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Ergonomic Posture Analysis of Automobile Assembly Jobs based on Multi-Year Observation Data

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Abstract

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Posture is represented as a composite of the positions of all human joints, and human naturally takes posture at any moment whether it is good or bad. Good posture is a necessary condition for healthy life. Now, the importance of good posture becomes a universal truth. On the contrary to this, bad postures induce various illnesses or disorders, in particular, musculoskeletal disorders.

Musculoskeletal disorders bring pains or agonies in musculoskeletal systems, and can be exacerbated to some kinds of cumulative disorders. In the industrialization era, repetitive works become main jobs for workers, so that the workers have to specialize in the repetitive works. Consequently, the prevalence of musculoskeletal disorders, which are work-related disorders, has been growing higher.

Plenty of researches have been conducted to prevent or deal with the work-related musculoskeletal disorders. The researchers have focused on grasping risk factors for work-related musculoskeletal disorders so far. The results clearly reveal that awkward posture, excessive force, and repetition during work are the most influential factors. Among these factors, the working posture is the one mostly referred to.

Nonetheless, dissimilar to the work-related musculoskeletal disorders, contributing factors for working posture have not been investigated enough. Previously, it was mainly concerned how a working posture varies when a worker takes a specific posture, for example reaching, in a particular context. There is no single study on the understanding the contributing factors for the working posture among various factors in a work site.

This dissertation starts with this motivation, and aims to resolve this research question: which factors are the contributing factors for working postures, and how much are they influential? It is practically impossible to consider every variable to resolve this question, so the study should be preceded by selecting a candidate set of expected contributing factors. To get the candidate set, we primarily referred to literature on this issue. Unfortunately, there was little researches on this subject, so we additionally paid attention to the studies on the risk factors for the work-related musculoskeletal disorders.

The first part of this dissertation is an overview study of existing systematic reviews. Through the overview study, risk factors for work-related musculoskeletal disorders were collected, and the terminologies were standardized. Moreover, associations between the risk factors and work-related musculoskeletal disorders were analyzed for each body

part. Based on the result of the analysis, the candidate set was drawn. The candidate set was composed of individual and physical exposure factors.

For the drawn candidate set, the factors were measured through field researches. A series of field research had been conducted in an automobile assembly plant for seven years. The gathered data contained the two factors mentioned above and the working posture. Through statistical analyses of the data, the contributing factors were finally determined. Then, their influence was analyzed as well.

Existing ergonomic assessment methods normally deliver a risk level and an action level. However, the results are not differential, and the basis is not very concrete. Moreover, these existing methods do not consider from job satisfaction and job stress viewpoints. To this end, at first, comparisons among the existing methods were carried out. Then, job satisfaction was estimated using the assessment methods. Finally, quantitative models for job satisfaction and job stress were suggested using statistical analysis and machine learning techniques.

While pooling the data from the work site, we attempted to find ergonomic problems in the work site and to resolve the problems. It is so much important to clear up ergonomic problems from ergonomic and working postural perspectives. Hence, in this dissertation, the ergonomic problems in an automobile assembly plant were figured out. Then, appropriate interventions were suggested. After that, through a follow-up study, the effectiveness of the implemented interventions was analyzed by comparing before and after the interventions regarding the working postures and the results of ergonomic assessment methods.

Lastly, to manage musculoskeletal disorders in the work site effectively, it is required to manage numerous information efficiently. The efficiency of information management is determined by ease of data input and retrieval. From this perspective, a database system is the most proper system for monitoring the information on musculoskeletal disorders. Thus, we constructed a database system appropriate to the work site. The database system was built on a web-based platform to increase the accessibility. Additionally, software for postural analysis was developed for more reliable and accurate analysis of the working posture. The two systems suggested in this study are expected to help both academic researchers and practitioner in the real field.

Keywords: working posture, musculoskeletal disorders, risk factors, video observation, follow-up study

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Chapter 1. Introduction

1.1 Research Background

Human body posture is defined by relative positions of body parts and linked angles of joints. Over the past decades, plenty of studies have been revealed the importance of the good body posture. Especially, pain in specific body parts such as neck and back is highly and directly related to the body posture and adaptation.

In ergonomics and occupational safety fields, posture has been treated as one of the most critical variables. The posture was referred as 'working posture', and the working posture is highly related to the industrial comfort (Corlett & Bishop, 1976).

Critical risk factors causing musculoskeletal disorders (MSDs) are known as excessive force, awkward working posture, and repetitiveness. Amongst these three factors, the working posture is the mostly referred factor (Jaffar et al., 2011). Awkward working posture means that any joint or body part is out of good range of motion because of bending or twisting. In this state, more burden or stress is put on muscle, ligament, and tendon.

It is proved that there is a significant relationship between awkward working posture and occurrence of work-related MSDs (WMSDs) by many researchers. In the early stage of the research on the working posture, attempts to investigate the level of burden on each body part depending on the working posture were taken. Most studies aimed to

quantify and evaluate the stress on each body part by observing the working posture and using simulation method.

Based on this knowledge, methodologies to distinguish comfort and discomfort working posture have been researched. These studies proposed the level according to the stress on each body part or joint, and suggested the methods to evaluate the overall stress synthetically. As a result of these studies, ergonomic postural assessment methods were developed such as 'rapid upper limb assessment (RULA)', 'rapid entire body assessment (REBA)', and 'Ovako working posture assessment system (OWAS)' (Hignett & McAtamney, 2000; Karhu et al., 1977; McAtamney & Nigel Corlett, 1993).

Furthermore, studies to predict and estimate the human body posture have been conducted. These studies normally use computer simulation methods or image processing techniques to propose biomechanical models such as arm reach prediction under specific context and posture prediction when doing manual material handling (MMH) tasks. The studies on the posture prediction have been handled not only in the field of ergonomics but also in other engineering fields including computer science and electronic engineering.

Until now, many problems have been found and resolved by previous researchers. However, many questions that should be resolved remain still unsolved. In the following sections, the problems and research questions to be addressed are stated.

1.2 Research Questions and Research Purposes

In this section, four research questions that are fundamental to directing the research purpose are suggested. In the last chapter, these research questions will be discussed again to identify how they were handled through the research. This dissertation will examine four main research questions:

Research Question 1: What is the contributing factors for the working posture? Also, which factor is more influential than other ones on the working posture?

Research Question 2: How can ergonomic risk level of a job be measured regarding job satisfaction and job stress? How can job satisfaction and job stress be quantitatively estimated using existing ergonomic assessment methods?

Research Question 3: What are ergonomic problems in an automobile assembly plant? What are the outcomes of these ergonomic problems? What are the appropriate interventions, and are they useful in the real world setting?

Research Question 4: How can postural stress be evaluated easily? How can the information related to WMSDs in a work site be managed effectively and efficiently?

The purposes of this dissertation are to answer the research questions, and these four purposes are mutually related, rather than isolated.

Research Purpose 1

The risk factors for the WMSDs were determined in the previous studies, and the associations between the risk factors and WMSDs have been investigated quite well. However, the contributing factors for the working posture have not been figured out, and justly, the relationships between the contributing factors and the working posture also need to be investigated.

First, a candidate set of the contributing factors for the working posture were pooled from previous literature. Second, the risk factors for WMSDs and their associations were reviewed through an overview study. The reason why the risk factors for WMSDs were reviewed is that the working posture is known as one of the most crucial causations for WMSDs. Third, data on the factors included in the candidate set was gathered through a field research. Then, the relationships between the candidate set and the working posture were unraveled.

Research Purpose 2

Diverse methodologies to measure the risk level of a job have been suggested by previous researchers. Those methods have their strength and weakness, and a new method to quantify the risk level regarding job

satisfaction and job stress is still needed. Existing methods do not consider worker's job satisfaction and job stress directly, even though the fact that these psychological factors are causative for WMSDs is supported by numerous studies. Thus, we aimed to develop quantification methods for job satisfaction and job stress. To this end, statistical analysis and several machine learning techniques were used.

Research Purpose 3

In answer to the third question, work site investigations on an automobile assembly plant were conducted over seven years. Through the field research, information related to the individual factors, physical exposure factors, and environmental factors was gathered. Then, ergonomic problems in the plant were found by analyzing the gathered data. Based on the analysis results, appropriate ergonomic interventions were developed. Among these developed interventions, not all but some were implemented to the work site with constraints of financial and time perspectives. Then, a follow-up study was carried out, and the effectiveness of the interventions was measured by comparing before with after interventions in terms of the working postures and ergonomic risk levels.

Research Purpose 4

Despite a wide use of ergonomic assessment methods such as RULA and REBA, there is few tool to support ergonomic evaluation using these methods. Especially, a tool that aids a quantitative analysis of both working posture and ergonomic risk evaluation was not developed so far. Although technologies for motion capture and pattern recognition have been advanced rapidly, there are critical obstacles to adopting these technologies to the real fields. The obstacles are mainly about pragmatic issues. Hence, the tool for ergonomic analysis of the video or picture is still needed.

Information that should be handled for effective WMSDs management is many and varied. In this regard, a database system can help to manage the needed information.

To resolve these questions, two desktop based application systems were developed. One is a working postural analysis system. This system provides (1) a calculation of the joint angle, and (2) results of the ergonomic risk level using these values. The other is a web-based database system for managing the information on WMSDs in a work site. These two systems can help both practitioners and researchers who are in the field of ergonomics and occupational safety.

1.3 Document Outline

This dissertation is organized such that it flows from answering the research questions. The overall structure of this dissertation takes the form of eight chapters, including this introductory chapter. A notable property of this dissertation is that from Chapter 3 to Chapter 7, each chapter can be regarded as an independent and complete study. Those chapters are composed of its own abstract, introduction, method, results, and discussion like a typical academic article. Brief descriptions on the subsequent chapters are presented below.

Chapter 2 begins by laying out the theoretical dimensions of the basic concepts including MSDs and working posture. Additionally, specific schemes for classification of the working posture were reviewed.

Chapter 3 is concerned with an overview study of risk factors for WMSDs. The results of the overview study on the systematic reviews of the risk factors for the WMSDs are reported. Moreover, associations between the risk factors and WMSDs were investigated, and the level of evidence for the associations was stated too. The results of this chapter are partially used to complete a candidate set proposed in Chapter 4.

Chapter 4 presents the findings of the contributing factors for the working posture. Data on the candidates set of the contributing factors was gathered through a work site investigation. Descriptive statistics of the candidate set was calculated, and the results of correlation analysis and regression analysis between the candidate set and the working posture are reported in this chapter.

Chapter 5 suggests a method for quantification of job satisfaction and job stress. This chapter also contains brief explanations of used methodologies such as statistical analysis and machine learning techniques. Using these techniques, quantitative model for job satisfaction and job stress were estimated based on the existing ergonomic assessment methods.

Chapter 6 describes a case study to find ergonomic problems in an automobile assembly plant. Field investigations were carried out to gather needed information, and ergonomic analysis was also conducted. Then, appropriate interventions were developed, and some of them were implemented to the work site. Through a follow-up study, the effectiveness of the interventions applied to the work site was measured by comparing before with after interventions regarding the working posture and ergonomic risk level.

Chapter 7 introduces a working postural analysis system and a web-based database system for WMSDs management. Those two systems were self-developed, and the functions and strong points are described in this chapter.

Finally, the conclusion gives a brief summary and critique of the findings. Also, discussions of the implication of the findings and limitations were stated with future research directions.

The overall procedure of this dissertation is illustrated in Figure 1.1.

