Final Report - Ergonomics in the Electronics Industry

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Introduction

The electronics industry employs millions of workers globally. Due to the lower labor costs, financial incentives and decreased environmental regulation multinational electronics companies from Europe, Japan and America primarily have relocated their manufacturing to south east Asia (China, Malaysia, Indonesia) (Williams, 1998).

The electronics industry is highly diverse in terms of its processes, tasks and physical exposures to the workers. Task variation is high and there is wide spectrum of processes (Koh, 2004). The Electronics Industry Association identifies 8 major segments of the industry: electronic components, consumer electronics, telecommunications, defense communications, computer and peripheral equipment, industrial electronics, and medical electronics (Williams, 1998). These segments of the electronic industry include many processes, from final assembly of consumer products to fabrication of highly specialized electronic components such as resistors, electron tubes, LED's, etc…

Of recent significance is the rising prominence of the microelectronics sector. Microelectronics pertains to the manufacturing of micro circuits and microchips. The primary processes in the microelectronics sector are semiconductor fabrication, integrated circuit (IC) assembly, printed circuit board (PCB) fabrication/assembly, and final product assembly (Table 1)

Table 1 - Primary process in the microelectronics industry (Koh, D. et al.,2004)

Semiconductor wafer fabrication	**Printed circuit board (PrCB) fabrication**
Crystal purification and growth	Resin bonding
Wafer preparation	Impregnation
Epitaxy and oxidation	Laminating
Photolithography	Photomasking and etching
Doping and type conversion	Cutting and drilling
Metallisation, interconnections and packaging	Marking and testing
Semiconductor assembly	**Printed circuit board (PrCB) assembly**
Die separation	Parts preparation
Die attach bonding	PrCB ''stuffing''
Wire bonding	Soldering, touch-up
Encapsulation	Marking and testing
Housing and marking	**Final product assembly**
Testing	Parts preparation
	Parts assembly
	Testing
	Housing assembly
	Marking and packaging

The majority of workers in the electronics industry are employed in the assembly processes compared to the fabrication processes (Koh et al., 2004). The electronic industry employs a high percentage of female workers, but depending on the process male worker may predominate (Williams, 1998). Male workers are typically assigned tasks requiring heavy lifting/pushing/pulling such as fabrication and maintenance, while female workers tend to be placed in assembly line tasks that require high levels of precision (Koh et al., 2004). In the majority of literature on the electronic industry female workers are studied. It is not uncommon for study populations to be >90% Female (Abbas et al.,2001; Chandrasakaran et al.,2003, Ho, S. F., & Phoon, W. H., 1997; Harlow et al., 1999)

Electronic Industry Ergonomics

The manufacturing of electronics is associated with a high incidence of occupational illness due to chemical, radiation, psychosocial and ergonomic hazards, with the foremost occupational hazards primarily being chemical exposure. (Koh et al., 2004 ; LaDou & Rohm, 1998, Marano et al., 2010). Limited research on the ergonomic hazards associated with the manufacturing of electronics has been done.

The electronics industry appears to be be very similar to other manufacturing industries, however it is also unique in several key ways. The Electronics industry developed in the late 20th century and is relatively new (Yoon C., 2012). This has encouraged an exceptionally strong culture of secrecy to guard proprietary technologies. Additionally, the industries technology is new and continues to change rapidly as new products are designed. The processes and equipment in the electronics industry are replaced/changed at a more rapid rate than other industries (Quintana et al., 2008). An additionally unique aspect of the electronics industry is that it has resisted widespread automation (Quintana et al., 2008; Shalin et al.,1996). The rapidly changing technology, often demanded on very short lead-times, requires manufacturing processes to change often. Most companies have opted for manual electronics assembly because of its flexibility and to avoid the expensive setup and maintenance costs associated with automated processes (Quintana, 2008; Helander and Burri, 1995).

The result of these factors is that ergonomic programmes and research have not been able to be widely conducted at the international level. The high levels of secrecy have limited access to conduct research and the rapidly changing nature of the industry quickly makes findings outdated.

What follows is a review of current literature pertaining to the two primary sectors of the microelectronics industry (semiconductor fabrication, printed circuit assembly), electronic product assembly and occupational safety and health management programmes.

