ERGONOMICS RISK ASSESSMENT AND SYMPTOMS OF MUSCULOSKELETAL DISORDERS AMONG FEMALE PRODUCTION LINES OPERATORS IN SEMICONDUCTOR FACTORY

by

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LIST OF ABBREVIATIONS AND SYMBOLS

EEC	Ergonomics Excellent Centre
EOL	End-of-Line
FOL	Front-of-Line
HREC	Human Research Ethics Committee
H_0	Null Hypothesis
IC	Integrated Circuits
IDCs	Industrially Developing Countries
MMH	Manual materials handling
MSDs	Chronic Musculoskeletal Disorders
NIOSH	National Institute for Occupational Safety and Health
OSH	Occupational Safety and Health
REBA	Rapid Entire Body Assessment
SPSS	Social Package Statistical Software
SOCSO	Social Security Organization
VDT	Video Display Terminal
WMSDs	Work-related Disorder
%	Percentage

PENILAIAN RISIKO ERGONOMIK DAN GEJALA MUSKULOSKELETAL DALAM KALANGAN OPERATOR PENGELUAR PEREMPUAN DI KILANG SEMIKONDUKTOR

ABSTRAK

Kajian ini dijalankan untuk mengkaji penilaian risiko ergonomik dan gejala MSDs dalam kalangan operator pengeluar perempuan di kilang semikonduktor. Tahap risiko MSDs dalam kalangan operator pengeluar wanita telah dikenal pasti melalui kaedah Penilaian Pantas Keseluruhan Badan (REBA). Faktor-faktor risiko ergonomik dikaitkan dengan gejala MSDs. Hubungan dengan faktor-faktor ini telah dikenal pasti dengan menggunakan ujian khi-kuasa dua. Maklumat mengenai kajian ini telah dikumpulkan melalui pengedaran borang soal selidik kepada 144 responden dengan panduan daripada penyelidik. Pergerakan dan postur badan responden semasa beberapa kitaran kerja diperhatikan. Hasil kajian tahap risiko MSDs bagi keseluruhan responden menunjukkan 77.1% mempunyai risiko sederhana, diikuti dengan 18.8% responden yang berisiko tinggi dan 4.2% mempunyai risiko yang rendah. Hasil kajian turut mendapati bahagian badan yang menunjukkan peratusan yang tinggi terhadap kesakitan dan ketidakselesaan adalah buku lali/kaki (91.0%), bawah kaki (90.3%), bahu (83.3%), belakang atas (81.9%) dan leher (81.3%). Hasil kajian bagi faktor risiko ergonomik berkaitan dengan pekerjaan menunjukkan leher berpanjangan membongkok ke hadapan (93.8%) dan pergerakan lengan/tangan yang berulang adalah faktor risiko ergonomik tertinggi dalam kalangan responden. Hal ini diikuti dengan berdiri berpanjangan (89.6%), bekerja dengan tangan di atas bahu (86.8%) dan membawa beban berat (83.3%). Hubungan antara gejala MSDs dan faktor risiko ergonomik telah dikenalpasti. Terdapat hubungan yang signifikan antara lokasi kesakitan dan ketidakselesaan dengan leher berpanjangan membongkok ke hadapan pada leher ($p=0.003$), bahu ($p=0.021$) dan lengan ($p=0.016$); bekerja dengan tangan di atas bahu pada bahu ($p=0.011$) dan belakang badan atas ($p=0.022$); pergelangan tangan membengkok berpanjangan pada leher ($p=0.003$), bahu ($p<0.001$), pergelangan tangan/ tangan ($p=0.026$), lengan ($p=0.036$) dan belakang badan atas ($p<0.001$); duduk berpanjangan pada leher ($p=0.049$), pinggul ($p<0.001$), peha ($p=0.019$), lutut ($p<0.001$), buku lali/ tapak kaki ($p<0.001$) dan bawah kaki ($p<0.001$); berdiri berpanjangan pada leher ($p=0.049$), pinggul ($p<0.001$), peha ($p=0.019$), lutut ($p<0.001$), buku lali/ tapak kaki ($p<0.001$) dan bawah kaki ($p<0.001$); pergerakan berulang lengan/ tangan pada leher ($p=0.003$), bahu ($p=0.021$) dan lengan ($p=0.016$) dan membawa beban berat pada pinggul ($p<0.001$), lutut ($p=0.001$), buku lali/ tapak kaki ($p<0.001$) dan bawah kaki ($p<0.001$). Kesimpulannya, terdapat tanda-tanda gejala MSDs dalam kalangan operator pengeluar perempuan di kilang semikonduktor. Pihak pengurusan dan juga individu perlu mengambil perhatian kerana ia melibatkan kualiti hidup pekerja dan prestasi syarikat.

