# A Study of the Ergonomics Evaluation of a Water Heater's Case Manufacturing Factory

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## Abstract

Unnatural working postures usually cause musculoskeletal problems for workers in work field, especially in traditional industry. Many analysis and survey methodologies have been developed to identify unnatural postures and disorder risks in workplaces. The Ovako Working Posture Analyzing System (OWAS) and Nordic Musculoskeletal Questionnaire (NMQ) are the representative methods and applied widely. This study applied the both tools to investigate the work field of a manufacturing factory of the water heater's case. We divided the manufacturing process into nine workshops, took the pictures of working motions by DV camera and analyzed the postures on OWAS. From the OWAS results, we could identify the risks level of musculoskeletal symptoms as four Action Categories (AC). And from the comparison of OWAS and NMQ results, we could provide the suggestions to improve the working methods and environment. From the results of OWAS, we found that the operators' head/neck and back were above AC3 in some workshops. If the situation continued in long period, the operators might have the risk to get musculoskeletal symptoms. From the investigation of NMQ, we also found that the percentage of aches on neck, shoulders and lower back were higher than other parts of body. The correlation between aches and jobs was more than 75%. So we provided some suggestions to improve: work rotation and adjustment of work surface/height to fit in with Ergonomics. Then the risks of musculoskeletal symptoms would be reduced.

**Key Words**: Musculoskeletal Symptoms, Job Analysis, Risk Evaluation, OWAS, NMQ

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# 1. Introduction

The Repetitive Trauma Disorders (RTDs) also known as Repetitive Strain Injures (RSIs) can be defined as musculoskeletal symptoms caused by long-time and repetitive overuse of some body part. Such injuries are usually slight at the beginning and often neglected until when muscles, tendons, ligaments and nerve system take on permanent injuries. Therefore, such disorders can also be termed as Cumulative Trauma Disorders (CTDs). For example, Carpal Tunnel Syndrome (CTS), Tenosynovitis, Tendinitis and Trigger Finger are common repetitive injuries. In addition, such injuries often take place in arms, shoulders, neck, back and legs. In manufacturing industries, workers are often requested to repeat doing some job for the sake of efficiency. If workers accomplish their job at unnatural postures for a long time, risks of RTDs will increase, especially in the case of traditional industries. The personal effects of RTDs on workers include local pain of body parts, ache, numbness, and even loss of limb functions. As to the businesses, it may bring about problems such as lowered productivity, efficiency and morale, loss of working hours as well as disruption of the management. Such injuries are considerably common in various industries with considerable labor force lost to musculoskeletal symptoms (Putz-Anderson, 1988). In U.S, RTDs was the most popular occupational injury in 1991, accounting for 61% of the total occupational injury cases approximately. The working hour loss in all industries due to such injury may amount to 16 million working days and more than 60% suffering lower back ache are related to overworking. In the manufacturing process of water heater's outer case, many workshops are of highly repetitive job, which is very likely to cause musculoskeletal symptoms. In case of small factories whose workers are mostly veteran hands may suffer a lot if some worker is forced to leave. The business operation of the company will be affected as well. Hence, it is essential to find out the injury risk factors and preventions.

Therefore, this study will adopt the widely used OWAS to analyze and discuss workshops of manufacturing factory of the water heater's case to find out the objective results. In addition, an authoritative musculoskeletal symptoms questionnaire (NMQ) is used to ask for the subjective recognition of workers. Then, compare the results of the two analysis tools to confirm and improve the musculoskeletal symptoms risk factors to reduce the job-related injury risks. So this study mainly uses OWAS and NMQ to conduct job analysis and injury survey of the workshops of a water heater's case manufacturing company to find out musculoskeletal symptoms risk factors and status quo as well as prevention of injuries. Hence, the purposes of this study are: (1) to apply OWAS to conduct job analysis by shooting the workers on job alive with DV and analyzing actions in slow motion for being input into OWAS to find out risk factors; (2) to apply NMQ to survey the distribution of workers' RTDs and their correlation to job; (3) to compare the two analysis tools to discuss the compliance of body parts RTDs risks acquired by job analysis and musculoskeletal symptoms as felt by workers; (4) to propose injury prevention suggestions: regarding the injury risk factors obtained from the above analysis, some ergonomics treatment suggestions such as design and improvement of workshops and tools are proposed to prevent injuries.

# 2. Literature Review

## 2.1 Musculoskeletal symptoms causes

Ergonomic Risk Factors (ERF's) is defined by U.S. OSHA (The Occupational Safety and Healthy Administration) as "a job, procedure, or operational condition that may lead to risks of repetitive injuries". When risk factors exist in working site under certain circumstances, exposure to such a place shall be limited or avoided to pursue the objective of 100% healthy and safe working environment. Risks causing RTDs may include: pressure, posture, force, temperature (risk is higher at lower temperature), hand glove protection, shocking and repetitiveness, term and tools used (Silverstein and Hughes, 1996; Killough and Crumpton, 1996; Marley and Kumar, 1996). In 18th century, Ramazimini proposed that "labor disorder and injury" was related to factors such as "abnormal action" and "unnatural posture" (Cameron, 1996). If workers use unnatural posture for repetitive or long time work, risks such as tiredness, ache or injury may easily increase (Keyserling *et al.*, 1992). Therefore, Marras and Schoenmarklin (1993) pointed out that causes of RTDs were repetitive and long time use or over exercises of muscles, tendons, ligaments and nerve system, especially when the worker had to use some body part forcefully at unnatural posture to accomplish the job. Thus, it can be known that unnatural working postures are the main cause of musculoskeletal symptoms. And the correlation between unnatural postures and possible symptomatic parts is listed as in Table 1 (Corlett and Manenica, 1980; Keyserling *et al.*, 1992).