Semiconductor Fabrication

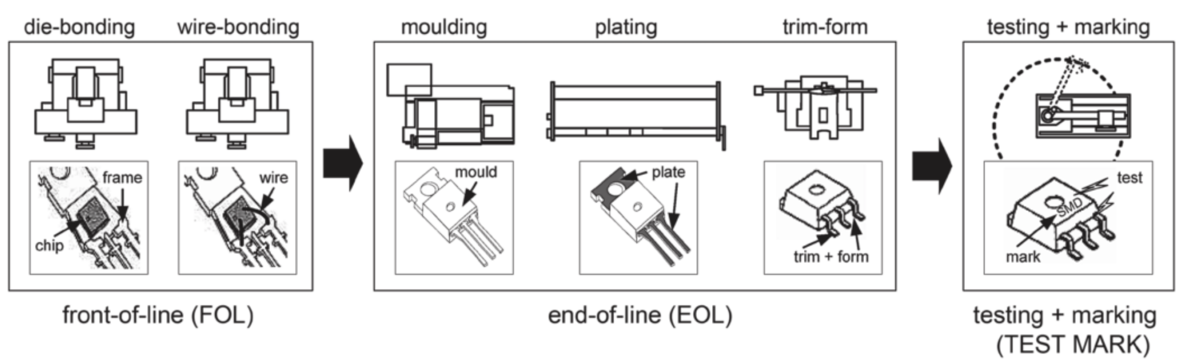
Semiconductor factories manufacture integrated circuits used as voltage regulators for various products: power supply for computers, switching devices, etc.. The manufacturing process for semiconductors factories are described as follows (Figure 1) (Saw et al., 2010):

I. Front-of-line (FOL) - Die-bonding, wire-bonding, wafer handling, occurs in clean room environment

II. End-of-line (EOL) - Moulding, electroplating and trim-form, occurs in industrial environment with different types of heavy machinery

III. Testing and Marking (TEST MARK) Processes

Figure 1 - Overview of semiconductor manufacturing process



Several ergonomics studies have been conducted in semiconductor factories in developed countries. Pocekay et al. (1995) conducted a large cross sectional study that included over 3000 workers from 8 semiconductor manufacturing sites across the United States. Using non-fabrication workers as a control group Pocekay et al. found that fabrication room workers had significantly higher levels of musculoskeletal symptoms at various body sites. These findings were found to be associated with inadequate equipment design and repetitive wafer-handling activities. No Ergonomic interventions were offered to addressed these findings

To my knowledge there has only been a two studies conducted at semiconductor factories in newly industrialized countries (Abdullah et al., 2009; Chandrasakaran et al., 2003). A cross sectional study of Malaysian workers (N=200) in various processes of a semiconductor manufacturing facility were evaluated for whole body postural risk using the Rapid Entire Body Assessment (REBA). Over 60% of workers were found to be at very high risk while over 30% were considered high risk (Abdullah et al.,2009). Chandrasakaran et al. (2003) conducted a similar study on malaysian Semiconductor workers (N=529) and found similar ergonomic issues with over 80% of workers having musculoskeletal symptoms in the past year with back (57.8%), lower leg (48.8%) and shoulder (44.8%) being the most common sites. Both of these studies showed a clear association between musculoskeletal pain/risk of pain and the semiconductor industry.

Printed Circuit Assembly (PCA)

PCA factories manufacture motherboards for electronic products. The manufacturing process for PCA factories are described as follows (Yeow & Sen 2003):

I. Component Preparation Process - Raw materials are prepared, Printed circuit boards (PCB) prepared
II. Surface-mounted technology component placement process - Surface-mounted electronic

components are placed and soldered to the PCB.

III. Manual component insertion process - The leaded electronic components are inserted and soldered to the board.

IV. Manual visual inspection process - The board passes through a series of visual inspections to check for poor solder joints and error in component mountings or insertions.

V. In-circuit electrical test (ICET) process - The components on the board are tested individually.

VI. Functional electrical tests (FCT) process - The board is tested for its overall function.

VII. Quality assurance process - The completed board is visually inspected again and packed.

Several ergonomics field studies have been conducted in Malaysian PCA factories to improve ergonomic working conditions (Sen & Yeow, 1990, 2003; Yeow & Sen, 2000, 2002, 2003, 2004). Microelectronics manufacturing is the leading industry in Malaysia (Government of Malaysia, 2001, Chandrasakaran et al.,2003). Sen and Yeow studied several PCA processes; (printed circuit assembly, manual component insertion, visual inspection, electrical testing and surface mounted technology (SMT). Data was collected using a mix of subjective assessment, direct observation and interviews to assess the ergonomic issues faced by workers. Consistent worker pain and discomfort were found across all processes. These studies were limited in that they did not have a control group. Discussion of Sen and Yeow's proposed interventions is discussed in a future section of this report.