ERGONOMICS RISK ASSESSMENT AND SYMPTOMS OF MUSCULOSKELETAL DISORDERS AMONG FEMALE PRODUCTION LINES OPERATORS IN SEMICONDUCTOR FACTORY

ABSTRACT

This study was conducted to investigate the ergonomics risk assessment and symptoms of MSDs among female production lines operators in semiconductor factory. The level of the MSDs risk among female production lines operators were identified through Rapid Entire Body Assessment (REBA) method. The ergonomics risk factors were associated with symptoms of MSDs. The associations were identified by using chi-square test. The information about this study was collected through distribution of questionnaires to 144 respondents with guidance from researcher. Respondents' movements and postures during several work cycles were observed and photos were taken by the researchers. Results for the level of the MSDs risk for overall respondents were 77.1% respondents had medium risk, followed by 18.8% respondents had high risk and 4.2% respondents had low risk. This study also found that the body region showed high percentage of pain and discomfort were ankles/feet (91.0%), lower legs (90.3%), shoulders (83.3%), upper back (81.9%) and neck (81.3%). Results for ergonomics risk factor related to work showed that prolonged neck bending forward (93.8%) and repetitive movements of arms/hands (93.8%) were the highest ergonomics risk factor among respondents. This followed by prolonged standing (89.6%), working with hand above shoulders (86.8%) and carrying heavy loads (83.3%). Relationships between the symptoms of MSDs and ergonomics risk factor were identified. There were significant association between location of pain and discomfort with prolonged neck bending forward at the neck ($p=0.003$), shoulders ($p=0.021$) and forearms ($p=0.016$); working with hand above shoulder at the shoulders ($p=0.011$) and upper back ($p=0.022$); prolonged wrist bending at the neck ($p=0.003$), shoulders ($p<0.001$), wrist/hands ($p=0.026$), forearms ($p=0.036$) and upper back ($p<0.001$); prolonged sitting at the neck ($p=0.049$), hips ($p<0.001$), thighs ($p=0.019$), knees ($p<0.001$), ankles/feet ($p<0.001$) and lower legs ($p<0.001$); prolonged standing at the neck ($p=0.049$), hips ($p<0.001$), thighs ($p=0.019$), knees ($p<0.001$), ankles/feet ($p<0.001$) and lower legs ($p<0.001$); repetitive movements of arms/hands at the neck ($p=0.003$), shoulders ($p=0.021$) and forearms ($p=0.016$) and carrying heavy load at the hips ($p<0.001$), knees ($p=0.001$), ankles/feet ($p<0.001$) and lower legs ($p<0.001$). As the conclusion, there was presence symptoms of MSDs among female production lines operators in semiconductor factory and should be considered by the management as well as the individual because it involves quality of life of the workers and the company reputations.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Malaysia is among the five largest exporters of semiconductor devices in the world valued at RM96.5 billion or 39.4% of total electronics export. The Malaysian semiconductor industry is facing threats from low cost countries with limited innovative capabilities such as China, Thailand, and Vietnam. The nation wants to improve productivity and reduce occupational safety and health (OSH) problems in semiconductor industries to be competitive in the emerging globally competitive environment (Wong and Richardson, 2010).

Electronics production is what drives semiconductor demand and a great deal of this production has moved to Asia over the last several years. Current growth in electronics production is the main driver of the global semiconductor industry. Growing demand for smart phones, tablets, digital televisions, wire-less infrastructure, network hardware, computers, automobile electronics, industrial electronics, and electro-medical devices are stimulating global demand of semiconductors. Global semiconductor sales were up 9.9 percent in 2014 and are forecast to keep growing through 2016 (United States Department of Commerce, 2015). Figure 1.1 shows Malaysia located among the top 10 in the projected top markets for semiconductor exports (2015-2016) and projected top markets for

semiconductor manufacturing equipment exports (2015-2016) while Figure 1.2 shows the top 10 semiconductor manufacturing equipment export markets to 2016.

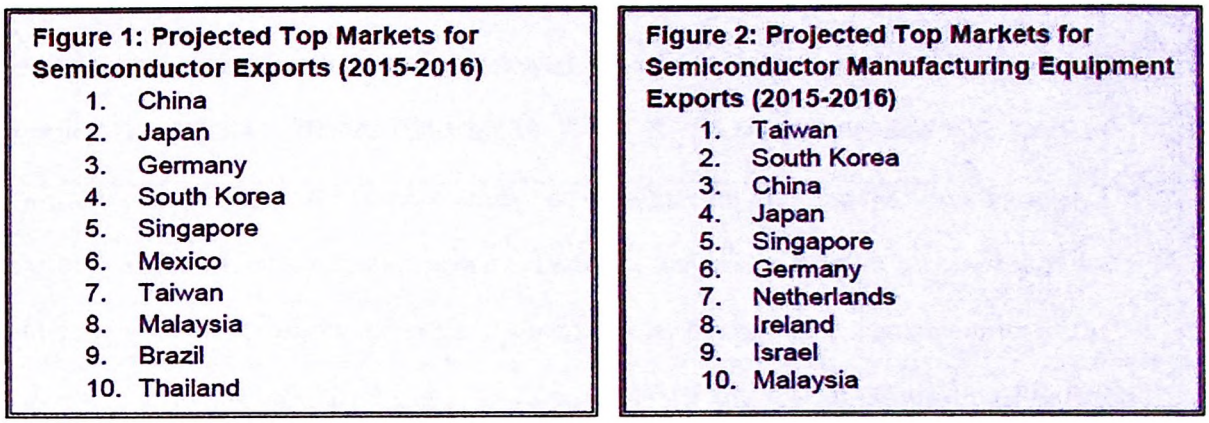

Figure 1.1: Projected Top Markets for Semiconductor Exports (2015-2016) and Projected Top Markets for Semiconductor Manufacturing Equipment Exports (2015-2016).