## 2.2 Relationship between RTDs and jobs

A survey on the safe and healthy working environment in Taiwan made by Institute of Occupational Safety and Health (IOSH, 1996/2001) pointed out 39% of workers interviewed had body parts aches, more than 40% of which were low back and shoulders aches. The 76% of interviewees believed that aches were job-related or possibly. Such rate increased to 84% in 1999 while 39% of interviewees from the manufacturing industries had body aches. 79% of those had symptoms believed that their body aches were job-related or possibly. And statistics of other ratios of job-related aches were as shown in Table 2. The percentage of female interviewees from the traditional industries who believed their aches were job-related or may be job-related was more than 80%. The employees gradually attach more importance to problems of unnatural postures (IOSH, 2001). Namely, the self-consciousness of the employees increased gradually. Therefore, companies shall attach more importance to the improvement of working environment and working methods to ensure the body and mind health of the workers.

**Table 1.** Relationship between unnatural postures and possible symptomatic parts

| No. | Unnatural posture | Part/symptom |
|---|---|---|
| 1 | Standing (particularly, stand on one foot) | Foot, waist |
| 2 | Standing still | Leg nerve compression |
| 3 | Sitting without back support | Waist |
| 4 | Sitting without back support | Low back ache |
| 5 | Sitting without proper height foot rest | Knees, foot, waist |
| 6 | Sitting with too high elbow support | Trapezius, long trapezius, levator scapulae muscle |
| 7 | Kneeling | Increase heart rate and oxygen consumption, leg nerve compression |
| 8 | Squatting | Leg nerve compression |
| 9 | Vacant upper arm | Shoulders, upper arm |
| 10 | Raising arms | Shoulders, upper arm |
| 11 | Head bending back | Neck |
| 12 | trunk slightly buckling | Increase heart rate and oxygen consumption, back ache |
| 13 | Trunk seriously buckling | Increase heart rate and oxygen consumption, back ache |
| 14 | Trunk twisting and buckling | Back ache |
| 15 | Trunk bending forward and raising weights | Waist |
| 16 | Neck slightly bending | Neck ache, stiffness |
| 17 | Neck seriously bending | Upper back and arm ache, neck ache, stiffness |
| 18 | Neck twisting and bending | Neck and shoulders ache, headache |
| 19 | Using foot pedal | Low back, hips and knees ache |
| 20 | Joints keeping extreme postures | Joints involved |

**Table 2.** Job-related aches percentage (unit: %)

| | Sensible aches of body parts percentage | | | | | | | | | | Job-related | Possibly job-related |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | Neck | Shoulders | Upper back | Low back | Elbows | Hand wrist | Hips | Knees | Foot ankle | Total | | |
| All industries | 33.96 | 40.75 | 12.27 | 48.32 | 14.67 | 31.75 | 10.16 | 9.99 | 9.95 | 38.59 | 39.27 | 39.89 |
| All industries (male) | 32.42 | 9.18 | 11.59 | 50.04 | 16.32 | 34.88 | 9.61 | 10.90 | 9.70 | 37.30 | 40.07 | 38.27 |
| All industries (female) | 35.98 | 42.81 | 13.15 | 47.45 | 12.51 | 27.64 | 10.88 | 8.79 | 10.27 | 40.43 | 38.22 | 42.02 |
| Manufacturing industries | 32.79 | 39.12 | 11.95 | 49.48 | 14.96 | 30.99 | 10.46 | 8.28 | 8.23 | 38.28 | 37.07 | 41.96 |
| Manufacturing industries (male) | 29.76 | 38.03 | 11.39 | 49.16 | 15.48 | 31.92 | 11.65 | 9.69 | 8.50 | 36.00 | 39.77 | 40.59 |
| Manufacturing industries (female) | 36.06 | 40.30 | 12.56 | 49.82 | 14.40 | 29.99 | 9.18 | 6.76 | 7.94 | 42.24 | 34.14 | 43.44 |
| Technicians and assistant professionals | 44.44 | 45.07 | 13.53 | 46.29 | 11.48 | 19.17 | 7.24 | 7.74 | 6.62 | 29.30 | 33.31 | 37.26 |
| Technicians and assistants (male) | 43.52 | 42.47 | 11.65 | 44.09 | 12.65 | 19.62 | 8.04 | 8.41 | 7.91 | 27.21 | 32.46 | 35.14 |
| Technicians and assistants (female) | 45.64 | 48.44 | 15.95 | 49.15 | 9.96 | 18.59 | 6.19 | 6.87 | 4.93 | 32.55 | 34.41 | 40.01 |

