None of them had ever received this kind of training before this study. A questionnaire survey was performed to collect the trainees’ subjective judgments on this training course.

All these trainees were females and their main tasks include wafer container carrying, transporting, loading and unloading tasks among various wafer processing tools and storage racks. The 300mm wafer container is called a front opening unified pod (FOUP), and weighs about 9 kg while containing one lot (25 pieces). These trainees were distributed to eight areas: wafer start, lithography, diffusion, thin films, control wafer recycle, etch, ion implantation, and chemical mechanical planarization areas.

The shift working system in the study semiconductor manufacturing company involves four teams with a two-shift system. The two shifts are a 12-hr day shift and a 12-hr night shift. Two of the four teams (one for the day shift and one for the night shift) work two consecutive days, then rest for two days. The teams alternate every two days. The training courses were arranged on their rest days.
2.2 The ergonomics-based wafer handling training course

This training course combined past experience of wafer handling with the ergonomic guidelines for tackling occupational MSDs (Kroemer and Grandjean, 1997; Rodgers, et al., 1986; Sanders and McCormick, 1993; Sedgwick and Gormley, 1998; Waters, et al., 1993). The purpose of this training course was to make the wafer handlers aware of the adverse effects of manual FOUP handling, and to confer upon each worker the responsibility of maintaining a safer posture at work (i.e. a self-directed intervention), with the final aim of reducing MSDs.

The structure of the training course began with the standard work postures and lifting-related techniques for manual FOUP handling. Secondly, the guides for safely transporting FOUPs by a trolley were provided. Thirdly, work-related risk factors for the onset of MSDs identified early in the wafer fab were also covered. Finally, practical MSD cases and their causes happened in the wafer fab were illustrated in detail. In total, 27 slides were used in the training course. The trainer, an associate professor, is the author who has taught ergonomics-related courses in the university for five years, and he was once a safety and hygiene engineer of this study semiconductor company.

In addition to training, three posters were produced and pasted down on the board to remind workers of avoiding awkward postures while handling a FOUP.
2.3 *The questionnaire after training intervention*

The questionnaire was mainly designed to collect the trainees’ subjective judgments on the training intervention after receiving the training course. This questionnaire comprised two parts. The first part contained questions on background information, such as age, years of occupation, monthly income, frequency of suffering from MSDs, and frequency of taking medical treatment in the past six months. The second part contained questions about trainees’ perception after receiving the training course. They comprised perceived training effects, keeping standard work postures, attitude to personal safety issues, and requirement for this kind of training.

2.4 *Objective measures before and after training*

In addition to the subjective responses to the training via the questionnaire, two objective measures were also collected before and after training for verifying the effects of this training intervention. One measure was identified risk factor ratio (IRFR), and the other was prevalence of MSDs. These two objective measures were obtained through the field observations and interviews with the workers, respectively.
2.4.1 Field observations

The identified risk factor ratio (IRFR) was defined as the number of workers exposed to a specific risk factor in percentage of all of the observed workers. About 18% of the workers were randomly selected from each working area including wafer start, lithography, diffusion, thin films, control wafer recycle, etch, ion implantation, and chemical mechanical planarization areas. A total of 70 workers were selected to be observed once before training. It took around 40 minutes for each individual observation in order to completely identify the risk factors for the worker.

The MSDs checklist, developed by Occupational Safety and Health Administration (OSHA, 1995), was adopted as the assistant tool to identify the risk factors for the wafer handlers. This is due to that a previous study has confirmed that the MSDs checklist is a sensitive and useful tool in identifying the musculoskeletal risk factors in the wafer fabs (Lu, et al., 1999). The MSDs checklist includes three parts: Part A checks the risk factors that might lead to upper extremity problems, Part B checks the risk factors associated with back pain and lower extremity disorders, and Part C evaluates the risk factors about manual material handling tasks. The action limit is set at five risk score. If the evaluated risk score of Part A is equal to or over five, then ergonomic interventions should be performed to keep workers from the upper extremity problems. Besides, if the
sum of the risk scores of Parts B and C is equal to or over five, then some improvement actions need to be taken to prevent workers from back pain and lower extremity disorders.