Source: U.S. Department of Commerce, 2015

Figure 1.2: Top Semiconductor Manufacturing Equipment Export Markets to 2016.

Source: U.S. Department of Commerce, 2015

The term "ergonomics" is derived from two Greek words: *ergon*, meaning work, and *nomos*, meaning law. Therefore, ergonomics is a managerial multidisciplinary science that creates the principles that need to be followed in order to ensure productivity and work efficiency (Irimie, 2008; Boatca and Cirjaliu, 2015). Ergonomics is the scientific study of people at work and the goal to reduce stress and eliminate injuries and disorders associated with the overuse of muscles, bad posture, and repeated tasks. This is accomplished by designing tasks, work spaces, controls, displays, tools, lighting, and equipment to fit the employee's physical capabilities and limitations (National Institute of Occupational Safety and Health, 2016).

Ergonomics is about integrating knowledge derived from the human sciences to match jobs, systems, products and environments to the physical and mental abilities and limitations. Ergonomics is an important facet of occupational safety and health (OSH) that needs to be optimized for the wellbeing of people at work. Ergonomics is a relatively new field in Malaysia in comparison with Japan, the United States and the United Kingdom. Nevertheless, the philosophy, essence, principle and concepts of ergonomics are important and to disregard them would be a handicap in efforts to promote OSH in the workplace. When ergonomic principles are not applied to the workplace, chronic musculoskeletal disorders (MSDs) such as back injuries, arm and hand problems, accidents and eye-strain may be common. The number of accidents related to musculoskeletal diseases (MSDs) increased from 14 cases in 2006 to 194 cases this year. Industries suffer from tangible and intangible losses because of increased medication costs, decreased productivity, work quality and decreased worker morale (Department of Occupational Safety and Health, 2013).

According the Section 15: General duties of employers and self-employed persons to their employees of the Occupational Safety and Health Act 1994 (Act 514) which state respectively that: Section 15(1), "It shall be the duty of every employer and every self-employed person to ensure, so far as is practicable, the safety, health and welfare at work of all employees"; Section 15(2) (a) and (b), "without prejudice to the generality of Subsection (1), the matters to which the duty extends include in particular which it is the provision and maintenance of plant and systems of work that are, so far as is practicable, safe and without risk to health; the making of agreements for ensuring, so far as is practicable, safe and absence of risk to health in connection with the use or operation, handling, storage and transport of plant and substances" (Legal Research Board, 2015).

This study was focused on the semiconductor factory that located in Ipoh, Perak. This semiconductor factory is the global provider of semiconductor assembly and test services for many of the world's most successful electronics companies. Besides, it offers an integrated suite of packaging and test services such as wafer bumping, wafer probing, wafer grinding, a wide range of lead frame and substrate IC packaging including leaded, QFN, BGA and Flip Chip packages, and high-end RF and mix-signal test services. The company's turnkey services include design, assembly, test and failure analysis, electrical and thermal characterization. With approximately 10,000 employees worldwide, this semiconductor factory has one of its branched in Ipoh, Perak (22,000 square feet of wafer bumping facility) Malaysia; Wales, United Kingdom; Chengdu, People's Republic of China; Batam, Indonesia and Sunnyvale, California, USA. The company is headquartered in Kuala Lumpur, Malaysia.

This semiconductor factory branched in Ipoh, Perak, Malaysia commenced its operations in 1992, produced an integrated circuits (IC) assembly and test facility. Currently, the company has a total staff strength of about 4000 mainly consists of 2200 operators, 830 technicians and supervisors, 200 engineers and 150 staff. Facilities occupy a total built-up area of 570,000 square feet and a minimum class 5,000 clean room. The Company provides full turnkey solutions to its customers in wafer probe, wafer grinding, IC packaging and test, tape and reel, drop ship, process and manufacturing engineering research, package design and development, test software development.

The Company's packaging capability includes all types of lead frame based packages ranging from micro to high pin-count packages, leadless packages, thin packages, lead frame modules, laminated based modules, wafer level, CSP and flip chip. Its test capability comprise of analog, linear, high end mixed signal and radio frequency. The Company is certified with various Quality and Environment Standards such as ISO 9001:2008, ISO 14001:2004 and ISO 16949:2009. However, employees at this semiconductor factory cannot be apart from ergonomic problem that may cause MSDs as a result from their work. Therefore, ergonomic risk assessment and symptoms of MSDs among production lines operators need to be determined.