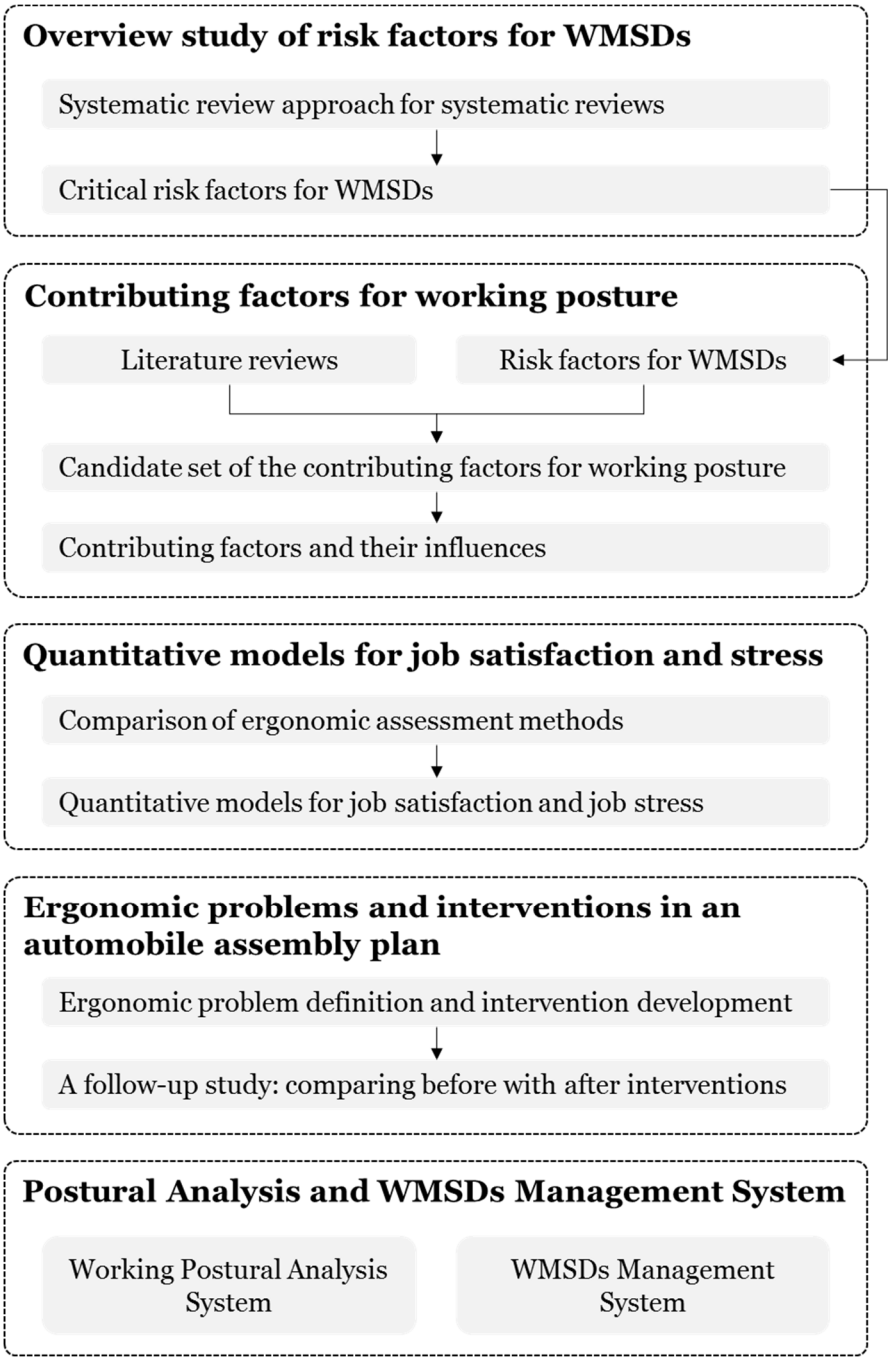

Figure 1.1 Overall procedure of this dissertation

Chapter 2. Literature Reviews

2.1 Musculoskeletal Disorders

2.1.1 Definition of musculoskeletal disorders

According to the definition by National Safety Council (NSC), MSDs are injuries or pain in the body's joints, ligaments, muscles, nerves, tendons, and structures that support limbs, neck, and back (Hadler, 2005). MSDs are known that they occur mainly because of awkward working posture, repetitiveness in the job, MMH, excessive force, vibration, and so on. There are a great variety of risk factors for MSDs.

Jobs that have a high occurrence rate of MSDs are simple repetitive work, MMH tasks, jobs handling hand tools or all sort of machinery, visual display terminal (VDT) work, and assembling work. Most MSDs are cumulative disorders, and they are cumulative when microfractures that occur in soft tissue such as muscular tissue accumulate and leave an impairment in body tissues (Sanders & McCormick, 1987).

In particular, when MSDs are caused by work-related risk factors, then they are called WMSDs. Terminologies referring MSDs are diverse, and some representative ones are as follows: cumulative trauma disorder (CTD), repetitive strain injury (RSI), occupational overuse syndrome (OOS), and VDT syndrome (KOSHA, 2005).

2.1.2 Risk factors for the MSDs

Until now, a large number of studies have tried to determine the risk factors that affects the prevalence of MSDs. Bernard and Putz-Anderson (1997) reported that physical work-related factors, psychosocial factors, environmental factors, and individual factors affect WMSDs in the upper extremity. These factors do not influence on the WMSDs independently, but influence multifactorially.

More recently, literature has emerged that offers systematic reviews or overview studies. Although there is still controversy about the influence of the factors, the risk factors for MSDs can be categorized into three groups: individual factors, work-related factors, and psychosocial factors.

2.2 Working Posture

2.2.1 Definition of working posture

Position is a general term for a configuration of the human body. There is no clear definition of the 'posture' in ergonomics literature. Posture may represent 'human body position', and it may be regarded as the configuration of the body's head, trunk, and limbs in space or as a 'quasistatic biomechanical alignment' (Corlett et al., 1985). Normally, posture means a composite of the positions of all the joints of the body at any given moment (Dendamrongvit, 2002).

Researches on the posture of human being have been studied consistently since about 60 years ago. Posture is one of the most important factors regarding ergonomics and occupational safety. In this respect, posture is especially referred as 'working posture', and it is closely related to the industrial comfort (Corlett & Bishop, 1976).

Good working posture is one of the most critical factors that enhance the performance of the task and decrease job stress and discomfort (Haslegrave, 1994). Awkward working posture means that when the status of certain joints is out of comfortable range of motion due to bending and twisting. In this state, many burdens are loaded on muscles, tendons, and ligaments.

Moreover, from the energy consumption perspective, the working posture while performing some tasks is a factor that can influence energy requirements (Sanders & McCormick, 1987). In this regard, the working posture should be considered thoroughly.

2.2.2 Working posture measurement methods

Working posture measurement methods can be classified into four by measurement technique: (1) self-report technique, (2) instrument-based technique, (3) direct measurement technique, and (4) observation technique (David et al., 2008; Genaidy et al., 1994; Winkel & Mathiassen, 1994).

Among these measurement techniques, observation technique has been widely used in the real industries and fields. In the area of ergonomics, the observation method has been used to quantify physical exposure at the workplace (Buckle et al., 1986; Corlett & Bishop, 1976). The observation technique has some advantages such as non-intrusive characteristics and no need for expensive tools. However, the researcher should be trained well for right classification in a short period. To resolve this disadvantage, the observation method using video recording is most commonly used.

Ergonomic assessment methods using the observation technique are as follows: RULA, REBA, OWAS, 'Video Registration and Analysis of working positions and movements (VIRA)', 'PLIBEL', and 'Rodger's muscle fatigue assessment'.

Most of the methods are MSD assessment methods rather than posture assessment methods. It is because that many methods consider not only working posture but also other risk factors such as force and repetitiveness.

However, it is still true that the working posture has been treated as one of the most important issues in ergonomic assessment. The working

posture can be a major factor related to the risk of musculoskeletal injuries (Hignett & McAtamney, 2000). Hence, most of the tools focus relatively more on the working posture. The tools such as RULA, REBA, and OWAS are a sort of the working postural analysis tool.

There are many differences between theses ergonomic assessment methods. The differences can be listed as follows: purpose, body parts, risk factors considered by the tool, types of jobs the method is appropriate for, the inputs needed for the method, the expected output of the method and limitations of the method.

The body parts and risk factors considered by each assessment method are described in Table 2.1. These were retrieved and revised from Occupational Health and Safety Council of Ontario (2008)'s article. Considered risk factors are as follows: force, posture, height, reach, frequency, duration, and vibration.

Table 2.1 Comparison among working posture assessment methods

Assessment Method	Body part						Risk factors considered
	Hand/ Wrist	Lower arm	Upper arm	Head/ Neck	Back	Legs	
Checklist methods (multiple hazards considered)							
Washington State Checklists	o	o	o	o	o	o	F, P, Fr, V
MMH - lifting, lowering, pushing, pulling, and carrying							
NIOSH Lifting Guideline	△	△	△	x	o	△	F, P, H, R, Fr, D
ACGIH: Lifting TLV	△	△	△	x	o	△	F, P, Fr, D
Snook Tables	△	△	△	x	o	△	F, P, Fr, D
Upper limb							
RULA	o	o	o	o	o	△	F, P, Fr
Strain Index	o	o	o	x	x	x	F, P, Fr
LUBA	o	o	o	o	o	x	P
Combined methods							
Rodger's Muscle Fatigue Assessment	o	o	o	o	o	o	F, P, Fr
REBA	o	o	o	o	o	o	F, P, Fr
OWAS	x	x	△	o	o	o	F, P, Fr
QEC	o	o	o	o	o	x	F, P, Fr, V

Note. o (directly considered); △ (indirectly considered); x (not considered).
F (Force); P (Posture); H (Height); R (Reach); Fr (Frequency); D (Duration); V (Vibration).

2.3 Classification Scheme for Working Posture

Some researchers have tried to classify the working posture. In the earlier studies, bad posture was described from an ergonomics perspective. Armstrong (1986); Van Wely (1970) presented bad postures and probable site of pain or other musculoskeletal symptoms. In this regard, classification schemes for the working posture in a specific context such as standing, sitting, and so on have been proposed. Karhu et al. (1977) classified the working postures based on the subjective evaluation of discomfort and the health effect of each posture. The classification yielded 72 postures.

The classification schemes provide the criteria mainly using angular deviation of a body segment from the neutral position. Genaidy et al. (1994) categorized the classification techniques into: (1) macropostural classification (Karhu et al., 1977), (2) micropostural classification (Armstrong et al., 1982; Keyserling, 1986; Kilbom et al., 1986), and (3) postural-work activity classification (Baty et al., 1986; Foreman & Troup, 1987; Ryan, 1989).

In macropostural classification, the working posture was classified along each body part including neck, back, upper extremity, and lower extremity. The movement of the body part was also defined. The status of each body part was classified into four types: bending, rotation, elevation, and position. The macropostural classification is described in Table 2.2.

Table 2.2 The macropostural classification

Body part	Posture	Reference
Neck	Straight; Bent forward; Bent sideways; Bent backward; Twisted	Heinsalmi (1986)
Back	Straight 'neutral'; Bent; Straight and twisted; Bent and twisted	Karhu et al. (1977)
Upper extremity	Both arms on or below shoulder level; One arm above shoulder level; Both arms above shoulder level	Karhu et al. (1977)
Lower extremity	Loading on both extremities, straight 'standing'; Loading on one extremity, straight 'standing'; Loading on both extremities, bent 'squatting'; Loading on one extremity, straight 'squatting'; Loading on both extremities, kneeling; Body is moved by the extremities 'walking'; Both extremities hanging free 'sitting'	Karhu et al. (1977)

The micropostural classification describes in greater detail the non-neutral postures around the joints of the musculoskeletal systems. Moreover, postures of the joints were grouped according to the angle of each joint. The micropostural classification is described in Table A.1 in

Appendix A. However, the criteria for the classification of body postures and movements with respect to the body angles is not concretely defined in the majority of the selected observation methods (Juul-Kristensen et al., 1997).