The observers, three graduate students, were specially trained by the author who met them regularly to maintain the quality and consistency of the field observation throughout this project. Before formal observations, the three observers were asked to observe six wafer handlers for testing their inter-rater reliability. Few differences were found between each pair of the three observers for the ratings on MSDs checklist (their intra-class correlations were all above 0.94). It was confirmed that each observer was familiar with the standard check procedure and followed the identical evaluation criteria.

In order to prevent workers from modifying their behaviors for the observers (Hawthorne effect), the workers were not told what day they would be observed. The observers, who wore the clean room clothes, look like the wafer handlers, secretly performed the field observation. Also, the observers were blinded to intervention status of the workers. In addition to MSDs checklist, the observer used a digital camera to capture the identified risk factors. The field observations were arranged one month before the training session for collecting the baseline information. One month immediately after the training, the field observations were performed again for
evaluating the training effect. However, only a half of the early observed 70 workers were randomly selected and observed again for the sake of cost efficiency. The procedure and evaluation criteria were the same as those of the pre-training observations.

2.4.2 Interviews with the workers

The prevalence of MSD was defined as the number of workers suffered from MSD on a specific body part in percentage of all of the sampled workers. The musculoskeletal disorders were considered as present if they were attributed to the wafer-handling tasks and had lasted for more than one week during the previous six months. The MSD status of each sampled worker was collected by the individual interview. The identical question for each individual interview was as follows: Have you had any musculoskeletal disorders (pain, discomfort or reduced mobility) during the previous six months? What body positions do the musculoskeletal disorders develop (neck/shoulders, arms, wrists, lower back, legs, and feet)? How long do the musculoskeletal disorders last? After the field interviews, the researcher recorded the responses and calculated the prevalence of the MSDs for each body part. The researchers were the same as the observers mentioned early. The field interviews were performed one month before the training session for collecting the baseline information. Subsequently, 12 months after
the training session, the prevalence of MSDs was collected again for evaluating the training effect. Since it needs a long time to spontaneously recover from the MSDs (Elders, et al., 2000), it is not comprehensive to collect the MSD status immediately after training. Therefore, the interviews for collecting the follow-up prevalence of MSDs were considered being performed one year after the end of the training.

2.5 Research procedure

The whole research was divided into three periods: pre-training (the first two months), receiving training (the third month), and post-training (from the fourth to the sixteen month).

During the pre-training period, 70 workers were randomly selected from all of the 300mm wafer handlers for collecting baseline information in terms of IRFR and prevalence of MSD. The IRFRs were obtained through field observation with the MSDs checklist. The selected 70 workers gave their oral consent to indicate their willingness to be observed and to perform normal duties at their own pace and using their own postures as usual. Each individual observation took about 30 to 45 minutes. After field observation, the workers were then interviewed with the researcher for collecting their MSD statuses.
In the receiving training period, the same training course was given two times in the study semiconductor company. All of the wafer handlers in the 300mm wafer fab were asked to attend one of these two sessions. The training course took 120 minutes including lecture, discussion, and test time. At the end of the training, the 400 trainees were asked to complete the questionnaire at home (and were given up to one week to do so). A total of 274 returned completed paper questionnaires, for a 68.5% response rate of those who received the wafer handling training.

One month after training, 35 workers were randomly selected from the early investigated 70 workers for observing their risk factors again. The same observers also secretly performed the field observation with the MSDs checklist. These workers were not told what day they would be observed. Comparisons between pre- and post-training were made to check whether the identified risk factor rates after training were significantly less than those before training. Finally, one year following the training session, the MSD statuses for six body parts were collected again from the same 35 workers as mentioned above. In order to prevent the Hawthorne effect of these 35 workers, the researchers promised them to keep their individual information secret from the other persons and asked them to honestly report their MSD statuses. In addition, it is believed that the workers would not intentionally approve the training intervention
because the training courses were arranged on their rest days and they had no overtime pay.