1.2 Problem Statements

National Institute for Occupational Safety and Health (NIOSH) chairman Tan Sri Lee Lam Thye said the level of awareness, knowledge and implementation of ergonomics in companies in the manufacturing sector should be promoted and enhance further. This is due to the rising number of occupational disease such as MSDs has affected employees' work performance and productivity. According to Social Security Organization (SOCSO) statistics, in 2013, ergonomics-related cases stood at 694, from the total 2360 occupational disease cases. Which means for every four occupational cases, are reported to SOCSO, while one will be related to ergonomics. Besides, a study conducted by NIOSH's Ergonomics Excellent Centre (EEC) showed the compensation for ergonomics-related disorders is higher than the average. The right design of work stations, tools and machines will prevent accidents at the workplace and improve employees' work performance, productivity, medical bills or insurance and cut down on sick leave (Premananthini, 2015).

MSDs related to the workplace are among the most costly health problems in today's society (Looze *et al.*, 2010). Although it is known that ergonomics can contribute immensely to productivity improvements, the ergonomics approach is still not an accepted discipline in many industrially developing countries (IDCs) struggling to increase productivity. They think that ergonomics is expenditure rather than investment (Wong and Richardson, 2010).

MSDs related to work is on the rise. Reported cases of MSDs had been increase since 2008 according to NIOSH chairman Tan Sri Lee Lam Thye. According to the statistic from the SOCSO, employees who suffer from MSDs, common WMSDs have been increasing

since 2006. People with musculoskeletal disorder suffer from joints, nerves and muscles injuries. In 2006, 14 people reported such cases and the numbers jumped to 238 in 2010 while last year, a total of 268 people were recorded of such disorder (Department of Safety and Health, 2013).

Questionnaire and ergonomic checklists to evaluate the workplace design in the Module process and reported that musculoskeletal disorder symptoms are frequently complained in shoulders (59.8%), neck (49.5%), wrists (39.5%), and upper back (30.6%). Apparently, more efforts are required to investigate the WMSDs among TFT-LCD operators in the Array process and the Cell process (Lu *et al.*, 2015).

Semiconductor industry is produced Integrated Circuit (IC) chips. While working in production lines, it involves a lot of movement that may cause ergonomic problems such as reaching, standing for a long time, bending, pay attention and others. Workers often raise concern about back and neck pain, eyestrain, and headaches, which are often associated with highly repetitive movement (Wong and Richardson, 2010).

The low back, neck, shoulders, and upper limbs are the body parts most subject to risk. Among the factors associated with the risk for developing work-related MSDs are individual, physical workplace, organizational, and psychosocial factors. (Looze *et al.*, 2010).

Based on the issue and phenomenon all above, we can see that the statistics of the occupational disease increase rapidly year by year especially ergonomic related cases towards MSDs from 14 persons (2006) to 694 persons (2013) according to statistics from SOCSO. The awareness, knowledge and implementation of ergonomics in semiconductor

manufacturing companies still weak and need to be enhance. As the statistics of MSDs increase, the work performance, productivity among operators are also affected. The worse things are the medical bills, insurance and sick leave also increase which can effects more on the financial of the company. This is due to this MSDs is among the most costly health problems nowadays.

Besides, based on the previous research and survey, shoulders, neck, wrist, upper back, ankles, feet and low back were found to be the body parts with high prevalence of WMSDs. This is due to working posture and body movement that includes reaching, standing for a long time, bending and pay attention. The prevalence of the WMSDs among operators is higher that the engineers.

Hence, it is important to identify the level of MSDs risk, ergonomic risk factor and symptoms of MSDs among operators in the semiconductor production lines as this factory received a lot of complaints on ergonomics problem.

1.3 Research Objectives

1.3.1 General Objectives

To determine the ergonomics risk assessment and symptoms of Musculoskeletal Disorder (MSDs) among female production lines operators in semiconductor factory.

1.3.2 Specific Objectives

1. To determine the level of the MSDs risk among female semiconductor production lines operators through Rapid Entire Body Assessment (REBA) method.
2. To determine the ergonomics risk factor and symptoms of Musculoskeletal Disorders (MSDs) among female production lines operators in semiconductor factory.
3. To determine the association between symptoms of Musculoskeletal Disorders (MSDs) and ergonomics risk factors among female production lines operators in semiconductor factory.

1.4 Hypothesis

There is significant association between symptoms of Musculoskeletal Disorders (MSDs) and ergonomics risk factors among female production lines operators in semiconductor factory.

1.5 Significance of the Study

According to the survey conducted among 810 employees of nine semiconductor manufacturers in Taiwan, shoulders (42.0%), ankles and feet (33.1%), and low back (30.9%) were found to be the body parts with high prevalence of WMSDs. In addition, the prevalence of WMSDs in operators was higher than that in engineers, implying that more attention should be paid to operators. Further, the WMSDs in low back seem to increase with job experience, and hence this cumulative trauma disorders need to be managed as early as possible (Lu *et al.*, 2015).