Chapter 3. An Overview Study of Risk Factors for WMSDs

An overview study is one of the most effective ways to investigate and understand the existing epidemiological studies. This approach can be applied to the studies on the risk factors for work-related musculoskeletal disorders. Hence, we overviewed the existing systematic reviews that reported about the risk factors for the work-related musculoskeletal disorders and associations between them. Investigated databases contain 'CINAHL Plus', 'NIOSHTIC', 'Cochrane Library', 'PubMed', 'Science Direct', 'Springer Link', and 'ACM Digital Library'. From all searched articles, 20 articles were extracted according to inclusion criteria which are the type of the article, language, publication year, accessibility, systematic review, contents, and association. Based on the results of this overview study, the associations between the risk factors and work-related musculoskeletal disorders in the body parts could be understood. The associations were evaluated with referring the relative risk such as odd ratio or hazard ratio. Although we conducted an overview study of the systematic reviews on the risk factors for WMSDs, it is thought that not the whole risk factors were included.

Keywords: overview study, systematic review, risk factors, work-related musculoskeletal disorders

3.1 Introduction

3.1.1 WMSDs and overview study

Risk factors causing WMSDs can be classified into three categories: (1) individual factors, (2) psychosocial factors, and (3) physical factors (Winkel & Mathiassen, 1994). Individual factors are determined by personal properties such as gender, age, body dimension, medical history, and skill level. These factors cannot be artificially manipulated. Psychosocial factors are related to emotions of people, such as job satisfaction, working condition satisfaction, and job autonomy. Physical factors are related to MMH, awkward posture, repetitive work, excessive muscular strength, vibration, lack of rest, and so on. These factors do not affect and induce WMSDs solely but affect by some combination of the factors.

Typical work-related risk factors for WMSDs are repetitive work, high-intensity work, stressful posture, mechanical stress, extreme temperature, and vibrations. Works that have these kinds of risk factors impose a heavy strain on worker's musculoskeletal systems, and the risk factors play a major role in bad health and curtail work performance or productivity.

A large number of cross-sectional studies and review articles published over the last 20 years have mostly included both cross-sectional and longitudinal studies (Bongers et al., 1993; Bongers et al., 2002; Bouter & van der Wal, 2001; Davis & Heaney, 2000; Malchaire et al., 2001; van der Windt et al., 2000; Woods, 2005). However, only a few reviews have exclusively focused on longitudinal studies (Bongers et al., 2006; Hartvigsen et al., 2004; Hoogendoorn et al., 2002; Kuijpers

et al., 2004; Linton, 2000; Linton, 2001). In addition, most of the existing review articles are limited in scope as they only refer to a single region of the body (Bouter & van der Wal, 2001; Davis & Heaney, 2000; Hartvigsen et al., 2004; Hoogendoorn et al., 2000; Kuijpers et al., 2004; Linton, 2001; van der Windt et al., 2000).

There are many types of WMSDs, and each type of WMSDs has different risk factors. Hence, it is so important to comprehend the reported relationships between risk factors and WMSDs. However, it is not easy to grasp these relationships by a single research. Thus, it is needed to integrate information derived from different studies on this research objective (da Costa & Vieira, 2010). In this way, associations between risk factors and WMSDs can be evaluated effectively and reliably with consideration upon the level of evidence.

In recent years, systematic review method has been conducted to evaluate the evidence for many suggested risk factors for WDSDs. However, there has been no critical evaluation of the systematic reviews. It is needed to appraise the published systematic reviews by using PRISMA Statement (Preferred Reporting Items for Systematic review and Meta-Analyses) (Moher et al., 2009). By using the PRISMA Statement, the reporting quality can be examined and enhanced. In addition, an overview of systematic reviews represents a new and better approach to incorporate evidence from existing systematic reviews (Higgins & Green, 2008).

The information reported in this study is essentially dependent on the validity of the primary studies and the previous systematic reviews. However, as systematic reviews may become dated rapidly, it is advisable to include the most recent publications too (Pieper et al., 2014).

Hence, in this overview study, as a way to comprehend the results, existing systematic reviews were analyzed comprehensively.

The findings in a single research are not very concrete; they vary in confusing irregularity across contexts, classes of subjects, and countless other factors. Accordingly, the overview study should be performed deliberately and precisely. To this end, PRISMA Statement was adopted in this study for a better quality of the overview study.

3.1.2 Risk factors for the WMSDs

Risk factors and affected body parts considered in the previous systematic reviews are described in Table 3.1. We thoroughly reviewed the whole factors through the overview study. Table 3.1 includes representative studies, not the whole ones.

Table 3.1 Risk factors and body parts affected

Risk factors	Body part	Reference
Psychosocial factors	Back, neck, and shoulder	Bongers et al. (1993)
General risk factors	Neck, upper limbs, and low back	Bernard and Putz-Anderson (1997)
Psychosocial factors and private life	Back	Hoogendoorn et al. (2000)
Occupational factors	Shoulder	van der Windt et al. (2000)
Psychosocial factors	Neck	Ariëns et al. (2001)

Risk factors	Body part	Reference
Psychosocial factors	Upper limbs	Bongers et al. (2002)
Psychosocial factors	Low back	Hartvigsen et al. (2004)
General risk factors	The whole body except lower extremity	da Costa and Vieira (2010)

3.1.3 Research objectives

This study aims to investigate the association between the risk factors and WMSDs. To this end, an overview study approach was conducted. Furthermore, previous reviews were critically appraised using PRISMA Statement, and for a better quality of this overview study, the PRISMA Statement was adopted (Moher et al., 2009). Moreover, a variety of concepts were gathered and listed up. Then the terminologies were standardized.

3.2 Methods

3.2.1 Search strategy

This paper focused entirely upon the studies on the risk factors for WMSDs and their influence on the body parts. Publications were retrieved by a search of various online journal databases including 'CINAHL Plus', 'NIOSHTIC', 'Cochrane Library', 'PubMed', 'Science Direct', 'Springer Link', and 'ACM Digital Library'. This paper surveyed articles published from January 1980 to December 2015.

The search keywords were as follows: risk factors, musculoskeletal disorder, injury, cumulative trauma disorder, systematic review, and meta-analysis.

3.2.2 Inclusion criteria

The inclusion criteria were as follows. (1) Type of the article: only peer-reviewed articles were included. Other publication forms (unpublished working papers, master's or doctoral dissertations, newspapers, and books, etc.) were excluded. (2) Language: articles in English were only included. (3) Publication year: articles published before 1980 were excluded because the studies conducted before 1980 was too old to refer. (4) Accessibility: articles with full text were only included. The articles that only abstracts or titles are accessible were not included. (5) Systematic review: only articles that conducted systematic review were included in this study. (6) Contents: articles focused on the work-related MSDs were contained only. The articles focused on the disorder or

injury itself were excluded. (7) Association: articles reported the associations between risk factors and disorders or injuries were included. Articles that reported only prevalence rate and did not mention about the risk factors were not selected.

We conducted an overview study of systematic reviews on the risk factors for WMSDs. Hence, only systematic reviews were included among searched articles. Two reviewers independently evaluated potentially eligible studies identified by the search. The articles were judged based on two reasons: (1) whether they were a systematic review or not, and (2) whether they focused on the risk factors for the work-related or occupational MSDs. The judgments were made by investigating the titles and abstracts. The articles were read if the titles or abstracts provided insufficient information for a clear decision.

The inter-rater agreement was measured for the selection of potentially related articles and finally included articles by using a Cohen's kappa. According to Landis and Koch (1977)'s suggestion, κ of less than zero is associated with the poor agreement, .01-.20 as slight agreement, .20-.40 as fair agreement, .41-.60 as moderate agreement, .61-.80 as substantial agreement, and .81-1.0 as almost perfect agreement. Based on this κ statistics, the inter-rater agreement between two reviewers was calculated.

We did not consider articles that conducted systematic reviews on the other diseases such as heart disease, cardiovascular disease, etc. The number of articles from each online database can be seen in Table 3.2. In addition, an exhaustive hand search was carried out, and bibliographies of relevant articles were examined for other possible inclusions. Total 20 articles were finally included and analyzed.

Table 3.2 Number of articles from each online database

Online database	Number of articles		
	Search results	Potentially related	Finally included
CINAHL Plus	238	0	0
NIOSHTIC	3,717	4	0
Cochrane Library	1,750	2	0
PubMed	4,865	34	6
Science Direct	2,123	2	1
Springer Link	1,362	4	3
ACM Digital Library	186	0	0
Others (hand-searched)	-	-	10
Total	14,408	62	20

Note. There is no duplicate article across the databases. Only one article was left if there were duplicate ones in different databases.

3.2.3 Quality assessment of the included studies

PRISMA Statement was developed to investigate the reporting quality of systematic reviews and meta-analyses (Moher et al., 2009). The PRISMA Statement was revised from QUOROM Statement (Quality of Reporting of Meta-analyses) developed in 1994. In this study, the strength and weakness of the included systematic reviews were assessed using the PRISMA Statement.

The PRISMA Statement was adopted for two objectives: (1) to assess the previous systematic review articles, and (2) to improve the quality of our overview study. In this regard, a checklist, suggested by the PRISMA Statement, was used.

3.2.4 Data collection

All risk factors and affected body parts were gathered from the included articles. The data pulled from each study included study design, population sample size, outcome measured, risk factors, and affected body parts. Statistically significant association between risk factors and body parts were extracted along with their reported effect estimates such as odd ratio (OR) and hazard ratio (HR).

3.2.5 Data analysis

3.2.5.1 Risk factors and body parts

Understandably, different review articles considered different risk factors. In addition, for the same risk factor, different terminologies were used. For instance, 'seniority' was expressed as 'duration of employment', 'experience', or 'duration of farming' specifically in the study on the farming. Hence, we standardized the terminologies based on the frequency of occurrence in previous studies. For the body parts, this standardization process was also performed like the case of the risk factors.

3.2.5.2 Association between risk factors and WMSDs

Every association between risk factors and WMSDs was gathered, and the results were quite inconsistent across studies in general. To resolve this problem, we adopted a level of evidence concept and strength of association (Davis & Heaney, 2000). We firstly evaluated the level of

evidence, and when the level is higher than 'insufficient evidence', the strength of association was calculated.

The level of evidence was determined using a quantitative approach for each type of risk factors. The assessment of the level of evidence depended on the consistency of the results and the methodological quality of the included articles. The categorization for the level of evidence and the strength of association were adopted from the previous studies (Hartvigsen et al., 2004; Long et al., 2012). The detailed explanation on the level of evidence and the strength of association is shown in Figure 3.1.

Associations between risk factors and WMSDs were pooled from the included reviews based on the reported effect estimates such as OR and HR. The relative risk (RR) was calculated, and 95% confidence interval (CI) was reported. We reported risk estimates including OR, HR, and RR, if possible. The statistical analyses were conducted using IBM SPSS Statistics Version 21 (IBM Corp., Armonk, NY, United States).