**Table 3.** Musculoskeletal symptoms survey methodologies

| Methodology (Author) | Characteristics | Application |
|---|---|---|
| OWAS (Karhu *et al.*, 1981) | (1) An objective technology for evaluation of working postures. (2) Rules for redesign of working methodology and environments. (3) COWAS: use computer program to record and calculate workload of each action and the impact of specific job upon the entire posture. (4) Computerization makes data input and analysis much easier. | Steel and iron industry; garage; farmhouse; construction |
| Posture Targeting method (Corlett *et al.*, 1979) | (1) Easy to learn and precise. (2) High repetition and reliability in technical level. (3) Data suitable for computer analysis. | Welding worker |
| AET method (Rohmert and Landau, 1983) | (1) Low cost working system appraisal tool. (2) Measuring not required. (3) It has been applied by Britain, Luxemburg and Finland. | Car engine assembly; Steel and iron monitoring |
| Job Profiles method (Wagner, 1985) | (1) Designed mainly for repetitive job, short cycled, medium precision and un-technique job. (2) Able to draw individual working verification distribution map as well as comparison diagrams. | Wire outer case peeling worker |
| Armstrong *et al.*, 1986 | Describing each job in a series of steps or units for analysis. | |
| EMG (Aaras *et al.*, 1988) | (1) Able to measure suitable muscles physiologically. (2) Too sensitive to produce errors. (3) Impossible to record all suitable muscles. (4) Recordings of big muscles may be untrue without recording the actions in general. | Conductor; timber industry; car assembly |
| Posture Checklist (Keyserling *et al.*, 1992) | (1) Fast, high sensitive measuring of working risk factors. (2) Including some questions on objective evaluation of unnatural postures and lasting time. Various unnatural postures have three occurrence frequencies with three types of forces for alternative. (3) Body parts under discussion: lower limb, trunk and neck. (4) Suitable for long time and non-repetitive work. | Engine manufacturing plant; Steel and iron industry; greenhouse |
| RULA method (McAtamney and Corlett, 1993) | (1) Grading system: points from the total number table can be divided into 9 grades with consideration of muscle usage and force received. (2) Quick survey method with considerations of working postures, force, state, repetitive job and muscle exhaustion. (3) No special measuring equipment requested with only note board and pen needed. No disruption of working field. (4) Special technique training not requested. | Tailor; VDU operator; Clothing industry; supermarket cashier; microscopic user; car manufacturing industries; other manufacturing industries related to upper arm injury |
| BRIEF (Humantech, 1993; IOSH, 1995) | Confirming ergonomics risk factors in the working environment. | |
| PLIBEL method (Kemmlert, 1995) | (1) Suitable for defining risk factors of various body parts. (2) Suitable for repetitive jobs. (3) Able to conduct standardized and practical analysis of human factors of the working environment. | Timber worker; Book binding; Laundry; recycling business |
| PATH method (Buchholz *et al.*, 1996) | (1) 30 hours training for the use of the method. (2) Data input by computer card reading. (3) Suitable for non-repetitive, non-cycling, long term or irregular cycles. (4) Inapplicable in analyzing upper arms. | Construction |
| Killough and Crumpton, 1996 | (1) Questionnaire and field work are compared simultaneously. (2) developing a risk indicators according to five factors (repetitiveness, unnatural posture, force, working term and tools) | Construction |
| Andersson *et al.*, 1996 | (1) Considering force upon arms and movements. (2) Measuring force upon hand during repetitive jobs. (3) Placing a delicate small box upon wrist to measure movement (displacements in three dimensions, acceleration and velocity). (4) Data input directly for computer analysis. | |

## 2.3 Musculoskeletal symptoms survey method

In this study, musculoskeletal symptoms survey was mainly conducted by field job analysis method and questionnaire. By reviewing the literature, the two methods were deliberated and discussed respectively.

### 2.3.1 Job analysis method

Scholars have developed some different techniques or methodologies to observe body movements in order to study the relationship between the actions on the working field and the musculoskeletal symptoms. These include working field direction observation (OWAS, RULA, PLIBEL, AET, posture targeting and BRIEF) by using camera or video camera to record actions for follow-up observation or by using precision instruments to record the movements of certain body parts (direction, acceleration, velocity and displacement) as well as EMG analysis. The common job analysis methodologies were as listed in Table 3. This study applies OWAS for analysis as introduced below.

**Table 4.** OWAS coding system

| Body part | OWAS code | Description of posture |
|---|---|---|
| Head | 1 | free |
| | 2 | bent forward |
| | 3 | bent to the side |
| | 4 | bent backward |
| | 5 | twisted |
| Back | 1 | straight |
| | 2 | bent |
| | 3 | twisted |
| | 4 | twisted and bent |
| Arms | 1 | both arms below shoulder level |
| | 2 | one arm at or above should level |
| | 3 | both arms at or above shoulder level |
| Legs | 1 | sitting with legs under seat level |
| | 2 | standing with both legs straight |
| | 3 | standing or kneeling on one leg, leg straight |
| | 4 | standing or kneeling on both legs, legs bent |
| | 5 | standing or kneeling on one leg, leg bent |
| | 6 | kneeling on one or both knees |
| | 7 | walking or moving |
| Weight or force handled | 1 | less than 10kg |
| | 2 | over 10kg but less than 20kg |
| | 3 | over 20kg |

OWAS (Ovako Working Posture Analyzing System) proposed by Finnish Ovako Oy steel company in 1973 is mainly to define the body postures during working and grade according to the possibility of injury (Karhu *et al.*, 1981). The OWAS method defines individual codes for postures of each body part (see Table 4) for evaluation of the discomfort to set up systematic rules for improvement plans. The coding follows mainly two rules: (1) general body characteristics; (2) body parts for lining up and mixing to get the coding system. The study personnel may give certain action a code during field observation to represent a posture. After recording all the field observation data, the possibility of injury may be determined by standards in four categories (Action Categories, AC), from AC1 representing no treatment required to AC4 representing immediate treatment required to improve. General studies usually propose postures of AC3 above for discussion or comparison to improve the discomfort and provide suggestions to improve working methodology or working environment. With respect to small and medium enterprises, OWAS is a considerably economic analysis method (Santos *et al.*, 2007) and it is widely used.