2.6 Statistical analysis

The analysis used the SPSS statistical software package. First, descriptive statistics were computed for all the questionnaire responses. Next, the Spearman Rank Correlation coefficients were calculated among each pair of the nine responded questions. The next part of the analysis used z-test to examine significant differences in both IRFR and prevalence of MSD between pre- and post-training. The significant level was set at \( p < 0.05 \).

3. Results

3.1 Questionnaire responses to the training

Table 1 summarizes the responded results of the first part of the questionnaire. About 70% of the respondents were 21~30 years old, and more than 50% of the respondents worked in this company within two years. 54.7% of the respondents were monthly paid 601~750 USD for the wafer handling job. For the question about suffering from
musculoskeletal disorders (Q4), to which 89.1% at least suffered one time in the past six months, while 10.9% were never. As for the question about taking medical treatment for musculoskeletal disorders (Q5), to which 67.5% at least took one time in the past six months, while 32.5% were never. These results implied that about 20% of the respondents tried to spontaneously recover from musculoskeletal disorders instead of taking medical treatment.

The trainees were also asked about their attitude towards the wafer handling training course. The questions appear in Table 2, along with their responses. For the four questions (Q6~Q9) on positive impact on the workers, 86.5% or more of the respondents either responded ‘agree’ or ‘strongly agree’. These results indicated that most of the respondents believed that the training course was effective in reducing the MSDs by keeping standard work postures. In addition, this training course made most trainees pay more attention to their safety issues in the workplace and require this kind of the training.

Table 3 shows the results of the correlation analyses among responses to the nine questions. There were significant (p < 0.05) correlations among over a half of the pairs of the studied variables, although only 11% of the correlation coefficients would be considered moderate ( |r| from 0.4–0.69), and the rest were low or weak ( |r| of 0.39 or
less). It indicates that the perceived training effect was significantly correlated with the frequency of suffering from MSDs (r=0.21, p<0.01), frequency of taking medical treatment for MSDs (r=0.16, p<0.01), frequency of keeping standard postures (r=0.36, p<0.01), attitude to safety issues (r=0.20, p<0.01), and requirement for the training (r=0.44, p<0.01). The frequency of suffering from MSDs was significantly correlated with the age (r=0.21, p<0.01), years of occupation (r=0.29, p<0.01), monthly income (r=0.14, p<0.05), frequency of taking medical treatment (r=0.63, p<0.01), perceived training effect (r=0.21, p<0.01), and requirement for the training (r=0.16, p<0.01).

3.2 Identified risk factors before and after training

Since the observed risk factors were similar among the eight working areas, the obtained results were pooled and then the average risk score for the 70 workers was calculated before training intervention. The average risk score in Part A of the MSDs checklist was 1.53, which was less than the action limit (i.e. risk score = 5). The summation of the mean risk scores in Parts B and C was 9.16, which was too high as compared to the action limit. These results indicated that the company should take some improvement actions immediately to eliminate the high risk about back pain and lower extremity disorders. The risk factors identified from the 70 sampled workers before
training are listed in Table 4. Accordingly, the corresponding results obtained one month after training are also listed in Table 4 for comparisons.

Three risk factors after training were significantly less than the baselines. The greatest reduction in the identified risk factor ratio (IRFR) was transporting a full FOUP manually over three meters (a drop of 51.4%), followed by those for twisting the trunk over 45° (a drop of 31.5%) and bending the trunk forward over 20° (a drop of 24.2%). The other IRFRs were not significant different between pre- and post-training periods.

3.3 Prevalence of MSDs before and after training

The prevalence of MSDs in each of the six body positions one month before and 12 months after the training was compared in Table 5. A significant decrease (p < 0.05) in the prevalence of MSD from pre to post training was found in the legs (a drop of 19.3%). Although an obvious reduction in the prevalence of MSD was also found in the lower back (a drop of 12.0%) and feet (a drop of 6.5%), these decreases were not statistically significant from pre to post training. The rest of body parts, neck/shoulders, arms and wrists, were not positively impacted by the training intervention.