Electronic Product Assembly

Relative to other sectors of the electronics industry, many studies have been conducted on electronic product assembly. Product assembly refers to the final assembly of the electronic products and is most often conducted using an assembly line model (Abbas et al., 2001). Assembly line processes typically begin with assembly of lighter/smaller components with increased repetition, while the end of assembly line requires less repetitions but higher forceful exertions (Abbas et al., 2001). This factor causes there to be a variety of potentially hazardous physical exposures to workers in this environment depending on location on assembly line.

Abbas et al. (2001) sought to assess risk factors associated with carpal tunnel syndrome (CTS) in 198 workers in an Egyptians television assembly factory. Clerical workers in the same factory were used as a control group. Data was collected using interviews and physical examination. Assembly workers were responsible for manually installing pre-made components (resistors, transistors) into electronic boards requiring high levels of precision. There was additionally included in the study assembly workers who often used vibrating hand tools. Assembly workers were significantly more likely to report CTS suggesting an association between electronics assembly and risk of CTS.

Harlow et al. (1999) conducted a large study on occupational risk factors to female workers in the maquiladora industry, including over 100 workers from the electronics industry. Harlow et al. found that electronics assembly workers had a 20% to 35% increased likelihood of reporting lower back, upper back, neck, shoulder and leg pain compared to non-assembly workers. Tan, G. L. E. (1997) reported similar findings from two electronic assembly factories in Malaysia producing electronic components and audio equipment respectively. More than 40% of the workers reported musculoskeletal problems in the neck and back. Ho, S. F., & Phoon, W. H. (1997) again found similar rates of pain among Singaporean workers assembling disk drives, with 44.8% of workers reporting pain in at least one body site. Ho & Phoon found the most common sites affected were the hands and shoulders.

Summary of Ergonomic Risks

Summary of studies that have found significant association with some form of electronics manufacturing and aches/pains in at least one body site:

I. Hands:
   A. Electronics Assembly
      1. Ho, S. F., & Phoon, W. H. ,1997;
II. Wrist:
   A. Electronics Assembly
      1. Abbas et al., 2001
III. Neck:
   A. Electronics Assembly
      1. Harlow et al., 1999; Tan,1997; 2003;
IV. Shoulders:
   A. Electronics Assembly
      1. Ho, S. F., & Phoon, W. H. ,1997; Harlow et al., 1999
   B. Semiconductor Fabrication
      1. Chandrasakaran et al.,2003

V. Eyes:

   A. Printed Circuit Assembly (PCA)

      1. Yeow & Sen, 2004

VI. Legs:

   A. Electronics Assembly

      1. Ho, S. F., & Phoon, W. H. ,1997; Harlow et al., 1999

   B. Semiconductor Fabrication

      1. Chandrasakaran et al., 2003

VII. Low back:

   A. Electronics Assembly

      1. Harlow et al, 1999; Tan,1997; 2003

   B. Semiconductor Fabrication

      1. Chandrasakaran et al.,2003

VIII. Upper Back:

   A. Electronics Assembly

      1. Harlow et al., 1999

IX. Full Body:

   A. Semiconductor Fabrication

      1. Abdullah et al., 2009;

Occupational Health and Safety Management.

Ergonomic hazards found in electronics manufacturing have motivated the need for effective occupational safety and health programmes. General ergonomic interventions to prevent musculoskeletal and repetitive strain disorders to workers in the electronics industry should include redesign of tools, improving height relationship, orientation of work materials, and education on safe methods of manual handling is also important(Koh et al., 2004).

Sen and Yeow addressed ergonomic issues at several PCA factories using low-cost and simply ergonomic interventions with moderate success. An example can be seen in Table 2 (Sen & Yeow, 2003). Examples of low-cost, simple interventions include repairing chairs, issuing earplugs and slowing conveyor speed. They were successful in applying this methodology to improve worker comfort at minimal cost to the factory. However, these studies were limited in that they did not use control groups and were often small in sample size causing concerns about generalizable.