### 2.3.2 Questionnaire methodology

In working labor force, musculoskeletal symptoms are considerable common. If symptoms can be diagnosed precisely in a short time, early training and ergonomics improvements can be introduced to lower losses of working hours (Deakin *et al.*, 1994). To help understand the musculoskeletal problems and potential job-related risk factors, many countries study the recording and evaluation methodologies of musculoskeletal symptoms. The questionnaire methodology is regarded as one of the most direct methodologies for data collection (Kuorinka *et al.*, 1987). The questionnaire often used for RTDs survey is mostly design on the basis of body parts map along with design of choices regarding the subjective feelings of symptoms related to job. NMQ is a very good example of such questionnaires. Nordic Musculoskeletal Questionnaire (NMQ) was developed by Nordic Council of Ministries mainly for the purpose of: (1) becoming a tool for musculoskeletal symptoms diagnosis to analyze whether working environment and design of workshop and tools may trigger musculoskeletal symptoms risk factors; (2) improving working environment according to analysis results.

The NMQ design a standardized questionnaire about the musculoskeletal symptoms and injuries common among workers to make corresponding questions have clear definitions and be able to be compared with results of other job analysis methodologies. NMQ questionnaire has a limitation that the subjective response of interviewees to questions such as "symptom related to job or not?" sometimes cannot precisely reflect facts. Hence, other methodologies are recommended to work along with NMQ questionnaire to discuss the real relationship of types of musculoskeletal symptoms and jobs (Johansson, 1994). NMQ can accurately distinguish the symptoms of different workshops and can be applied in many diversified working environments. And it can incorporate quickly and easily large number of people (Dickinson *et al.*, 1992). At present, NMQ questionnaire has been widely used in North Europe, Britain and Canada to analyze occupational injury distribution and provide benchmarks for improving the working environments. NMQ questionnaire defines musculoskeletal discomfort and injury body parts of workers into 9 parts (see Figure 1), including neck, shoulders, upper back, low back, elbows, hands/wrists, hips/thighs, knees and feet/ankles. The rules for divisions are: (1) body parts that may accumulate symptoms; (2) interviewees and consultants can tell the difference from other body parts.

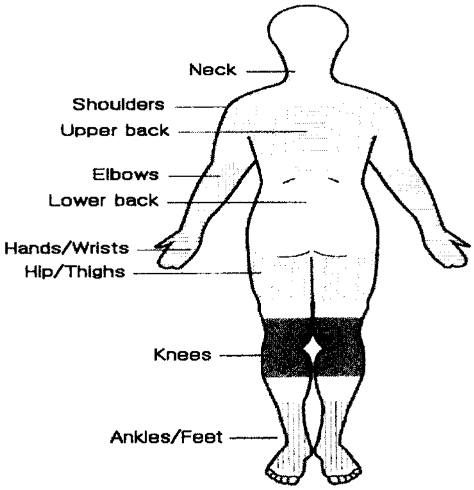


**Figure 1.** Nine parts of NMQ

The NMQ questionnaire can be designed as a General questionnaire or Specific questionnaire. General questionnaire mainly asks the interviews whether there is any musculoskeletal problem and where to tell the difference between discomfort or injury parts while, Specific questionnaire is to study more in-depth upon symptom of certain specific body part. No matter how NMQ is designed, the reliability of the questionnaire is about 77% to 100% with validity around 80% to 100%. Other common musculoskeletal symptoms questionnaires are as listed in Table 5.

**Table 5.** Musculoskeletal symptoms survey methodologies

| Method (Author) | Characteristics | Application |
|---|---|---|
| Karasek Job Stress Questionnaire (Karasek, 1979) | Six survey indicators: psychological need, physical need, time need, failure level, effort and performance. | |
| NMQ survey (Kuorinka *et al.*, 1987) | (1) Applicable in many types of working sites and able to incorporate many laborers easily. (2) Making a standard questionnaire of common musculoskeletal symptoms and injuries. (3) Discussing nine body parts respectively. (4) Reliability and validity are more than 80%. | Supermarket cashier; Truck driver; wrapper; NC operator; Factory engineer; Onsite supervisor |