4. Discussion
4.1 Perceived training effectiveness

The results of the correlation analyses among responses to the questionnaire indicate the perceived training effectiveness was significantly and positively correlated with the frequency of suffering from MSDs and frequency of taking medical treatment for MSDs. It means that the symptomatic workers tended to judge the training more effective than the asymptomatic ones. This phenomenon could be due to that the workers with more serious MSDs before tended to take medical treatment more frequently; hence they had higher motivation and interest to receive the training for tackling their MSDs. In other words, the healthy workers seemed to consider the training course less effective due to that they were younger and had little experience of suffering from MSDs, and in consequence they could not make sure of effectiveness of the training course.

In addition, the perceived training effect was also positively correlated with keeping standard postures, attitude to safety issues, and requirement for the training. Therefore, the workers who recognized the training more would tend to keep standard postures often, usually take care of themselves in the workplace, and require this kind of the training more.

Although the questionnaire survey results suggest a positive effect of the training
course, but the findings are somewhat limited because they are based on personal subjective judgments. Besides, the perceived training effectiveness is found to be affected by extraneous factors, such as the frequency of suffering from MSDs and frequency of taking medical treatments for the responded individuals. Accordingly, the training effects could not be merely determined by the questionnaire survey. It would be more convincing if the objective measures, in terms of the identified risk factor ratio and prevalence of MSDs, could support the findings in the questionnaire survey.

4.2 Changes of trainees' behavior after training

The purpose of this wafer handling training course was to prevent or reduce the risk factors associated with the onset of MSDs. The comparisons between pre- and post-training show that the most significantly decrease among all of the identified risk factors occurred in transporting a full FOUP manually over three meters (IRFR from 80.0% to 28.6%), as shown in Table 4. This is due to that a significantly high percentage of the workers could remind themselves of using trolleys to transport FOUPs and they realized this manner is good for safety and health after training. This finding supports the questionnaire survey results that mentioned most of the trainees (96.7%) paid more attention to their safety issues after receiving the training course.
As for the risk factor of twisting the trunk over 45° to take a FOUP, a significant reduction in its IRFR was also observed (from 48.6% before training to 17.1% after training). This finding is consistent with the responses to the questionnaire that indicated most trainees (88.3%) could remind themselves of keeping standard work postures after the training course. This behavioral change towards safer work method could be contributed to the training course, because the trainer had taught the workers to move their feet to take a FOUP from one side to the other instead of twisting their trunk.

A significant decrease was also found in bending the trunk forward over 20° from pre to post training, but this decrease in IRFR (from 67.1% to 42.9%) was not as much as those of the above mentioned two risk factors. This was due, in part, to the limitations in rack height and the quick-tempered workers. Although the workers had been taught to squat to take the FOUP from the lower rack, about 43% of the sampled subjects still bent the trunk forward quickly to take the FOUP. These observations recommended that replacing the lower racks with adequate ones would be a fundamental solution for eliminating this risk factor.

In summary, the training course has a positively great impact on the reduction in the identified risk factors with regards to awkward working postures and behavior. This finding supports the survey results that reveal most workers could keep standard work
postures after training. These findings are consistent with past studies that verify ergonomic training could affect employee perception and behavior (King, et al., 1997; Montreuil, et al., 2006; Nussbaum and Torres, 2001; Saleem, et al., 2003).

4.3 The reduction in prevalence of MSDs after training

There were no statistically significant differences in the prevalence of MSDs between pre- and post-training periods for any body parts except the legs, as shown in Table 5. The reduction of MSDs in legs could be explained by the significant reduction in the risk factor associated with lower extremity, such as manually transporting a full FOUP over three meters. It is believed that the current training course and posters were merely effective in preventing the workers from leg disorders. This result implies that the training intervention is not effective in preventing overall problems of MSD owing to the multidimensional nature of MSDs. In other words, the MSDs might result from heavy loads, prolonged work time, frequent monotonous movements, or improper work methods and postures. The training intervention is mostly effective in preventing the specific MSDs, which are mainly attributed to improper work methods and postures.

Although some studies have demonstrated that the ergonomic training program has a positive effect on the reduction in MSDs (Faucett, et al., 2002; Harrington and Walker,
2004; Lewis et al., 2002), there is ample evidence in literature that indicated training is not very effective (IJzelenberg, et al., 2007). It could be the differences in occupational settings cause different risk factors resulting in MSDs; and hence, the ergonomic training program could not success in all kinds of occupations. Naturally, failure in implementing ergonomic training also leads to ineffectiveness in preventing MSDs in the previous studies. Besides, the differences in methodologies for evaluating the impacts of ergonomic training may also cause different results.