Based on previous study, normally researcher will focus only to identify the symptom of MSDs rather than identify the level of MSDs risk. Therefore, the concern of this study is to assess the level of MSDs risk with different working area, different working posture and for overall female production lines operators in this semiconductor factory. Through Rapid Entire Body Assessment (REBA) method, the degree of the work body posture can be identified; calculate the REBA score, and using the final REBA score to identify the level of MSDs risk. Besides, there is lack of ergonomics intervention and implementations, training and awareness, ergonomics risk factor and symptoms of MSDs identification and data recorded in this semiconductor factory. Therefore, this research will help to provide the preliminary baseline data on the level of MSDs risk, ergonomics risk factor and symptoms of MSDs generated to minimize the ergonomics risk and improve the working posture of the operators in this semiconductor factory.

CHAPTER 2

LITERATURE REVIEW

2.1 Ergonomics

The term "ergonomics" derived from Greek ergo (work) and nomos (laws) to denote the science of work, ergonomics is a systems-oriented discipline, which now applies to all aspects of human activity. Physical ergonomics is concerned with human anatomy, and some of the anthropometric, physiological and bio mechanical characteristics as they relate to physical activity. Others relevant things includes communication, crew resource management, work design, work systems, design of working times, teamwork, participatory design, community ergonomics, cooperative work, new work programs, virtual organizations and quality management (Singh and Singh, 2014).

Ergonomics normally are known to be related to human and their job. In larger scope ergonomics examines human behavioral, psychological, and physiological capabilities and limitations. The focus of ergonomics implementation should removes barriers to quality, productivity and safe human performance by fitting products, tasks, and environments to people instead of forcing the person to adapt to the work. Besides, ergonomics is a broad science with wide variety of working conditions that can affect worker's comfort and health, including factors such as lighting, noise, temperature, vibration, heavy lifting, repetitive motion, workstation design, tool design, machine design, chair design and footwear and others (Jaffar *et al.*, 2011).

Ergonomics contributes to the optimization of both human well-being and a total system performance; that ergonomics is broader than just occupational health and safety; and that it includes issue like workplace design, job design, work organization design, etc (Pikaar *et al.*, 2007).

Ergonomics traditionally involves the physical aspects of work and evolved from studying the interactions between humans and their surrounding work environment (with environment defined broadly to include machines, tools, the ambient environment, tasks, etc.). The "ergo" of ergonomics means work. Work can, however, be interpreted broadly, in that it involves the general physical expenditure of energy to accomplish a goal. Thus, most of what of humans do (and their bodily processes) could be justifiably considered to be work, and thereby, ergo related (Dempsey *et al.*, 2006).

Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well being and overall system performance (International Ergonomics Association, 2000).

Ergonomics is the study of work or the science of designing the job to fit the worker, rather than physically forcing the worker's body to fit the job. Adapting tasks, work stations, tools, and equipment to fit the worker can help reduce physical stress on a worker's body and eliminate many potentially serious; disabling work related Musculoskeletal Disorders (MSDs). Ergonomics draws on a number of scientific

disciplines, including physiology, biomechanics, psychology, anthropometry, industrial hygiene, and kinesiology (Occupational Safety and Health Administration, 2000).

Ergonomics is defined as the application of human biological sciences with the engineering sciences to achieve optimum mutual adjustment of people and their work, the benefits measured in terms of human efficiency and well-being (Department of Environmental Health and Safety of California State University, n. d.). Ergonomics is the science of fitting workplace conditions and job demands to the capabilities of the working population. Effective and successful "fits" assure high productivity, avoidance of illness and injury risk, and increased satisfaction among the workforce (Cohen, 1997).

2.2 Musculoskeletal Disorder (MSDs)

MSDs or musculoskeletal disorders are injuries and disorders of the soft tissues (muscles, tendons, ligaments, joints, and cartilage) and nervous system. They can affect nearly all tissues, including the nerves and tendon sheaths, and most frequently involve the arms and back. Occupational safety and health professionals have called these disorders a variety of names, including cumulative trauma disorders, repeated trauma, repetitive stress injuries, and occupational overexertion syndrome. These painful and often disabling injuries generally develop gradually over weeks, months, and years. MSDs usually result from exposure to multiple risk factors that can cause or exacerbate the disorders, not from a single event or trauma such as a fall, collision, or entanglement. MSDs can cause a number of conditions, including pain, numbness, tingling, stiff joints, difficulty moving, muscle loss, and sometimes paralysis. Frequently, workers must lose time from work to recover;

some never regain full health. These disorders include carpal tunnel syndrome, tendinitis, sciatica, herniated discs, and low back pain. MSDs do not include injuries resulting from slips, trips, falls, or similar accidents (Occupational Safety and Health Administration, 2000).

Musculoskeletal disorders (MSDs) are injuries or disorders of the muscles, nerves, tendons, joints, cartilage, an disorders of the nerves, tendons, muscles and supporting structures of the upper and lower limbs, neck, and lower back that are caused, precipitated or exacerbated by sudden exertion or prolonged exposure to physical factors such as repetition, force, vibration, or awkward posture (National Institute for Occupational Safety and Health, 2015).