### 2.4 RTDs prevention and control

General treatments of RTDs include: neglect, rest, local prevention and treatment or surgery. The first two methods are rather passive to expect the automatic extinction of symptoms. However, they may have superficial effects but cannot uproot the disorders. If go on doing the same job, the symptoms may worsen. The later two methods may solve the present problems but they may also trigger new problems. Therefore, RTDs may not be cured and measures must be taken to prevent RTDs. First, we should observe and understand the ergonomic risk factors, which are usually job-related. In this aspect, the goals of controlling and preventing RTDs by ergonomics experts or scholars are: raise productivity, lower tiredness and improve musculoskeletal health (Westgaard and Winkel, 1996); the methodologies used are mainly in three aspects: design and redesign in engineering, administrative management control, and health care management (Marley and Kumar, 1996). In the aspect of design and redesign in engineering, to compensate for the lack of ergonomics engineering in industries, preventive measures are mainly focused on spare parts, operation, equipment, area configuration and redesign of environment (Genaidy *et al.*, 1995). However, engineering control alone cannot completely get rid of the musculoskeletal and productivity problems. Ergonomics attaches importance to safety and comfort while management attaches importance to productivity, quality and efficiency. They shall work together to get more efficient productivity and the control of working environment injury. In addition, the training of employers and employee to prevent musculoskeletal symptoms is also an important link in the ergonomics engineering. Take arm RTDs prevention and control as an example, Armstrong *et al.* (1986) proposed to discuss according to risk factors as follows: in repetitiveness, increase the job diversity, rotation (change repetitive body parts), the compliance of the increased job and the original job (shorted time of training and adaptation), no correlation of working pressure types. In changing the forces personnel bears, the object (weight, size, shape and the balance of force the arms to bear) is improved and pressure distribution is considered when designing the hand-held object, gravity center and force comply with arm features. The improvements of postures include lowering working platform, reducing overhead upholding and deviation. The pressure relief concentration can be made through increasing tool sizes, making R corners and adopting soft materials. Finally, it is important for control job to understand whether ergonomics treatment can make improvements.

## 3. Research Method

This study discusses whether there is any musculoskeletal symptom risk for workers in the manufacturing process of water heater's case. The research methodologies are field job analysis and questionnaire to lower musculoskeletal symptoms risks.

### 3.1 Samples

This study first divides the manufacturing process of the water heater's case into 9 workshops as listed in Table 6 including cutting, side-wrapping, pressing, hole-making, wrapping, welding, drilling, pressing die. Brief introductions to the making process are also listed in Table 6. In this factory, iron plate is processed into assembly parts to be assembled in other places.

**Table 6.** Nine workshops in the case factory

| No. | Workshop | Workshop procedure |
|---|---|---|
| 1 | Cutting processing | Cutting 4 corners of the iron plates |
| 2 | Side-wrapping processing | Wrapping up two sides of the iron plate by approximately 1cm. |
| 3 | Pressing processing | Pressing out a ventilation upon the iron panel |
| 4 | Hole-making processing | Making two holes upon the pressed iron plates for follow-up assembly |
| 5 | Wrapping processing | Wrapping the iron plate into semi-finished products after completing 4 processing workshops |
| 6 | Welding processing | Welding after adding iron plate upon the semi-finished products for follow-up assembly. |
| 7 | Drilling processing | Drilling 4 holes by the driller for follow-up assembly of moulds |
| 8 | Pressing die processing 1 | Putting the long iron plates upon the machine for pressing into moulds. |
| 9 | Pressing die processing 2 | Sending the semi-finished products for pressing die processing for follow-up welding. |

In addition to field job analysis, this study will also conduct individual worker musculoskeletal symptom questionnaire. Seven workers are interviewed with their basic data as listed in Table 7. Most of these workers have relatively long working years or are old-aged.

**Table 7.** Preliminary basic data of questionnaire interviewees

| No. | Gender | Height (cm) | Weight (Kg) | Working years | Age |
|---|---|---|---|---|---|
| 1 | Male | 160 | 70 | 21 years | 52 |
| 2 | Female | 150 | 75 | 6 years | 26 |
| 3 | Male | 175 | 75 | 21 years | 62 |
| 4 | Male | 173 | 70 | 12 years | 61 |
| 5 | Male | 171 | 83 | 10 months | 31 |
| 6 | Male | 167 | 61 | 10 months | 53 |
| 7 | Male | 174 | 83 | 10 months | 53 |
| Average (standard variation) | | 167.1(9.2) | 73.9(7.8) | 8.9(9.2) | 48.3(14.2) |

## 3.2 Field job analysis

Prior to the field job analysis, we first talk with onsite operators or foremen. In one hand, we ask questions about job content to serve as the reference for dividing workshops; on the other hand, we communicate with interviewees to get rid of doubts and reservations of the interviewees when being observed and recorded to make the field job analysis smooth. The questions for onsite operators and foremen are as follows: job content (such as procedures, product types, and shift information), personal feeling (whether having discomfort or injury, working environment improvements) and warnings. The job analysis methodology is to divide the job into several workshops by interview or observation. Then, the actions of workers are recorded according to various workshops to discuss the possible risk factors. By reviewing the posture analysis methodology literature, it is known that the study and analysis methodology of working posture must be simple, being easy for understanding and reliable (Corlett *et al.*, 1979). The OWAS adopted in this study complies with the three principles. In particular, a computerized OWAS program for onsite working posture analysis is much simpler (Li, 2000; Li and Lee, 1999). This study will use DV to shoot the actions of workers of various workshops and then code the working postures by slow motions for OWAS program (see Figure 2). After inputting the posture coding data, the program can immediately make analysis of the risk level of the action regarding the personal injuries of workers (see Figure 3).