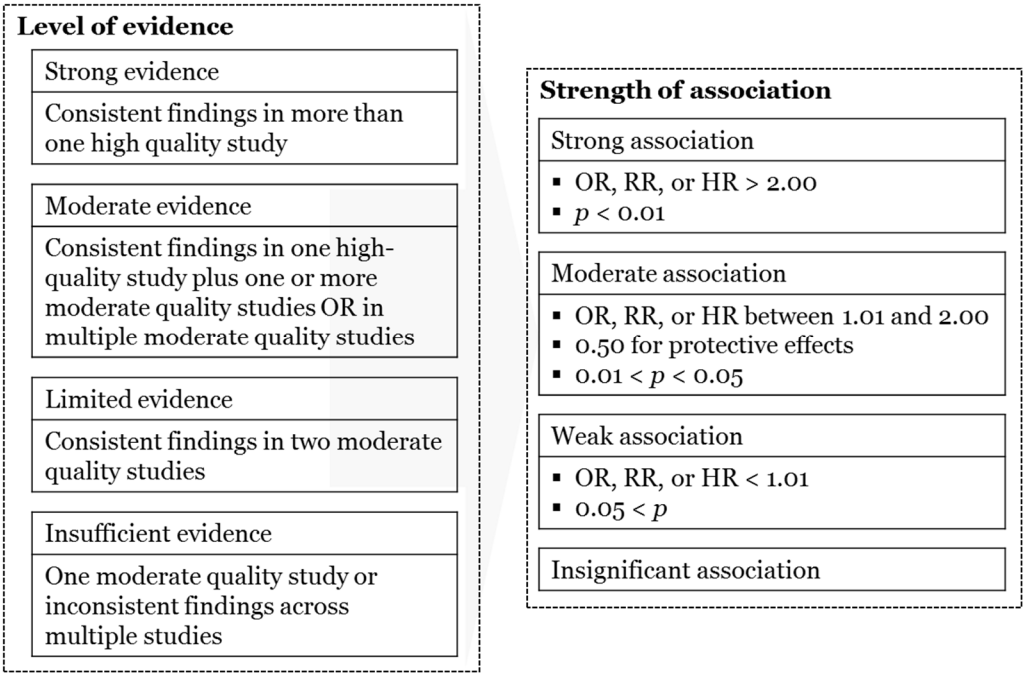

Figure 3.1 The level of evidence and the strength of association

3.3 Results

3.3.1 Search results

Ten articles were finally included after retrieving and screening from the searches of electronic databases. A hand search also revealed ten additional articles that were deemed eligible based on the inclusion criteria. Thus, total 20 review articles were included in the final analysis. The whole process is described in Figure 3.2. The Cohen's κ statistics were .85 (95% CI .84-.86), and .69 (95% CI .54-.84), respectively.

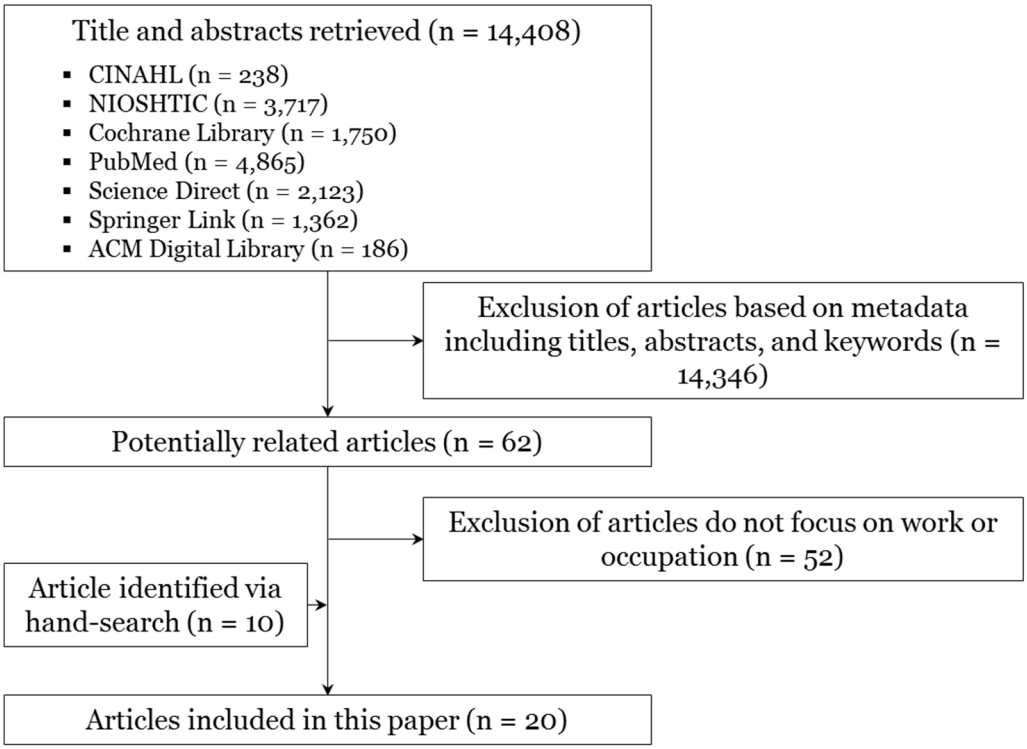

Figure 3.2 Flow diagram of finally selected articles

The number of primary studies per systematic review varied from 9 to 66. Table 3.3 shows the detailed characteristics of the selected review articles including period, the number of studies included, risk factors, body parts, and outcomes.

Period and the number of studies indicate the year of studies and number of primary studies included in each review article, respectively. Risk factors and body parts presented in Table 3.3 are representative ones, not detailed body regions. Outcomes denote that how the selected review assess the associations between risk factors and pain or disorders in the body parts. Most of the studies reported risk estimate.

Table 3.3 Study characteristics of the included review articles

Reviews	Period	#	Risk factors	Body parts	Outcomes
Davis and Heaney (2000)	-1999	66	Psychosocial factors	Low back	Frequency
Hoogendoorn et al. (2000)	-1997	13	Psychosocial factors	Back	Risk estimates
Linton (2000)	-1998	37	Psychosocial factors	Back and neck	Risk estimates
van der Windt et al. (2000)	-1998	29	Physical and psychosocial factors	Shoulder	Risk estimates
Ariëns et al. (2001)	-1997	29	Psychosocial factors	Neck	Risk estimates
Linton (2001)	-2000	21	Psychosocial factors	Back	-
Malchaire et al. (2001)	-2000	64	Individual, physical, and psychosocial factors	Upper extremity	Risk estimates

Table 3.3 Study characteristics of the included review articles

Reviews	Period	#	Risk factors	Body parts	Outcomes
Bongers et al. (2002)	1980-1999	26	psychosocial factors	Upper extremity	Risk estimates
Nelson and Hughes (2009)	1966-2007	18	Work-related risk factors	Back	Risk estimates
da Costa and Vieira (2010)	1997-2009	63	General	General	Risk estimates
Van Rijn et al. (2010)	-2009	17	Work-related factors	Shoulder	Risk estimates
Hauke et al. (2011)	2000-2009	54	Psychosocial factors	Whole body	Risk estimates
Mayer et al. (2012)	1975-2009	21	Physical factors	Neck and shoulder	Risk estimates
Paksaichol et al. (2012)	1980-2011	47	General	Neck	Risk estimates
Kraatz et al. (2013)	-2009	18	Psychosocial factors	Neck and shoulder	Risk estimates
Xu et al. (2013)	-2009	10	General	General WMSDs	Risk estimates
You et al. (2014)	1980-2012	9	Wrist posture	Hand and wrist	Risk estimates
Burström et al. (2015)	-2013	28	Whole-body vibration	Low back	Risk estimates
Kozak et al. (2015)	1998-2014	20	Biomechanical risk factors	Hand and wrist	Risk estimates
Vieira et al. (2015)	-2014	32	General	Whole body	-

Note. # denotes the number of primary studies included in the systematic reviews.

3.3.2 Critical appraisal of the previous reviews

The assessment procedure for each systematic review followed the checklist given by PRISMA Statement by Moher et al. (2009). However, there was a modification regarding alleviation or simplification on assessment criteria since the very purpose of development for PRISMA Statement was to assess the systematic reviews or meta-analyses under medical environment while this paper focuses on ergonomic risk factors for WMSDs. The modification required omission or assuaged perspective of criteria if the checklist required to evaluate medical-only items such as 'patient, problem, population, intervention, comparison, control, comparator, outcomes (PICOs)', etc.

The assessment was conducted in five main sections of title/abstract, introduction, method, results, and discussion. The title/abstract section and introduction section consist of 2 items each. The method section consists of 12 items, while the results section consists of 7 items. Finally, the discussion section consists of 3 items to evaluate. Each item was assessed in a binary manner: either 0 or 1, thus the maximum possible score is 25 points.

By the result of descriptive statistics, each section received an average score of 1.3, 2.0, 8.3, 4.9, and 2.9 respectively in order of title/abstract, introduction, method, results, and discussion. The results of evaluation of every article based on the PRISMA Statement are shown in Table 3.4.

Table 3.4 Appraisal of the previous reviews based on the PRISMA

Reviews	Observance of the PRISMA Statement					
	Title/ abstract	Intro	Method	Results	Discussion	Total
Davis and Heaney (2000)	1	2	5	5	3	16
Hoogendoorn et al. (2000)	2	2	9	5	3	21
Linton (2000)	0	2	9	6	3	20
van der Windt et al. (2000)	2	2	9	5	3	21
Ariëns et al. (2001)	2	2	9	6	2	21
Linton (2001)	1	2	9	6	3	21
Malchaire et al. (2001)	0	2	2	3	3	10
Bongers et al. (2002)	0	2	10	6	3	21
Nelson and Hughes (2009)	1	2	5	3	2	13
da Costa and Vieira (2010)	2	2	10	3	3	20
Van Rijn et al. (2010)	1	2	7	4	3	17
Hauke et al. (2011)	1	2	9	4	3	19
Mayer et al. (2012)	2	2	10	5	3	22
Paksaichol et al. (2012)	1	2	10	7	3	23
Kraatz et al. (2013)	2	2	9	4	3	20
Xu et al. (2013)	2	2	8	3	3	18
You et al. (2014)	2	2	9	6	3	22
Burström et al. (2015)	1	2	9	6	3	21
Kozak et al. (2015)	2	2	9	5	3	21
Vieira et al. (2015)	1	2	9	5	2	19

Note. number denotes the total number of satisfied PRISMA Statement items in each section.

Most of the studies which did not achieve the full ratings on the second checklist item of title/abstract section were missing their reviewed data source. In the introduction section, every study provided their rationale for reviews and their explicit statement of questions.

In both method and results sections, the most of the scores were lost from the checklist item related to the provision of full electronic search strategy, assessing the risk of bias of individual studies or across studies, and provision of additional analyses. The assessment criteria for judging the risk of bias were whether the reviewers conducted quality assessment process or not. If they described the quality of the study, they received a full mark for questionnaires relevant to the risk of bias of individual studies (checklist item 12 and 19). If they described the quality of evidence, the full mark for the checklist item relevant to the risk of bias across the study was given to each paper. In the case of papers with MQS, they received full marks for only the risk of bias of individual studies, not for the risk of bias across the studies.

3.3.3 Considered risk factors and body parts in previous studies

Whole risk factors and body parts gathered from the previous reviews were grouped and standardized. Table 3.5 contains every terminology used in the included articles. The risk factors were categorized into three groups, and they were (1) individual factors, (2) psychosocial factors, and (3) physical exposure factors.

Table 3.5 Standardization of terminologies on the risk factors

Original terminologies used in the previous studies	Risk factor
personal factors and medical history; individual factors; personal risk factors; individual risk factors; foundational factors; personal characteristic risk; personal factors	Individual factors
psychosocial work factors; psychosocial factors at work; psychosocial factors in private life; psychosocial risk factors; psychological factors; psycho-organizational factors; psychosocial factors; organizational aspects of work; psychosocial workplace factors; work-related psychosocial	Psychosocial factors
physical load; physical factors; biomechanical risk factors; physical workplace factors; physical exposure factors; work-related physical; occupational factors; work characteristic risk; work-related factors	Physical exposure factors

The whole list of the concepts included in each risk factor group is listed in Table 3.6. Psychosocial stressors related to the workplace were included into 'psychosocial factors', and those related to each individual were included into 'individual factors'.