Table 2 - Example of Sen & Yeow Assessment/Intervention (Sen & Yeow, 2003)

SN	Problem	Root-Cause	OHS Consequence	Ergonomic Intervention	Improvement
1i	Shortage of chairs	Overtime and trainee operators do not have chairs to sit on	↑ Discomfort due to standing throughout 12-hr shifts	Allocated a sufficient number of chairs	Eliminated standing for 12 hrs
1ii	Chair discomfort	1.2 ± 0.38 defects per chair	↑ 90% complained of seating discomfort, accidents, and injuries	Repaired all defective chairs	Eliminated all complaints
2i	Bad smell of solder fumes from the WSM	The toxic fumes were from the solder flux in the WSM	↑ 83.3% complained of headache, loss of concentration, dizziness, and nausea	Increased chute suctions pressure and compartmentalised the WSM area to minimise bad smell	Eliminated all complaints
2ii	Too much noise in MCI area	The nearby SMT and AI machines were noisy	↑ Health hazards ↑ Noise dose: 95.8 ± 7.2% (Standard used: 85 dBA and 8 hrs for a 100% dose)	Compartmentalised the SMT and AI machines to minimise noise Earplugs were introduced	↓ Health hazards ↓ Noise dose: 15.4 ± 3.3%
3i	Too many components to be inserted	High number of components to be inserted per PCA board by each operator within a short time	↑ 66.7% complained of high work stress	Reduced the number of components to be inserted per PCA board by each operator Reduced the maximum number of component types Set appropriate conveyor speed	↓ Complaints about work stress down to 26.7%
3ii	Difficulty in adapting to too many workstations every day	Operators changed workstations so as to allow flexibility to substitute for absent operators	↑ 76.6% of operators had problems adapting to too many different workstations	Operators were allocated a maximum of 2 workstations	↓ Complaints about work adaptation down to 6.7%
3iii	Too little time for the PWS operator to perform visual inspections	Each operator's task: inspect 73 components, repair errors, and load PCA board into WSM within the allocated time of 45 s per board	↑ 63.3% of operators complained of high work stress	Added one operator for visual inspection and repair work	↓ Complaints about work stress down to 6.7%
4i	Pain when inserting certain components	The components had sharp top edges	↑ 33.3% complained of minor cuts on fingers	Use of ergonomic finger work aids for pressing the sharp top-edged components and tight-pin connectors without pain	↓ Work hazard Eliminated complaints about pain and cuts on fingers
4ii	Difficulty in inserting certain components	Need to press hard the tight-pin connectors to ensure they are well inserted	↑ 53.3% complained of pain in fingers ↑ Work hazard		

Notes. SN—serial number of the problem, OHS—occupational health and safety, ↑—very high, ↓—reduced, WSM—wave solder machine, MCI—manual component insertion, SMT—surface mounted technology, $x + y$—average ± *SD*, AI—auto insertion, PWS—pre-wave solder, PCA—printed circuit assembly.

Burri and Helander (1991; Helander & Burri, 1994) conducted four fields studies at different manufacturing plants of IBM in the the United States from the 1978 inception of its ergonomics program onwards. Field studies were conducted at various location; manufacturing of subassemblies for copier machines, automatic finishing facility for diskettes, visual inspection and micro-assembly using microscope and circuit board manufacturing. Burrin and Helander coordinated with IBM and used a systematic approach to ergonomic improvement of manufacturing facilities. Data was collected using interview of both management and workers, as well as direct field measurement.

Burri and Helander's primary objective was to increase employee comfort and decrease injuries while improving productivity. Interventions were primarily centered around optimization of workstation designs as well as process modification with an emphasis on automation. Burri and Helander intervened at a higher process level compared to Sen and Yeow. Each Field study yielded similarly successful. There was a consistent decreases in injuries with increases in productivity. Burri and Helander's Field studies had several limitations. Similar to Sen and Yeow's work they did not use control groups so it is difficult to quantify the exact benefits of their ergonomic interventions. Additionally these studies occurred in the continental United States and therefore may not be generalizable to newly industrialized nations.

Conclusion

There appears to be a consistent association between the microelectronics industry and ergonomic hazards causing pain/discomfort to the workers. This association appears to hold regardless of factory location and sub-sectors of the industry. The ergonomic risks faced by workers in the electronics industry will continue to be a highly important topic as the industry is projected to grow. It is important that further research be done to continue to increase the amount of evidence of this association.

Ergonomically sound work environments have been shown to significantly impact productivity, throughput and yields (Pulat, 1997). General ergonomic interventions and programmes to prevent musculoskeletal and repetitive strain disorders to workers in the electronics industry should include redesign of tools, improving height relationship, orientation of work materials, and education on safe methods of materials handling(Koh et al., 2004). More research is needed to validate implementation of ergonomic programmes within the electronics industry

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