MSDs are injuries and disorders of the musculoskeletal system. The musculoskeletal system includes muscles, tendons, tendon sheathes, nerves, bursa, blood vessels, joints/spinal discs, and ligaments. MSDs may be caused or aggravated by the presence of one or any combination of the following risk factors: repetition, awkward or static postures, high forces, and contact stress. When these factors exist simultaneously, the risk of developing a MSD is significantly increased (Occupational Health Clinics for Ontario Health Worker, 2012).

2.3 Musculoskeletal Disorders Symptom

Based on Canadian Centre for Occupational Health and Safety (2016), pain is the most common symptom associated with WMSDs. In some cases there may be joint

stiffness, muscle tightness, redness and swelling of the affected area. Some workers may also experience sensations of "pins and needles," numbness, skin colour changes, and decreased sweating of the hands. MSDs may progress in stages from mild to severe.

Table 2.1: Occupational risk factor and symptoms of MSDs

Identified disorders, occupational risk factors and symptoms		
Disorders	**Occupational Risk Factor**	**Symptoms**
Tendonitis/tenosynovitis	Repetitive wrist motions Repetitive shoulder motions Sustained hyper extension of arms Prolonged load on shoulders	Pain, weakness, swelling, burning sensation or dull ache over affected area
Epicondylitis (elbow tendonitis)	Repeated or forceful rotation of the forearm and bending of the wrist at the same time	Same symptoms as tendonitis
Carpal tunnel syndrome	Repetitive wrist motions	Pain, numbness, tingling, burning sensations, wasting of muscles at base of thumb, dry palm
DeQuervain's disease	Repetitive hand twisting and forceful gripping	Pain at the base of thumb
Thoracic outlet syndrome	Prolonged shoulder flexion Extending arms above shoulder height Carrying loads on the shoulder	Pain, numbness, swelling of the hands
Tension neck syndrome	Prolonged restricted posture	Pain

Source: Canadian Centre for Occupational Safety and Health, 2016.

Early stage: Aching and tiredness of the affected limb occur during the work shift but disappear at night and during days off work. No reduction of work performance. **Intermediate stage**: Aching and tiredness occur early in the work shift and persist at night. Reduced capacity for repetitive work. **Late stage:** Aching, fatigue, and weakness persist at

rest. Inability to sleep and to perform light duties. The Table 2.1 below outlines occupational risk factors and symptoms of the most common disorders of the upper body associated with MSDs.

2.4 Semiconductor Manufacturing Process

Semiconductor device usually refers to an integrated circuit (IC or chip). In semiconductor device fabrication, electronic circuit are built on to a wafer of pure semiconductor material in a series of intricate processes. There is a high degree of automation in semiconductor fabrication factories and much of the work processes are enclosed and take place in clean rooms, humidity kept low and air circulated through high efficiency particulate absolute filtration units to ensure a dust free environment. These measures are for the protection of the highly sensitive product, where a single speck of dust or spot of condensation could cause damage. The work processes vary widely depending on the desired final product (Baxter *et al.*, 2010).

Semiconductor 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 labour costs are lower (Chee and Rampal, 2004).

Manufacturing processes for IC production can be categorized as front-of-line (FOL), end-of-line (EOL), testing and marking (TEST MARK) and, finally, quality check and packing processes

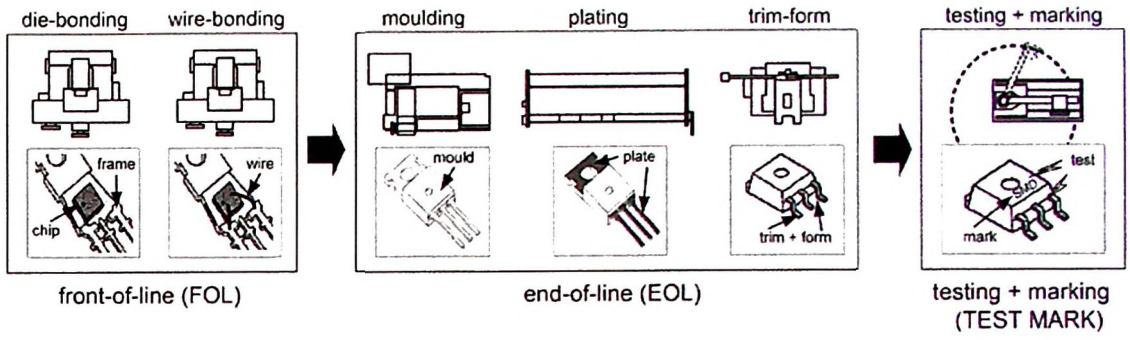

Figure 2.1: Overview semiconductor manufacturing processes

Source: Bin and Richardson, 2010

2.4.1 Front of Line (FOL)

Front-of-Line (FOL): This module includes die- and wire-bonding processes. Both processes take place in a clean environment (i.e., in a closed room surrounded by windows, and dust particles are no more than 10,000 units/m3). The workers working in shift environment and all workers must wear a full-face-covered uniform to avoid product contamination by vapor and dust (Wong and Richardson, 2010).