Table 3.6 Concepts included in the different categories of risk factors

Risk factor	Concepts included
Individual factors	Age; alcohol; asthma; body mass index (BMI); cervical lateral mobility; cervical mobility; education; gender; general health status; handedness; heart rate; height; hobby; lifestyle; medical history; number of children; personality; race; seniority; smoking; sports; weight; working skills; mental illness; physical illness; sleeping problems
Psychosocial factors	Absenteeism; authority; combined factors; conflicts; control; education; job conditions; job content; job control; job demands; job organization; job pace; job satisfaction; job security; mental exertion; monotonous job; motivation; responsibility; self-development; social support; job stress; time pressure
Physical exposure factors	Arm support; awkward posture; combined factors; distance to the workstation; excessive force; grip type; heavy loads; height of the workstation; MMH; non-adjustability; physical workload; repetitiveness; static efforts; vibration; visually demanding; job difficulty; job rotation; layout of work site; number of breaks; working time

Body parts were also standardized like the risk factors. Six body parts were selected, and they were as follows: (1) neck, (2) back, (3) upper arm, (4) lower arm, (5) hand/wrist, and (6) lower extremity. Then, general WMSDs was added to this six body parts. Hence affected body parts were categorized into total seven groups.

3.3.4 Risk factors for WMSDs and the evidence by body part

The results are shown in Table 3.7. The strength of associations was also contained in the table. The critical variables were as follows. (1) Individual factors: gender, medical history, personality, age, seniority, and working skills. (2) Psychosocial factors: job satisfaction, job stress, job control, job demands, social support, and authority. (3) Physical exposure factors: repetitiveness, awkward posture, MMH, physical workload, static efforts, and excessive force. The detailed explanation is described in the following sections.

Table 3.7 Associations between the risk factors and WMSDs by body part

Risk factors		Neck	Back	Upper arm	Lower arm	Hand/ wrist	Lower extremity	General WMSDs
Individual factors	Gender	+++	+		+			
	Medical history	+++						
	Personality	++		++				
	Age	++	-		++			
	Seniority	+++		+++				+++
	Working skills	++						
Psychosocial factors	Job satisfaction	++	+++	++				
	Job stress	++	++	++	++	++		
	Job control	+++	++	+++	+++			
	Job demands		++	++	+++	+++		
	Social support	++	++	++				
	Authority	+++						

Table 3.7 Associations between the risk factors and WMSDs by body part

Risk factors		Neck	Back	Upper arm	Lower arm	Hand/ wrist	Lower extremity	General WMSDs
Physical exposure factors	Repetitiveness			+++		+++		
	Awkward posture	++		+++		+++		
	MMH		+++	+++				
	Vibration						+++	
	Physical workload		+++	+++				
	Static efforts	++	++			++		
	Excessive force	++	++	+++		+++		

Note. +++ denotes strong association; ++ denotes moderate association; + denotes wear association; - denotes insignificant association.

3.3.4.1 Individual factors

Five systematic reviews dealt with individual factors. Among the individual factors, gender, medical history, and personality were mainly investigated. Five studies examined the effect of gender on the lower arm, hand/wrist, back, neck, and upper arm.

The effect of gender on the neck (OR 2.27, 95% CI 1.1-6.7) was strong, and the evidence for the effect on the lower arm (OR 1.59) or back was not sufficient. The effect of medical history was strong on the neck, however, on the other body parts, the evidence was insufficient to draw a specific conclusion.

Personality, age, seniority, and working skill were also examined by the previous systematic reviews. The effect of personality such as type A behavior or neurotic was moderate on the neck and upper arm. For age, there was a moderate effect on the neck (OR 1.04, 95% CI 1.02-1.07) and lower arm (OR 1.35). Effects of age on the back was insignificant (OR .28-.63). Seniority was reported to affect neck (OR 2.1, 95% CI 1.1-3.9), upper arm (OR 1.4-2.3), and general WMSDs. Working skills which might have some correlations with seniority was also reported to have a moderate effect on the neck (OR .4, 95% CI .1-.9).

3.3.4.2 Psychosocial factors

The major risk factors were job satisfaction, job stress, job control, job demands, social support, and authority. Job satisfaction gave effects on the back (OR 1.7-3.0, strong evidence), neck (OR 1.7, *p* .04, limited evidence), and upper arm (OR 1.3-2.7, moderate evidence). Job stress was reported to have a moderate effect on the back (OR 1.4, moderate

evidence), neck (OR 1.43, moderate evidence), lower arm (OR 1.4, moderate evidence), hand/wrist (OR 1.5, strong evidence), and upper arm (OR 1.5-2.0, moderate evidence).

For job control and job demands, both factors had major effects on several body parts. Job control was reported to have a strong effect on the neck (OR 4.2, $p < .001$, limited evidence), upper arm (OR 1.4-3.0, moderate evidence), and lower arm (OR 1.6-2.8, limited evidence), and moderate effect on the back (OR 1.37, moderate evidence). Job demands had a moderate effect on the back (OR 1.34, moderate evidence), hand/wrist (OR 2.2, moderate evidence) and upper arm (OR 1.1-1.5; 1.6-2.4, strong evidence). A strong association between job demands and lower arm also existed (OR 2.4; 1.3, limited evidence).

Associations between social support and body parts were supported by relatively concrete evidence. Social support had moderate effects on the back (OR 1.3-1.9, strong evidence), neck (OR 1.15, 95% CI .89-1.49, strong evidence; OR 1.76, 95% CI 1.24-2.50, strong evidence; OR 2.43-3.72, moderate evidence), and upper arm (OR 1.18, moderate evidence).

Authority which is related to influence at work and role ambiguity had moderate (OR 1.2; 1.7; 2.9, limited evidence) or strong (OR 2.2, 95% CI 1.3-3.7, limited evidence) effects on the neck. However, there were few studies, so the level of evidence was limited.

3.3.4.3 Physical exposure factors

Among the whole physical exposure factors, repetitiveness, awkward posture, MMH, vibration, physical workload, static efforts, and excessive force were the main risk factors, as they are known.

Repetitiveness was reported that it had a strong effect on the upper arm (OR 1.59; 2.3; 4.34, strong evidence), hand/wrist (OR 2.3, 95% CI 1.8-3.0; OR 2.3, 95% CI 1.7-2.9, strong evidence). The effect of awkward posture on hand/wrist was strong (OR 2.95; 1.44; 1.87, strong evidence). Moreover, it was also strong on the upper arm (OR 1.4; 1.6; 2.8; 3.1, moderate evidence) and neck (strong evidence).

MMH and physical workload were mainly related to the back and upper arm. Associations between MMH and back (OR 10.7, strong evidence) or upper arm (OR 1.50-2.6; 1.39-4.86, strong evidence) were strong. Associations between physical workload and back (OR 1.63; 2.4, moderate evidence) or upper arm (OR 1.5; 2.2; 3.2, moderate evidence) were also strong. These two factors showed similar association as expected by our knowledge.

Static efforts had moderate effects on hand/wrist (moderate evidence), neck (moderate evidence), and upper arm (OR 1.6, moderate evidence). Excessive force had strong effect on hand/wrist (OR 2.2, 95% CI 1.5-3.3; OR 4.2, 95% CI 1.5-11.7, strong evidence) and upper arm (OR 2.34 moderate evidence), and moderate effects on the back (OR 2.0, 95% CI 1.2-3.6; OR 1.4-1.6, moderate evidence) and neck (OR 1.9, 95% CI 1.25-2.93, limited evidence).

3.4 Discussion

It is known that different statistical methods and variety of studies can lead to different conclusions about the associations between risk factors and WMSDs. Methodological problems are inherent to epidemiological studies of the associations between risk factors and WMSDs (Walker-Bone & Cooper, 2005). Most of the studies related to the WMSDs causation and prevention adopted cross-sectional study designs. Due to the cross-sectional nature of the studies, it is hard to draw causal conclusions. To resolve this problem, we have included only systematic review articles that evaluated the methodological quality of the primary studies.

The primary objective of this manuscript was to identify the association between the risk factors for WMSDs and WMSDs in the body parts. To accomplish this goal, an overview study of the systematic reviews was carried out. Total 20 articles were included and analyzed. In addition, the outcomes including OR, HR, and RR for each pair of risk factor and body part were reported, if possible.

Secondarily, predictive risk factors of WMSDs were identified and described. Different terminologies for the same risk factor were standardized, and based on the results, risk factors were classified and analyzed.

With the results of our overview study, it is expected that effective interventions and injury-prevention strategies can be developed and managed. However, due to practical constraints, this study cannot provide a comprehensive review of every article on the risk factors for WMSDs. Although we used a robust search strategy, nearly 50% of our

studies were captured through a hand search. There may be a considerable number of studies that this overview study does not contain. Hence, further research should be conducted for a better understanding of the associations between the risk factors and WMSDs.

Most of the risk factors influence the development of WMSDs together with other potential factors, not by themselves. It is expected that a risk factor in the presence of another risk factor or factors may interact resulting in the prevalence of WMSDs. However, this study only focused on the influence of each risk factor solely.

The factors that no conclusion was drawn should not be considered as risk-free. Most of the case of no conclusion were due to the lack of evidence from existing studies. However, it does not mean that those factors are risk-free to WMSDs.

Chapter 4. Investigation of the Contributing Factors for Working Posture

To investigate the relative influence of the various factors related to working posture is necessary for making a better diagnosis and developing more effective interventions. In this regard, we firstly gathered an expected candidate set of the contributing factors for the working posture through literature reviews. The candidate set was composed of individual factors, physical exposure factors, and environmental factors. Among the factors included in the candidate set, the contributing factors were figured out by statistical methods such as correlation analysis and regression analysis. Then, the relative influences of those factors were measured. Furthermore, relationships between the contributing factors and psychosocial factors such as job satisfaction and job stress were also investigated. The results of this study can be used to set the priority of intervention for improving working posture, perceived job satisfaction, and job stress, with a view to WMSDs prevention.

Keywords: working posture, contributing factors, relative importance, work-related musculoskeletal disorders, job satisfaction, job stress

4.1 Introduction

4.1.1 Contributing factors for working posture

In an attempt to figure out the risk factors for WMSDs, many researchers examined the relationship between the risk factors and occurrence of WMSDs using epidemiological studies and systematic reviews. As aforementioned in Chapter 3, various kinds of risk factors were considered in the previous literature. In Chapter 3, we gathered the risk factors and reported the association between the risk factors and WMSDs through an overview study.

Although extensive research has been carried out on WMSDs, insufficient studies exist which adequately covers the contributing factors for the working posture. The previous studies focused on specific context including situational condition or variable. For example, one study considered only visual display terminal (VDT) operator, sitting environment, or other specific factors. There is no single study tried to reveal the associations between the contributing factors and working posture and relative influence of the contributing factors on the working posture.

It is well known that working posture is one of the most critical causes of WMSDs. Hence, to understand the relationships among the contributing factors and working posture can be very helpful for WMSDs prevention from both medical and ergonomic points of view. Furthermore, postural stresses on specific body part can be estimated using the results of this study. Accordingly, it can be used for work site management strategies including the design of work site layout, job rotation scheduling, and so on.

Nevertheless, researches on the contributing factors for working posture has not been carried out so far. Justly, the relative influence of the factors was not analyzed, even though the relative influence of the factors should be understood to provide better interventions in the work site. Due to a limited budget and time, setting appropriate priority among the contributing factors is so much important. Thus, to grasp the role of diverse factors and their relative influence on the working posture is crucial.