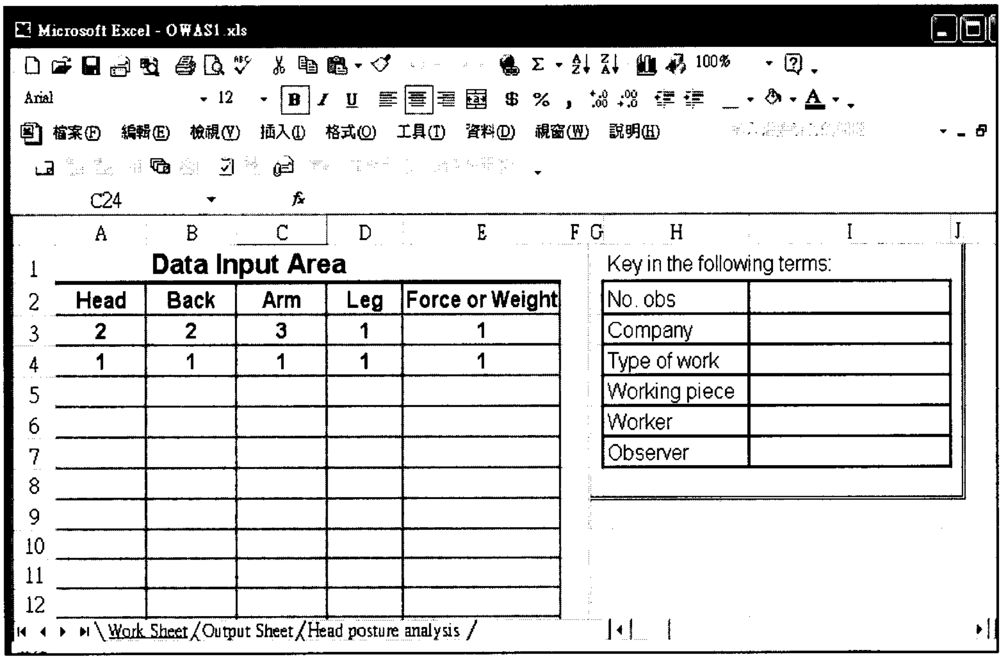


**Figure 2.** The OWAS data input

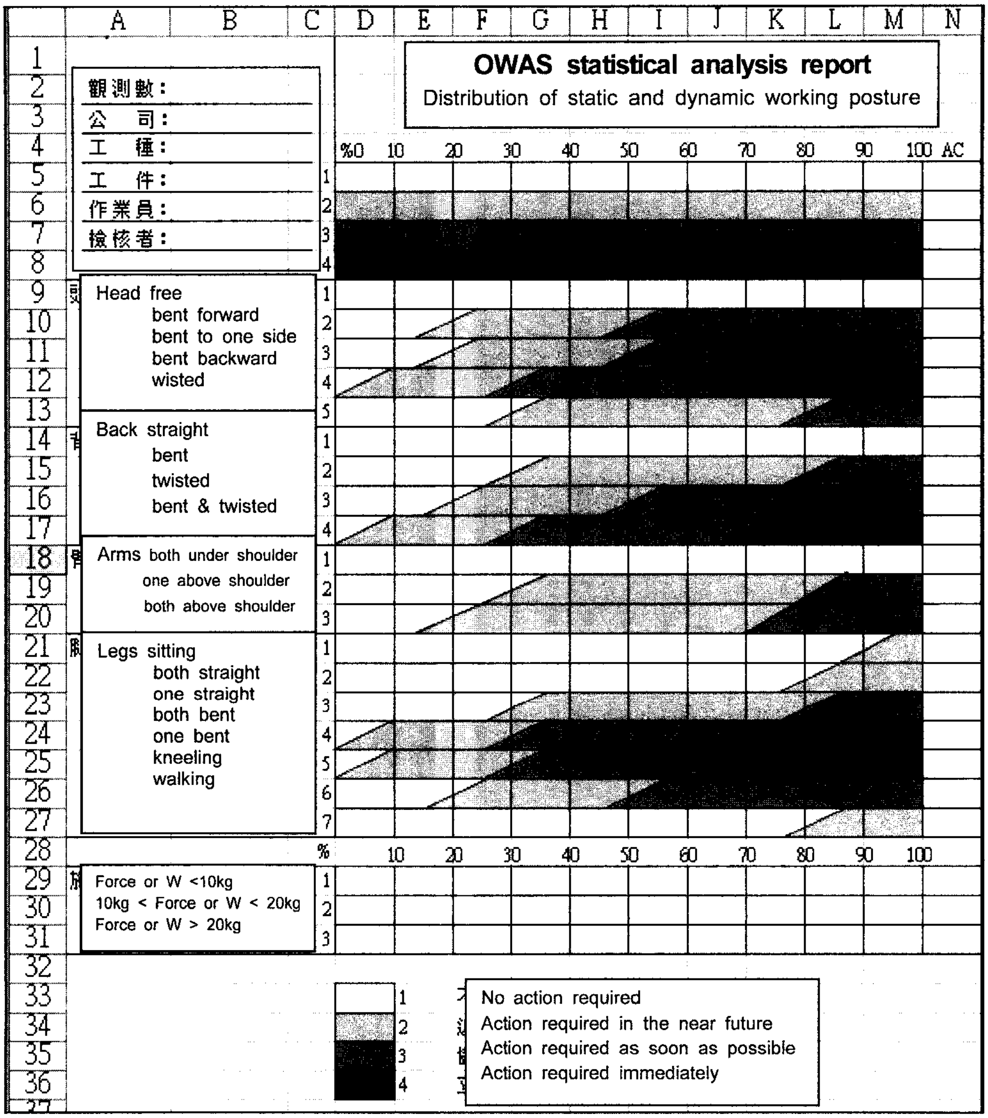


**Figure 3.** OWAS statistics analysis report

## 3.3 Questionnaire interview

Questionnaire is one of the most direct methods to understand the musculoskeletal symptoms and it can serve as a reference for solving the labor injury problem. Hence, questionnaire will be used for related analysis. The NMQ adopted for the design of the questionnaire in this study makes a standardized questionnaire about the musculoskeletal symptoms and injuries among the working labor to clear define the problems for comparison with results of other different job analysis method. This study will compare it with OWAS results.