Die bonding and die attachment are assembly processes in which after a wafer has been blade-sawed into individual dies, the die is mounted and fixed to the package or support structure like a lead frame. Wire bonding is a method of making interconnections between a microchip (die) and other electronics as part (in this case, the lead frame) of semiconductor devices assembly. The wires are generally made of gold, aluminium or

copper. Ultrathin wires (~15 μm in diameter, one third the diameter of human hair) connect the bonding pad of each device to the lead frame (Bin *et al.*, 2010).

2.4.2 End of Line (EOL)

End-of-Line (EOL): This includes processes from molding to trim–form. These processes use heavy machinery (e.g., injection molding and chemical plating machines). There are many types of heavy machinery in the EOL module, e.g., injection moulding machines, cutting and forming tools and electroplating machines (Wong and Richardson, 2010).

Moulding is the process of sealing a microchip die with a ceramic or plastic enclosure (tablet) to prevent physical damage or corrosion. This is done after wire-bonding has been completed. Operators load and unload magazines (metal boxes containing up to 40 lead frames) to the moulding machine. Mould compound tablets (1.5 cm in diameter) are auto-loaded into the machines where the lead frames will be covered by the tablets after moulding. The process takes ~3 min to complete. Electroplating (or plating) is the general name used in semiconductor manufacturing for a surface-covering technique. It is a process by which metals in ionic form are supplied with electrons to form a non-ionic coating (plate) on a desired substrate. A plate is indispensable because it is a corrosion inhibitor for semiconductor components. Electroplating machines integrate many chemical baths and a conveyer belt carries the components across the chemical baths. The operators' task is to monitor the electroplating machines throughout the process; trim-form consists in a moulded strip of components being loaded into a machine that cuts it into individual units

called integrated chips (IC). After trimming, the same machine will perform "leg forming" where IC legs are bent, cut and formed into a desired shape (Bin *et al.*, 2010).

2.4.3 Test and Marking

Testing and Marking: The products are 100% tested and marked with product information (i.e., date, product code, logo) before packing and being sent to customers (Wong and Richardson, 2010). The test includes placing the IC in cold (–40 °C) or hot temperature (+150 °C), and inducing electrical stress (up to 1 000 V) to test IC robustness and its functions by using fully automated IC testing and marking machine. The marking process is incorporated in a testing machine where good ICs will be marked with product information (product codes, date, logo, etc.) immediately after testing (Bin *et al.*, 2010).

2.5 Musculoskeletal Symptom among Semiconductor Production Lines Operators

Lu *et al.*, (2015) stated that, the prevalence of WMSDs highest in the neck and shoulder, followed by back, lower limbs, and upper limbs. Further, the prevalence of WMSDs in neck and shoulders increase with the operator's job experience till the fifth year and falls thereafter. The day shift operators had a significantly higher prevalence of WMSDs in neck and shoulders than the night shift operators. Female operators tend to suffer a higher prevalence of WMSDs than male operators. Domestic operators had higher prevalence of WMSDs than foreign operators. Further, increase age groups lead to decreasing prevalence of WMSDs in neck and shoulders, upper limbs, and back.

Besides, questionnaire and ergonomic checklists applied to evaluate the workplace design in the module process and reported that musculoskeletal disorder symptoms are frequently complained in shoulders (59.8%), neck (49.5%), wrists (39.5%), and upper back (30.6%) (Lu et al., 2012). Subjective assessment showed that workers were suffering from neck and back pains and most complaints came from the processes in FOL (die bonding and wire bonding) (Bin *et al.*, 2010).

Worker who performs processes jobs in a long duration of standing may experience discomfort in the legs, neck and shoulder. If the standing position is continuously practiced and remedy actions for workplace improvement are taken passively, the worker may feel discomfort and fatigue particularly in the lower limb muscles (legs and thighs), lower back, and feet. As long term consequences, prolonged standing contributes severe health problems such as chronic venous disorders, circulatory problems, possibility of increase stroke risk, difficulty in pregnancy, and degenerative damage to the joints of the spine, hip, knees and feet (Halim and Omar, 2011).

The head and neck, upper trunk and low back were also prevalent in the population and less than 1% of the workers reported affectations in daily life activities. Upper extremity pain was 17 times more likely among those who carried objects for 2–8 hrs than those who did not. Lower extremity pain was more than 6 times more likely to happen when the worker walked around for most of the workday (Prado-Lu, 2004).

The prevalence rates patterns among the different body areas were similar between full-time and part-time operators. Neck symptoms were the most frequently reported, followed by shoulder, wrist, upper arm-forearm, and finger symptoms. Back symptoms also were

common (Hsu and Wang, 2003). The prevalence of musculoskeletal symptoms in the last 12 months among the women assembly workers was highest for the back, followed by lower leg, shoulder, upper leg and neck (Chandrasakaran, 2003).