With the object of figuring out which factors may influence on the working posture, it is practically impossible to consider every single factor including information on the workers, working conditions, organizations, and so on. Hence, we took a note of the risk factors for WMSDs reported in Chapter 3. As long as the relationship between working posture and WMSDs is not only correlative but also causative, it is quite plausible that similar factors may affect both occurrence of WMSDs and awkward working posture.

The reported risk factors for WMSDs were individual factors, physical exposure factors, and psychosocial factors. These factors might be highly related to the working posture significantly in respect that the working posture is one of the most critical factors for the occurrence of WMSDs. However, in this study, we included physical exposure factors, individual factors, and environmental factors into the candidate set of contributing factors. Psychosocial factors were not included in the candidate set.

4.1.2 Job satisfaction and job stress

Job stress is a psychosocial factor that is highly related to WMSDs. Existing researches support that the more psychosocial stress workers feel, the higher prevalence rate of WMSDs. Leino and Hänninen (1995) reported that excessive mental exertion is rather more influential than physical burden on the back and upper limb disorders. Some research also supported that the portion of WMSDs caused by physical factors is not that high (Bongers et al., 1993). For the measurement of the WMSDs, the prevalence rate was one of the most frequently used variables in the previous studies. Besides the prevalence rate, the job stress was also considered as an effective predictor for the WMSDs.

Besides the job stress, it is helpful to know how satisfied the workers feel about their job and how much pressure they feel. Thus, job satisfaction is one of the critical factors for the development of WMSDs like job stress as well.

In addition, it was reported that there were moderate or strong associations between WMSDs and both job satisfaction and job stress in the previous studies (da Costa & Vieira, 2010; Linton, 2001; van der Windt et al., 2000). Hence, it is quite plausible to treat these factors as important factors.

4.1.3 Research objectives

This study aims to figure out the critical contributing factors that affect working posture and understand the relationships between the contributing factors and the working posture. Moreover, the relationships between the contributing factors and job satisfaction and job stress were investigated.

To this end, practical field research data was gathered through work site investigations. The working posture of every worker was recorded, and the video observation data was analyzed with consideration of the work site information. Then the overall data was analyzed using statistical methods including correlation analysis and multiple linear regression analysis.

4.2 Methods

To gather the candidates of the contributing factors, we reviewed the previous literature. The literature on this question were all hand-searched. In addition, more candidates were pooled from the risk factors for WMSDs reported in Chapter 3.

4.2.1 Data collection

Data on the contributing factors and working posture were collected through field investigations. The field investigations took place in a large-sized automobile manufacturing plant in South Korea. The whole assembly lines in the plant were investigated, and total 1,098 jobs and same number of workers were examined from the year 2007 to 2015 over seven times (2007: 122 jobs, 2009: 34 jobs, 2010: 164 jobs, 2012: 149 jobs, 2013: 480 jobs, 2014: 39 jobs, 2015: 110 jobs).

A direct observation method and subjective assessment including general survey were used to collect all information needed. Physical exposure factors were gathered through workplace investigation, and individual factors were collected by interviews with the workers. To measure psychosocial factors, both methods were used. For effective working posture assessment, workers were directly recorded from different angles including the front and side. All measurements and measuring methods are described in Table 4.1. Descriptions and responses of whole investigated factors are listed in Table 4.2.

Table 4.1 Measurements and measuring methods

Measurement	Measuring methods
Individual factors	The direct survey method was used with a developed questionnaire. (e.g. gender, age, height, weight, handedness, years of service, and medical history in body part)
Physical exposure factors	Job characteristics were collected based on job standard guidelines and actual conditions gathered by interviews with workers (e.g. job cycle time, the number of jobs per hour, rotation between jobs, the weight of heavy loads, etc.). Workplace characteristics were collected by direct measurements (e.g. height of the working point, horizontal distance to the working point, and information on tools)
Environmental factors	Environmental factors were collected by indirect measurements. (e.g. noise and illumination)
Job satisfaction and job stress	Job satisfactions of all works were examined through interviews with workers. In addition, job stress for the job was also measured.
Working posture	For effective working posture assessment, workers were directly recorded from both front and side. If necessary, additional body parts (e.g. wrists and fingers) were recorded intensively for specific jobs.

Table 4.2 Description and scale of the investigated factors

Factors investigated		Description	Type of variable (measure)
Age		Worker's age	Ratio (year)
Height		Worker's height	Ratio (cm)
Weight		Worker's weight	Ratio (kg)
BMI		Worker's BMI	Ratio (kg/m²)
Handedness		Worker's dominant hand	Nominal (left; right; both hands)
Seniority		Years of service of the worker	Ratio (year)
Medical history	Neck	Medical history in the body part : Whether there was a pain, disorders, or medical treatment in the body part.	Nominal (no; yes)
	Upper arm		
	Lower arm		
	Hand/wrist		
	Back		
	Lower extremity		
Number of jobs per hour		Number of jobs workers finish per hour	Ratio (times)
Rotation between jobs		Whether rotation between jobs is enforced or not	Nominal (no; yes)
Rotation period		The period of the rotation	Ratio (hour)

Table 4.2 Description and scale of the investigated factors

Factors investigated		Description	Type of variable (measure)
Whole body posture		Type of body postures mainly taken during jobs stand; stoop; squat; overhead; seat; inside the vehicle	Nominal (stand; stoop; squat; overhead; seat; inside the vehicle)
Static efforts		Whether a job needs a prolonged posture : longer than 1 minute	Nominal (no; yes)
Force acting on the upper extremity		Degree of the force acting on the upper extremity	Ordinal (4-point scale)
Fist hammering		Whether a job requires fist hammering task : the task needs hitting parts with the side of the fist	Nominal (no; yes)
Repetitiveness	Upper arm	Degree of repetitiveness of the body part : times of repetitiveness in 1 minute less than 6; 6-10; 11-20; over 20	Ordinal (4-point scale)
	Lower arm		
	Lower extremity		
Clearance	Workspace	Whether there is enough clearance in the workspace or not	Nominal (no; yes)
	Hand	Whether there is enough clearance around the hands during a job or not	Nominal (no; yes)
Hand slipperiness		Whether the contact area with hands is slippery or not	Nominal (no; yes)
Weight of heavy loads		Weight of heavy loads lifted or handled	Ratio (kg)

Table 4.2 Description and scale of the investigated factors

Factors investigated	Description	Type of variable (measure)
Vibration	Vibration exposure level during jobs none; intermittent; often	Ordinal (3-point scale)
Visual demands	Visual demands during jobs low; medium; high	Ordinal (3-point scale)
Vertical height of the working point	Vertical height from the floor to the working point	Ratio (cm)
Horizontal distance to the working point	Horizontal distance from the worker's body to the working point	Ratio (cm)
Working surface	Working surface according to the worker up/front; flank; down/rear	Nominal (up/front; flank; down/rear)
Relative height according to the worker	Vertical height of the working point according to the worker's body beneath knee; between knee and shoulder; over shoulder	Nominal (beneath knee; between knee and shoulder; over shoulder)
Length of tools	Length of a tool regarding lengthened reach : may affect the horizontal distance to the working point	Ratio (cm)
Force needed to push-pull	Degree of the force needed for push-pull tasks none; low; medium; high	Ordinal (4-point scale)
Illumination	Whether the lighting is good or bad good; bad	Nominal (good; bad)

Table 4.2 Description and scale of the investigated factors

Factors investigated		Description	Type of variable (measure)
Temperature		Perceived temperature by the worker cold; hot; proper	Nominal (cold; hot; proper)
Job satisfaction		How much the worker satisfied with a job	Ratio (5-point Likert scale)
Job stress		How much stress the worker feels during a job done	Ratio (5-point Likert scale)
Working posture	Neck	Angles of six body joints (to frontal plane) were measured. The degree is positive when the joint is in flexion, and negative when the joint is in extension.	Ratio (degree; °)
	Shoulder		
	Elbow		
	Wrist		
	Back		
	Knee		

When videotaping the workplace, following two things were considered (Keyserling, 1986). (1) At least two cameras should be positioned at a different angle to the worker so that the working postures can be identified correctly during playback. (2) One job should be recorded during several job cycles because working posture can vary from cycle to cycle due to the nature and demands of the job.

4.2.1.1 Individual factors

Individual factors which were expected to influence the working posture were worker's physical features such as height, weight, body shape, and medical history. These factors were reported that they were associated with WMSDs among workers in various fields. Finally selected individual factors were gender, age, height, weight, BMI, handedness, and seniority (years of service). They were gathered through interview and direct survey.

4.2.1.2 Physical exposure factors

Physical exposure factors were divided into two categories: (1) job characteristics, and (2) workplace characteristics.

Job characteristics included job cycle time, the number of jobs per hour, rotation between jobs, and factors related to force, repetitiveness, or posture. These data were gathered by analyzing the job standard guidelines, direct observation, and interviewing the workers.

Workplace characteristics were investigated by direct measurement in the workplace. In this regard, following tools were used: (1) a tapeline for position information on the workstation (vertical height of the working point and horizontal distance to the working point), and information on the MMH (length/width/height of the lifting object, thickness of graspable part of lifting object, and information needed for NIOSH lifting equation), (2) electronic weighing machine for the weight of the heavy loads, and (3) force gauge to measure the force required to do certain pushing or pulling. In this study, Ergo FET was used as a force gauge (Hoggan Health Industries, West Jordan, UT, United States).

4.2.1.3 Environmental factors

Environmental factors such as noise, illumination, and temperature were measured by the observers or interviewing the workers.

4.2.1.4 Job satisfaction and job stress

The observers interviewed workers about how they feel about the job, including job satisfaction level, and job stress level for the job. Those factors were all measured using 5-point Likert scale.

4.2.1.5 Working posture

The observers gathered data on the working postures and body contact with the workstation or automobile for a period before approaching the worker to do direct measurements. The workers were asked to perform

jobs as usual, and then the workers were directly recorded using video cameras from the front and side for effective working posture assessment. If necessary, additional body parts (e.g. wrists and fingers) were recorded supplementally for more accurate analysis.

The working posture can be represented in terms of angles between body segments and the line of gravity in the photographic plane (Paul & Frings-Dresen, 1994). Five joints including neck, shoulder, elbow, wrist, and back were selected to define the working posture in many previous studies. In this study, we added one more joint-knee-to the joint set, and total six joint angles were measured. In the previous studies on postural analysis, five joints (except knee) were treated as the main joints (Hignett & McAtamney, 2000; Kim & Kim, 2012; McAtamney & Nigel Corlett, 1993).

Angles of these joints were measured by analyzing each frame of recorded videos. In measuring angles of the joints, self-developed working postural analysis software 'AngloMeter' was used. The software can be seen in Figure 4.1. Using AngloMeter, main working postures of all jobs were analyzed. More detailed information about the software is explained in Chapter 7.

Selection of the observed job and posture was obtained from a target posture. The target posture of the job was chosen based on the posture holding time or the level of postural stress (McAtamney & Nigel Corlett, 1993). We adopted maximum holding time concept discussed by Miedema et al. (1997). The posture to be assessed was the one held for the greatest amount of the job cycle or the one that the observer considered as stressful to the musculoskeletal system according to the ergonomic expertise.

Figure 4.1 AngloMeter: a working postural analysis system

The posture of the body parts was measured using the degree of angles of each joint. The status of each joint is either flexion or extension. We set the degree of angle positive when the joint is in flexion state. For example, when the neck is in 60° flexion, the degree of angle the neck is 60, and when in 60° extension, the degree is -60. In this sense, every degree of angles was calculated except knee and elbow joints, because knee extension and elbow extension are not normal states, and they were not observed in our investigation.