In questionnaire statistical analysis, this study input the basic data such as age, height, weight, working years, current occupational working years, title, gender, and working area as well as choices made by workers on the questionnaire into EXCEL for basic statistics, then input the data into SPSS software for statistical processing. Mainly, the relationships between body parts aches and jobs are discussed. The OWAS results may refer to the risk factors in various workshops. The workshop risk level can be compared with results of NMQ questionnaire to discuss its relationship.

## 4. Research Results and Analysis

To find out the manufacturing industries workers' risk factors, we used DV to shoot and play working actions. The working code is to capture a picture every 5 seconds. The OWAS coding system was used to code head/neck, back, arm, leg and weight for data input into the OWAS software. After coding, data was input to get the workshop data distribution by the software as listed in Figure 3. These data mainly include the general job injury AC values. The results of this study are as listed in the following Table 8, which will be deliberated in the following section.

### 4.1 OWAS analysis and improvement

At first, we analyzed the postures of all workshops of the working procedure as listed in Table 9. We found no status above AC3, indicating there is no working posture in the factory requesting improvement. However, the whole body OWAS analysis finds out working posture with above AC2 values accounting for more than a half on 4 workshops, indicating slight injury of the postures, which require follow-up observation. In particular, the seventh workshop requests to make holes and the workers usually have to lower head and bend down to operate the machine. Such a posture takes most of the working time (above 80%, see Table 8). Therefore, although it is no more than AC3 above, it shall be noted for improvement. This study suggests increasing the height of the machine for improvements.

This study proposed some improvement plans regarding these workshops. With respect to the working postures of the above workshop workers with above AC3 values (obviously injurious, requiring immediate improvements), we put forward the work rotation plan to decrease harms to workers or work design to adjust work surface and work height to be in line with ergonomics, making sure that workers have good working environment and lowering risks of musculoskeletal symptoms.

Table 8. Percentages of workshop OWAS body parts repetitive risk factors

| Workshop | Body part | Posture | Percentage | AC value |
|---|---|---|---|---|
| 1 | Head | Free | 90.0 | 1 |
| | Back | Back bending and twisting | 60.0 | 3 |
| | Hand | Arms lower than shoulders | 100.0 | 1 |
| | Foot | Standing on both feet | 80.0 | 2 |
| | | Standing on one foot | 20.0 | 1 |
| 2 | Head | Free | 31.6 | 1 |
| | | Head bending forward | 68.4 | 3 |
| | Back | Back bending | 47.4 | 2 |
| | | Back twisting | 52.6 | 3 |
| | Hand | Arms lower than shoulders | 100.0 | 1 |
| | Foot | Standing on both feet | 47.4 | 1 |
| | | Standing on one foot | 52.6 | 2 |
| 3 | Head | Free | 100.0 | 1 |
| | Back | Back straight | 57.1 | 1 |
| | | Back twisting | 42.9 | 2 |
| | Hand | Arms lower than shoulders | 100.0 | 1 |
| | Foot | Standing on both feet | 42.9 | 1 |
| | | Standing on one foot | 57.1 | 2 |
| 4 | Head | Free | 100.0 | 1 |
| | Back | Back straight | 20.0 | 1 |
| | | Back bending and twisting | 30.0 | 3 |
| | Hand | Arms lower than shoulders | 100.0 | 1 |
| | Foot | Standing on both feet | 80.0 | 2 |
| | | Standing on one foot | 20.0 | 1 |
| 5 | Head | Head bending forward | 100.0 | 3 |
| | Back | Back bending | 66.7 | 2 |
| | | Back bending and twisting | 33.3 | 3 |
| | Hand | Arms lower than shoulders | 100.0 | 1 |
| | Foot | Standing on both feet | 100.0 | 2 |
| 6 | Head | Free | 7.1 | 1 |
| | | Head bending forward | 57.1 | 3 |
| | | Neck side bending | 35.7 | 2 |
| | Back | Back bending | 92.9 | 3 |
| | | Back twisting | 7.1 | 1 |
| | Hand | Arms lower than shoulders | 100.0 | 1 |
| | Foot | Standing on both feet | 100.0 | 2 |

| | | | | |
|---|---|---|---|---|
| 7 | Head | Free | 17.1 | 1 |
| | | Head bending forward | 80.0 | 3 |
| | | Neck side bending | 2.9 | 1 |
| | Back | Back straight | 8.6 | 1 |
| | | Back bending | 91.4 | 3 |
| | Hand | Arms lower than shoulders | 100.0 | 1 |
| | Foot | Sitting | 100.0 | 2 |
| 8 | Head | Free | 87.5 | 1 |
| | | Neck side bending | 12.5 | 1 |
| | Back | Back straight | 87.5 | 1 |
| | | Back bending | 12.5 | 1 |
| | Hand | Arms lower than shoulders | 100.0 | 1 |
| | Foot | Sitting | 100.0 | 2 |
| 9 | Head | Free | 100.0 | 1 |
| | Back | Back straight | 100.0 | 1 |
| | Hand | Arms lower than shoulders | 100.0 | 1 |
| | Foot | Sitting | 69.2 | 1 |
| | | Standing on one foot | 30.8 | 2 |