2.6 Factors of Musculoskeletal Disorders

MSDs are associated with work patterns that include: fixed or constrained body positions, continual repetition of movements, force concentrated on small parts of the body, such as the hand or wrist, and a pace of work that does not allow sufficient recovery between movements. Besides, MSDs at work are associated with these factors: Work postures and movements, repetitiveness and pace of work, force of movements, vibration, temperature, lack of influence or control over one's job, increase pressure (e.g., to produce more), lack of or poor communication, monotonous tasks, and perception of low support (e.g., manager or co-worker). Certain workplace conditions, for example, the layout of the workstation, the speed of work (especially in conveyor-driven jobs), and the weight of the objects being handled influence these factors (Canadian Centre for Occupational Health and Safety, 2016).

The major ergonomic hazards were repetitive movements, poor standing posture, and the lifting of heavy goods (Yu *et al.*, 2013). The most prevalent ergonomic hazards in small, medium and large companies were repetitive movements and awkward posture (Lu, 2008).

Repetitive processes and manual material handling are the major problems in the hand tool manufacturing. Therefore, musculoskeletal disorders (MSDs) are related to such high repetitive processes and working in bad posture. Thus, to improve the efficiency of the workers their posture needed to be assessed and corrective measures should be adopted to avoid the musculoskeletal disorders (Singh, 2010).

Manual materials handling (MMH), especially lifting, represents a major occupational safety and health risk in industry. Musculoskeletal and low back disorders are often atribute to overexertion of the body when the operator works to meet the demand of MMH task. The use of ergonomic principles in the design and evaluation of human work has been advocated and promoted in the workplace to minimize the occurrence of work-related musculoskeletal injuries (Lin *et al.*, 2006).

The major ergonomic exposure was moving hands/ wrists, followed by standing and lifting with hands. Higher body pain were 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. Neck/ shoulder pain was significantly associated with sitting and lifting. Lifting was also associated with hand/wrist pain. Upper-back pain was associated with climbing steps and low back pain with hand/wrist movement. Workers that exposed to prolonged standing experienced pain at the lower limbs. Semiconductor assembly EOL workers experienced more pain in each body site (Chee and Rampal, 2004).

Factors associated with low back pain included excessive work, prolonged work, poor posture, assembly line work and cold environment. Poor posture and improper body

mechanics could place undue stress on the joints and muscles leading to pain, soreness or even muscle rupture (Prado-Lu, 2004).

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. The work postures and movements that were predominant among the women assembly workers were repetitive hand and wrist movements, standing, manual lifting, sitting and pushing and pulling (Chandrasakaran, 2003).

In wafer preparation and polishing, a combination of lifting weights and prolonged standing led to high pain prevalences in the low back. Semiconductor assembly middle of line workers, especially the molding workers, who did frequent lifting, had high pain prevalences in the neck/shoulders and upper back. In the semiconductor assembly end of line work section, chip inspection workers who were exposed to prolonged sitting without back support had high prevalences of neck/shoulder and upper back pain, while chip testing workers who had to climb steps to load units had a high prevalence of lower limb pain. Workers in the assembly of electronic components, carrying out repetitive tasks with hands and fingers, and standing in awkward postures had high pain prevalences in the neck/shoulders, arms, and hands/wrists (Chee *et al.*, 2004).

2.7 Rapid Entire Body Assessment (REBA)

The REBA technique (Rapid Entire Body Assessment) is a postural analysis system sensitive to musculoskeletal risks in a variety of tasks, especially for assessment of working

postures found in health care and other service industries. The posture classification system, which includes the upper arms, lower arms, wrist, trunk, neck, and legs, is based on body part diagrams. The method reflects the extent of external load/forces exerted, muscle activity caused by static, dynamic, rapid changing or unstable postures, and the coupling effect. This technique provides five action levels for evaluating the level of corrective actions. Action level 0: corrective action including further assessment is not necessary; action level 1: corrective action including further assessment may be necessary; action level 2: corrective action including further assessment is necessary; action level 3: corrective action including further assessment is necessary soon; and action level 4: corrective action including further assessment is necessary now (Dohyung, 2007).

The REBA method analyzes posture by measuring the articular angles and by observing the load or force and repetitiveness of movements and the frequency of position changes. The postures of the neck, trunk, upper and lower arms, legs, and wrists are grouped into ranges. Each posture range, relative to the anatomical regions evaluated, is associated with a score corresponding to values that get progressively higher as the distance from the segment's neutral position increases. Score A is the sum of the posture scores for the trunk, neck, and legs and the Load/Force score, whereas score B is the sum of the posture scores for the upper arms, lower arms, and wrists and the coupling score for each hand. The REBA score is obtained by entering score A and score B and by adding them to the Activity score (Hignett and McAtamney, 2000; Pillastrini *et al.*, 2007)

The REBA can be used when: the whole body is involved; the posture is static, dynamic, rapidly changing or unstable; the posture is frequently subjected to animated or