4.2.2 Data analysis

Based on the candidate set of contributing factors from the literature reviews, we conducted correlation analyses between these factors and the working posture. The results of the correlation analyses were not interpreted directly because of concern about the inter-correlations

among variables. Referring the results of correlation analyses, direct contributions of each factor were figured out through multiple linear regression analyses.

The relative influence of the contributing factors on the job satisfaction and job stress was analyzed by multiple linear regression analyses. Then, the comprehensive influence of the contributing factors could be understood. Figure 4.2 below shows the research procedure.

Drawing candidate set of contributing factors

- Literature review on the risk factors for the working posture
- Referring the risk factors for WMSDs (Chapter 3)

Preliminary analysis on the relationship

- Correlation analysis
- between the contributing factors and the working posture

Analysis on the contributing factors

- Multiple linear regression analysis
  - Independent variables
    : Contributing factors
  - Dependent variables
    : Working posture (angles of the body joints)
- Multiple linear regression analysis
  - Independent variables
    : Working posture (angles of the body joints)
  - Dependent variables
    : Job satisfaction and job stress

Figure 4.2 Procedure for grasping the contributing factors

4.3 Results

4.3.1 Candidates of the contributing factors for working posture

The candidates of the contributing factors gathered from the previous studies related to the working posture were as follows: (1) physical exposure factors, (2) tools or equipment, (3) individual factors, and (4) psychosocial factors. The detailed information is shown in Table B.1 in Appendix B.

Physical exposure factors included the vertical height of the working point, horizontal distance to the working point, adjustability of the workstation, height/position/slope of the pedal, and design of desk or chair. Tools or equipment was about the design of tools including length, weight, slope, and so on. Individual factors included gender, pregnancy, obesity, etc. Lastly, psychosocial factors appeared in previous literature were job satisfaction, job content, job security, and social support. Added to these factors, major risk factors for WMSDs reported in Chapter 3 were also included in the candidate set.

Finally included factors in this study were listed in Table 4.3. (1) Individual factors: gender, age, height, weight, BMI, handedness, seniority (years of service), medical history in each body part. (2) Physical exposure factors: number of jobs per hour, rotation between jobs, rotation period, force acting on the upper extremity, force needed to push-pull, static efforts, repetitiveness in each body part, clearance of workspace and hand, hand slipperiness, vibration, visual demands, vertical height of the working point, horizontal distance to the working point, relative height according to the worker, working surface, length

of tools, weight of heavy loads, and fist hammering. (3) Environmental factors: illumination, temperature, and noise.

Table 4.3 Final candidate set of the contributing factors

Group	Included factors in each group
Individual factors	Gender, age, height, weight, BMI, handedness, seniority (years of service), medical history in each body part
Physical exposure factors	Number of jobs per hour, rotation between jobs, rotation period, Force acting on the upper extremity, force needed to push-pull, static efforts, repetitiveness in each body part, clearance of workspace and hand, hand slipperiness, vibration, visual demands, vertical height of the working point, horizontal distance to the working point, relative height according to the worker, working surface, length of tools, weight of heavy loads, and fist hammering
Environmental factors	Illumination, temperature, and noise

In particular, physical exposure factors could be divided into five groups; group related to (1) force, (2) posture, (3) repetitiveness, (4) tools or equipment, and (5) workplace. The first group related to the force included force acting on the upper extremity, static efforts, vibration, force needed to push-pull, and weight of heavy loads.

The second group related to the posture contained overall body posture, postures of the neck, back, upper arm, lower arm, hand/wrist, and lower extremity. However, the postures of specific body parts were not included for the relationship analysis, because there was a strong and direct presumption that the posture of the specific body part was highly related to the working posture. Accordingly, only overall body posture was selected.

The third group related to the repetitiveness included repetitive use of the upper arm, lower arm, and lower extremity. The fourth group related to the tools or equipment was composed of type, length, circumference, weight, and torque needed. However, the only length of tools was included in the study, because the other variables were not fully gathered through the investigation.

The last group related to the workplace included the vertical height of the working point, working surface, relative height according to the worker, and horizontal distance to the working point.

4.3.2 Descriptive statistics

Total 942 jobs were analyzed, and descriptive statistics of the individual factors, physical exposure factors, working posture, job satisfaction, and job stress are reported in this section.

4.3.2.1 Individual factors

The workers were all males, and mean values of the workers' age, height, weight, BMI, and seniority were 43.83 years old (*SD* 8.414), 171.55 cm (*SD* 5.420), 69.51 kg (*SD* 8.287), and 23.60 (*SD* 2.432), and 16.94 years (*SD* 8.239) respectively.

4.3.2.2 Physical exposure factors

An average number of jobs per hour was 44.53 jobs (*SD* 16.32). Most of the jobs were cyclic, and the average cycle time of jobs was between one and two minutes. Job rotations were enforced in 845 jobs, and in the other 97 jobs, specific workers were fixed at one job. Rotation period was 1.63 hours in average (*SD* .988).

The average force acting on the upper extremity, the force needed to push-pull, repetitiveness in the upper arm, lower arm, and lower extremity were 2.40 (*SD* .764), 1.32 (*SD* .693), 1.96 (*SD* .374), 2.32 (*SD* .738), and 1.59 (*SD* .676) respectively. Those factors were all measured in 4-point scale as mentioned in Table 4.2. The number of jobs with static efforts, hand slipperiness, clearance of workspace and hand were 156, 37, 557, and 672 jobs respectively.

The mean value of vibration exposure level and visual demands were 1.84 (*SD* .827) and 2.02 (*SD* .628) respectively. The vertical height of the working point and horizontal distance to the working point were 113.41 cm (*SD* 47.09) and 49.22 (*SD* 14.59) respectively.

Whole body posture was categorized into six groups, the groups and their frequencies were as follows: stand (389 times), stoop (233), squat

(20), overhead (193), seat (66), and inside a vehicle (41). The number of jobs implementing MMH tasks was 231, and the average weight of heavy loads was 6.40kg (*SD* 4.22).

4.3.2.3 Working posture

The average angle of each body joint were as follows: neck flexion = 17.55 (*SD* 12.99), neck extension = 10.58 (*SD* 7.99), back flexion = 21.77 (*SD* 22.28), back extension = 6.13 (*SD* 4.48), shoulder flexion = 60.68 (*SD* 31.90), elbow flexion = 52.54 (*SD* 30.29), wrist flexion = 12.13 (*SD* 12.15), wrist extension = 15.85 (*SD* 15.46), and knee flexion = 20.28 (*SD* 34.29). The unit of the angle was degree as aforementioned in Table 4.2.

4.3.2.4 Job satisfaction and job stress

The average value of job satisfaction and job stress were 2.71 (*SD* .83) and 2.81 (*SD* .96) respectively.

4.3.3 Correlation analysis between working posture and contributing factors

To grasp the relationship among various factors, Pearson correlation analyses were conducted. In particular, for binary variables such as medical history (0=no; 1=yes), correlation coefficients were measured using Spearman's *rho*. The correlation coefficients were not directly

interpreted and only considered as references when conducting following linear regression analyses.

4.3.3.1 Individual factors

There was a little significant correlations between working posture and individual factors. Medical history had relatively large amount of significant correlations. In terms of body parts, upper arm, back, lower extremity, and hand/wrist were significantly correlated to the working posture. The Spearman's correlation coefficient were as follows. Upper arm with neck flexion (r = -.091, p = .019), neck extension (r = -.126, p = .036), back flexion (r = -.107, p = .002), and wrist flexion (r = -.188, p < .001). Back with neck extension (r = -.165, p = .006), back flexion (r = .112, p = .001), and wrist flexion (r = -.186, p < .001). Hand/wrist with wrist flexion (r = -.161, p < .001).

Age (r = .236, p = .035) and seniority (r = .256, p = .022) had significant correlations with only back extension. Worker's height had significant correlation with shoulder flexion (r = -.096, p = .003). In general, the individual factors had low correlation coefficients with the working posture even when the correlations were significant though.

4.3.3.2 Physical exposure factors

As mentioned in the previous section, physical exposure factors were grouped into five categories: force, posture, repetitiveness, tools or equipment, and workplace.

First, among factors related to the force, total three factors had significant correlations with the working posture. The significant correlations were as follows: force needed to push-pull with wrist extension (r = .198, p < .001) and back flexion (r = -.110, p = .001); weight of heavy load with shoulder flexion (r = -.107, p = .001) and wrist flexion (r = -.130, p = .003); fist hammering with wrist extension (r = .158, p = .001).

Second, in the case of the posture, the significant correlations were as follows: whole body posture with neck flexion (r = -.177, p < .001), neck extension (r = .124, p = .039), shoulder flexion (r = .345, p < .001), and knee flexion (r = .593, p < .001).

Third, among factors about the repetitiveness, the number of jobs per hour, rotation between jobs, rotation period, and repetitiveness in each body part had at least one significant correlation with working postures.

Fourth, there was no significant correlation between factors related to the tools or equipment and working posture.

Last, factors about workplace had relatively high correlation coefficients in average. Especially, vertical height of the working point, horizontal distance to the working point, and working surface were highly influential variables on the working posture. The significant correlations were as follows: vertical height of the working point with neck flexion (r = -.106, p = .006), back flexion (r = -.433, p < .001), shoulder flexion (r = .319, p < .001), elbow flexion (r = .211, p < .001), and knee flexion (r = -.439, p < .001); horizontal distance to the working point with back flexion (r = .340, p < .001), shoulder flexion (r = .270, p

< .001), and elbow flexion (r = -.309, p < .001); working surface with back flexion (r = .314, p < .001) and elbow flexion (r = -.124, p < .001).

4.3.3.3 Environmental factors

There was no significant correlation between environmental factors and working posture. Hence, it seemed that environmental factors had no influence on the working posture.

4.3.4 Correlation analysis between job satisfaction/job stress and working posture

Correlation analyses were conducted to grasp the relationships between job satisfaction/job stress and working posture. The other process were same as section 4.3.3. The correlation coefficients are shown in Table 4.4. Every working posture had significant correlations with job satisfaction and job stress at the .1 level except neck extension and back extension.

Table 4.4 Correlation coefficients of the correlation analyses

	Neck flexion	Neck extension	Back flexion	Back extension	Shoulder flexion	Elbow flexion	Wrist flexion	Wrist extension	Knee flexion
Job satisfaction	-.157***	-.107	-.317***	.022	-.369***	.176***	-.163***	-.125***	-.206***
Job stress	.163***	.062	.305***	-.070	.305***	-.137***	.124***	.119**	.193***

Note. *: p < .1, **: p < .05, ***: p < .01.

4.3.5 Regression analysis between working posture and contributing factors

The best subset of the candidate set was identified to get the best-fitting regression model. A stepwise method was used for this objective. To this end, the coefficient of determination (R^2) was used as a measure for the quality of regression models. It represents the amount of variability in the data explained or accounted for by the regression model. The *adj-*R^2 is the statistic that overcomes the weakness of R^2, overfitting problem. Thus, in this study, *adj-*R^2 was used as an indicator of goodness-of-fit of the regression model.

In all regression analyses, Multicollinearity among independent variables was evaluated using tolerance and variance inflation factor (VIF). The variables with low tolerance and high VIF tend to have a multicollinearity. The thresholds for tolerance and VIF were .1 and 10 respectively in this study.

4.3.5.1 Regression model for working posture

Based on the results of the correlation analyses, the candidates of contributing factors were selected from all factors investigated. The candidate set of contributing factors is listed in Table 4.5.