Because of the significant decrease in the identified risk factors after training, the study company has been decided to implement the training program in the other wafer fabs, and to incorporate this training into the new-employee education for the wafer-handling task job.

4.4 Limitations to this study

The absence of a control group in this longitudinal research design makes it difficult to ascertain the direct influence of the ergonomics-based wafer handling training on the reduction of MSDs. Some recovery factors may lead to the reduction in MSDs for the wafer-handling workers, such as medical treatment, spontaneous recovery, and rehabilitation activities. However, these recovery effects would be counteracted by the
continuous development of MSDs if the work-related risk factors were not eliminated or
controlled. Based on the field observation results, some risk factors indeed decreased
after the training intervention. Therefore, we believed that the follow-up reduction in
MSDs on the workers could be mainly attributed to this training intervention because no
changes in the wafer-handling work content were made except the changes in work
methods and postures after training.

It should be noted that this training intervention has no significant effects on the
identified risk factors about the content of wafer handling work and improper hardware
or settings, such as heavy weight of lifting, prolonged standing without back supports,
and poor starting position of lifting (Table 4). These unresolved risk factors may
account for why the follow-up prevalence of MSDs did not obviously reduce in
neck/shoulders, arms and wrists after training (Table 5). These findings reveal that the
training program can not resolve all the risk factors identified in the workplace.
Therefore, other ergonomic interventions, such as ergonomically redesigned
workstations or the introduction of new tools and equipments should be considered to
be implemented in the future.

Although this study had verified the positive effects of the training on the reduction
in MSDs, the cost/benefits analysis was not conducted here. This is due to that very few
compensation costs and days lost were reported and filed before the training project, and in consequently, only the post-training financial data were not adequate to assess the cost-effectiveness of the training project in the present study. Furthermore, it may need several years to fully recognize the economic benefits of the ergonomics project by comparing MSD related compensation costs and days lost between the pre- and post-intervention periods (Chhokar et al., 2005; Lewis et al., 2002).

5. Conclusions

From the survey results, we concluded that most workers believe in that the ergonomics-based wafer handling training is helpful to prevent workers from the MSDs. The field observation results indicated that most workers’ working postures and methods were significantly altered one month immediately following training. It meant that the implementation of training had a great impact on modifying workers’ behavior towards safer conditions, but the training had limited effects on the reduction in heavy loading, improper hardware and settings. Although the prevalence of MSD did not significantly decrease for any body parts except the legs, the company has evaluated the project as successful because of a significant reduction in the identified risk factors was observed after training. However, from a scientific point of view, this longitudinal study
has drawbacks since the lack of a control group makes it hard to verify the direct effect of the training on the reduction of MSDs. This study only provides a good example of how to modify workers’ behavior towards safer conditions through ergonomic training in the 300mm wafer fab. Further experimental study with a control group is still needed to conduct for confirming the effectiveness of ergonomic training on the reduction of MSDs.

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References


Chhokar, R., Engst, C., Miller, A., Robinson, D., Tate, R. B., Yassi, A., 2005. The three-year economic benefits of a ceiling lift intervention aimed to reduce healthcare


IOSH, 1996. *Evaluating the cumulative trauma disorders problem in the*
semiconductors industry. Institute of Occupational Safety & Health, IOSH 85-H326, Taiwan, ROC.


Wang, M.J.J., Chung, H.C., and Wu, H.C., 2004. Evaluating the 300mm wafer handling...


TABLE LIST

Table 1. Summary of the responses to the first part of the questionnaire, n = 274.

Table 2. Summary of the responses to the second part of the questionnaire, n = 274.

Table 3. The correlation analysis results, n = 274.

Table 4. The identified risk factor rates (IRFRs) one month before and one month after training.

Table 5. The prevalence of musculoskeletal disorder (MSD) obtained one month before and one year after training.