**Table 9.** Body posture OWAS analysis

| Workshop | Number of AC1 | Percentage | Number of AC2 | Percentage | Number of AC3 | Percentage | Number of AC4 | Percentage |
|---|---|---|---|---|---|---|---|---|
| 1 | 12 | 60.0 | 8 | 40.0 | 0 | 0 | 0 | 0 |
| 2 | 10 | 52.6 | 9 | 47.4 | 0 | 0 | 0 | 0 |
| 3 | 10 | 100.0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 5 | 50.0 | 5 | 50.0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 10 | 100.0 | 0 | 0 | 0 | 0 |
| 6 | 1 | 7.1 | 13 | 92.9 | 0 | 0 | 0 | 0 |
| 7 | 3 | 8.6 | 32 | 91.4 | 0 | 0 | 0 | 0 |
| 8 | 16 | 100.0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 13 | 100.0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 70 | | 77 | | 0 | | 0 | 0 |

## 4.2 OWAS and questionnaire relationship

It can be known from the questionnaire results that the interviewees are aged 48.3 on average with average working time of 8.9 years and daily working hours of 8.3 (Table 10). Seven of them have painful feelings at various body parts (light, serious), 4 of them consulted doctors accordingly, accounting for 57.14% of the interviewees. And the body parts aches details are as follows as shown in Table 11. The percentage of neck, shoulders, and lower back ache are the top ones with job-relationship more than 75%. On the other hand, the questionnaire results find out muscle ache resulting from unnatural working postures, in which case it may be needed to consult doctors for a while. As we analyzed each workshop with OWAS, we found that one or two workshop requesting long time stay in the workshop without proper rest and work rotation. And this may be the main reason for muscle ache.

**Table 10.** Basic data of interviewees

| Item | Average | Std. variation | Maximum | Minimum |
|---|---|---|---|---|
| Age | 48.3 | 14.2 | 62 | 26 |
| Working years | 8.9 | 9.2 | 21 | 0.83 |
| Daily working hours | 8.3 | 0.7 | 10 | 8 |

**Table 11.** Body parts aches

| Body part | Ache percentage | Job-related or not? | | | | How to deal with aches? | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Related | Maybe related | Unrelated | Unclear | Traditional or western medication | Self-help treatment | No medication | Other |
| Neck | 25.1 | 35.7 | 40.6 | 15.2 | 8.6 | 41.1 | 18.6 | 37.5 | 2.8 |
| Shoulders | 27.3 | 37.4 | 40.9 | 13.5 | 8.2 | 42.0 | 18.9 | 36.4 | 2.7 |
| Upper back | 11.7 | 41.3 | 39.9 | 12.0 | 6.8 | 42.1 | 19.2 | 36.0 | 2.7 |
| Elbows | 12.3 | 41.9 | 39.7 | 10.7 | 7.7 | 45.5 | 19.7 | 33.2 | 1.6 |
| Low back | 24.0 | 39.7 | 37.9 | 14.2 | 8.2 | 50.4 | 15.8 | 31.6 | 2.2 |
| Hands/wrists | 18.8 | 46.7 | 37.3 | 9.6 | 6.3 | 45.0 | 19.6 | 33.4 | 2.0 |
| Hips/thighs | 7.4 | 43.1 | 32.7 | 15.6 | 8.6 | 41.4 | 19.5 | 37.2 | 1.9 |
| Knees | 8.6 | 33.3 | 31.3 | 24.4 | 11.1 | 45.8 | 19.4 | 32.6 | 2.3 |
| Foot/foot ankle | 10.0 | 38.9 | 30.3 | 21.0 | 9.8 | 45.6 | 16.7 | 35.0 | 2.8 |

## 5. Conclusions

By OWAS analysis and NMQ questionnaire results, it can be known that neck and back injuries account for the highest percentage. Workers from Workshop 1 to 7 have neck/head and back working postures of AC3 (Action required as soon as possible), therefore, we proposed work rotation plan to lower worker injury or work design to adjust work surface and work height to be in line with ergonomics, making sure that workers have good working environment and lowering musculoskeletal symptoms risks. Preventive protection shall be taken when workers have musculoskeletal symptoms or musculoskeletal symptoms risks indicated by job analysis results to lower occupational injury risks. After NMQ questionnaire analysis, we found some workshops have very big probabilities to cause serious neck, shoulders and lower back musculoskeletal symptoms. Therefore, this study proposes improvement methodologies to lower workers' musculoskeletal symptoms probabilities: (1) work rotation: by working on shift to lower the repetitive musculoskeletal symptoms probabilities and monotonous feeling of workers; (2) the expansion of job can lower action repetitiveness, lower the musculoskeletal symptoms and flexible use of human power to increase justice; (3) workshop design: ideal workshop design can avoid unnatural working postures and the occurrence of highly repetitive actions. The work design includes working surface, working height; (4) proper break: finding out workshops that may cause musculoskeletal symptoms, proper rest time shall be granted to workers to lower probabilities of musculoskeletal symptoms.

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