Table 4.5 Candidate set of the contributing factors

Group	Included factors in each group
Individual factors	medical history (neck, back, upper arm, lower arm, hand/wrist, and lower extremity); age; height; BMI
Physical exposure factors	[Force] static efforts; force needed to push-pull; weight of heavy load; fist hammering; vibration; force acting on the upper extremity; visual demands
	[Posture] whole body posture
	[Tools] length of tools
	[Repetitiveness] number of jobs per hour; rotation between jobs; rotation period; repetitiveness in each body part
	[Workplace] vertical height of the working point; horizontal distance to the working point; working surface; relative height according to the worker
Environmental factors	none

4.3.5.1.1 Neck

The regression model for neck posture was statistically significant ($F(31, 618) = 5.566$, $p < .001$) only with *adj-*R^2 of .179. Among the candidate set, worker's height, whole body posture, and horizontal distance to the working point were significant at the .05 level. Worker's age, the number of jobs per hour, and visual demands were also significant at the .1 level. Table 4.6 includes the significant factors.

Table 4.6 Regression model for neck posture

Variable	Estimate (95% CI)	*β*	*p*	Tolerance	VIF
Worker' age	.110 (-.011; .231)	.071*	.074	.804	1.245
Worker's height	.322 (.141; .503)	.133***	.001	.874	1.145
Number jobs per hour	-.054 (-.117; .009)	-.065*	.092	.850	1.176
Whole body posture	-2.346 (-3.048; 1.644)	-.265***	< .001	.775	1.291
Force in upper extremity	-1.509 (-3.088; .070)	-.088*	.061	.574	1.742
Visual demands	-1.361 (-2.951; .229)	-.063*	.093	.912	1.097
Horizontal distance to the working point	-.149 (-.218; -.081)	-.162***	< .001	.881	1.135

Note. *: $p < .1$, **: $p < .05$, ***: $p < .01$, $R^2 = .218$, $adj\text{-}R^2 = .179$.

4.3.5.1.2 Back

The regression model for back posture was statistically significant ($F(31, 618) = 20.679$, $p < .001$) with $adj\text{-}R^2$ of .485. With a close look at the independent variables, medical history in back, rotation between jobs, whole body posture, repetitiveness in the lower arm, the vertical height of the working point, working surface, and horizontal distance to the working point were significant at the .05 level. Medical history in lower extremity, static efforts, the weight of heavy loads, and force needed to push-pull were also significant at the .1 level. Table 4.7 includes the significant factors.

Table 4.7 Regression model for back posture

Variable	Estimate (95% CI)	*β*	*p*	Tolerance	VIF
Medical history in back	6.645 (2.948; 10.342)	.119***	.000	.699	1.430
Medical history in lower extremity	-5.181 (-10.445; .082)	-.058*	.054	.885	1.130
Rotation between jobs	5.341 (.722; 9.960)	.072**	.024	.795	1.258
Whole body posture	-1.580 (-2.523; -.637)	-.105***	.001	.775	1.291
Static efforts	3.313 (-.424; 7.051)	.055*	.082	.788	1.269
Repitition in lower arm	2.428 (.420; 4.437)	.078**	.018	.741	1.350
Weight of heavy loads	-1.440 (-3.041; .161)	-.053*	.078	.878	1.139
Vertical height of the working point	-.305 (-.358; -.252)	-.567***	.000	.318	3.149
Working surface	3.464 (1.793; 5.136)	.122***	.000	.877	1.140
Horizontal distance to the working point	.330 (.238; .422)	.211***	.000	.881	1.135
Force needed to push-pull	-1.839 (-3.868; .190)	-.054*	.076	.858	1.165

Note. *: $p < .1$, **: $p < .05$, ***: $p < .01$, $R^2 = .509$, $adj\text{-}R^2 = .485$.

4.3.5.1.3 Shoulder

The regression model for shoulder posture was statistically significant (F (31, 617) = 11.848, $p < .001$) with $adj\text{-}R^2$ of .342. Worker's height, worker's BMI, whole body posture, the vertical height of the working point, working surface, horizontal distance to the working point, and

force needed to push-pull were significant at the .05 level. Hand slipperiness and relative height according to the worker were also significant at the .1 level. Table 4.8 includes the significant factors.

Table 4.8 Regression model for shoulder posture

Variable	Estimate (95% CI)	*β*	*p*	Tolerance	VIF
Worker's height	-.772 (-1.168; -.376)	-.131***	.000	.874	1.144
Worker's BMI	-.985 (-1.843; -.127)	-.074**	.025	.951	1.051
Whole body posture	6.546 (5.009; 8.083)	.303***	.000	.774	1.291
Hand slipperiness	10.037 (-.716; 20.790)	.061*	.067	.925	1.081
Vertical height of the working point	.235 (.149; .321)	.304***	.000	.318	3.149
Working surface	3.756 (1.030; 6.482)	.092***	.007	.876	1.141
Horizontal distance to the working point	.661 (.511; .811)	.294***	.000	.882	1.134
Force needed to push-pull	-4.114 (-7.420; -.807)	-.084**	.015	.858	1.165
Relative height according to the worker	5.501 (-.545; 11.548)	.103*	.074	.303	3.299

Note. *: $p < .1$, **: $p < .05$, ***: $p < .01$, $R^2 = .373$, $adj\text{-}R^2 = .342$.

4.3.5.1.4 Elbow

The adjusted coefficient of determination of the regression model for elbow posture was fairly poor with .117. However, the model was statistically significant (F (31, 618) = 3.767, $p < .001$). As independent

variables, horizontal distance to the working point and hand slipperiness were significant at the .05 level. In addition, force in upper extremity and length of tools were significant at .1 level. Table 4.9 includes the significant factors.

Table 4.9 Regression model for elbow posture

Variable	Estimate (95% CI)	*β*	*p*	Tolerance	VIF
Force acting on the upper extremity	-3.342 (-7.168; .483)	-.084*	.087	.574	1.742
Hand slipperiness	-14.248 (-26.143; -2.353)	-.090**	.019	.925	1.081
Horizontal distance to the working point	-.623 (-.789; -.458)	-.290***	.000	.881	1.135
Length of tools	-.035 (-.070; .001)	-.074*	.055	.929	1.076

Note. *: $p < .1$, **: $p < .05$, ***: $p < .01$, $R^2 = .159$, $adj\text{-}R^2 = .117$.

4.3.5.1.5 Wrist

The adjusted coefficient of determination of the regression model for wrist posture was very poor with .040, even though, the model was statistically significant (F (31, 618) = 1.879, p = .003). Among all variables included in the model, worker's age, hand slipperiness, the vertical height of the working point, working surface, relative height according to the worker, and hand clearance were significant at the .05 level. Additionally, worker's BMI and medical history in upper arm were significant at .1 level. Table 4.10 includes the significant factors.

Table 4.10 Regression model for wrist posture

Variable	Estimate (95% CI)	*β*	*p*	Tolerance	VIF
Worker's age	.111 (.004; .218)	.088**	.041	.804	1.245
Worker's BMI	.295 (-.051; .642)	.066*	.094	.951	1.051
Medical history in upper arm	-2.073 (-4.450; .304)	-.078*	.087	.716	1.397
Hand slipperiness	-5.013 (-9.352; -.673)	-.091**	.024	.925	1.081
Vertical height of the working point	.046 (.011; .081)	.178***	.009	.318	3.149
Working surface	1.689 (.590; 2.788)	.124***	.003	.877	1.140
Relative height according to the worker	-2.780 (-5.219; -.341)	-.156**	.026	.303	3.296
Hand clearance	2.294 (.318; 4.271)	.096**	.023	.836	1.197

Note. *: $p < .1$, **: $p < .05$, ***: $p < .01$, $R^2 = .086$, $adj\text{-}R^2 = .040$.

4.3.5.1.6 Knee

The regression model for knee posture had relatively higher adjusted coefficient of determination with .567, and was also significant (F (31, 618) = 28.459, $p < .001$). Among all variables included in the model, medical history in the lower extremity, whole body posture, workspace clearance, the vertical height of the working point, working surface, horizontal distance to the working point, and relative height according to the worker were significant at the .05 level. Table 4.11 shows the significant variables.

Table 4.11 Regression model for knee posture

Variable	Estimate (95% CI)	*β*	*p*	Tolerance	VIF
Medical history in lower extremity	8.362 (1.181; 15.543)	.063**	.023	.885	1.130
Whole body posture	14.425 (13.138; 15.711)	.646***	.000	.775	1.291
Workspace clearance	5.421 (1.567; 9.274)	.078***	.006	.836	1.197
Vertical height of the working point	-.330 (-.402; -.258)	-.411***	.000	.318	3.149
Working surface	-3.342 (-5.623; -1.061)	-.079***	.004	.877	1.140
Horizontal distance to the working point	-.203 (-.328; -.077)	-.087***	.002	.881	1.135
Relative height according to the worker	-10.277 (-15.338; -5.217)	-.187***	.000	.303	3.296

Note. *: $p < .1$, **: $p < .05$, ***: $p < .01$, $R^2 = .588$, $adj\text{-}R^2 = .567$.

4.3.6 Contributing factors and their relative influence

Through multiple linear regression analyses for each body part, influential contributing factors were obtained. The influence of each contributing factor was not same according to different body parts. The contributing factors for the posture of each body part are arranged in Table 4.12 below. Table 4.12 contains both significant and insignificant factors.

In the analysis process, factors that had high correlations with each other were excluded. Weight and seniority were not included in this respect. Weight was highly correlated with BMI, and seniority was correlated with age. Moreover, handedness was banned because the

sample size was not well balanced. Most of the workers were right-handed.

Table 4.12 Contributing factors for the posture of each body part

Contributing factors		Neck	Back	Shoulder	Elbow	Wrist	Knee
Age		.071	.029	.021	-.047	.088	.019
Height		.133	.000	-.131	.034	-.015	-.029
BMI		.029	-.016	-.074	.048	.066	.022
Medical history	Neck	-.030	-.019	-.009	.019	.032	.027
	Upper arm	-.061	.014	.010	.041	-.078	-.030
	Lower arm	-.008	-.047	.000	-.001	-.019	.037
	Hand/wrist	.005	.010	-.024	-.002	-.042	-.005
	Back	.003	.119	.054	.014	.005	.023
	Lower extremity	.010	-.058	-.004	-.052	-.037	.063
Number of jobs per hour		-.065	.022	-.016	.029	.008	-.029
Rotation between jobs		-.031	.072	.026	.044	-.036	-.004
Whole body posture		-.265	-.105	.303	-.003	.064	.646
Static efforts		-.003	.055	.030	.001	.007	-.031

Table 4.12 Contributing factors for the posture of each body part

Contributing factors		Neck	Back	Shoulder	Elbow	Wrist	Knee
Force acting on the upper extremity		-.088	-.037	.030	-.084	-.056	.016
Fist hammering		-.051	.033	.022	.032	.024	.001
Repetitiveness	Upper arm	.011	.015	.019	.008	-.019	-.028
	Lower arm	.037	.078	-.017	.061	.071	.013
Clearance	Workspace	-.049	-.009	-.010	.045	-.016	.078
	Hand	.030	.033	.006	.025	.096	.039
Hand slipperiness		-.045	.019	.061	-.090	-.091	-.022
Weight of heavy loads		-.041	-.053	-.051	-.032	-.033	.020
Vibration		-.034	.011	.013	-.003	.046	.027
Visual demands		-.063	.022	.033	.036	-.023	-.020
Vertical height of the working point		-.099	-.567	.304	.067	.178	-.411
Horizontal distance to the working point		-.162	.211	.294	-.290	-.019	-.087
Working surface		.057	.122	.092	-.058	.124	-.079
Relative height according to the worker		-.089	.068	.103	.068	-.156	-.187
Length of tools		-.046	.022	-.084	-.074	.051	-.002
Force needed to push-pull		.047	-.054	-.084	.055	.050	.011

Note. The number denotes the standard coefficient from the regression model.

4.3.7 Regression analysis between job satisfaction/job stress and working posture

According to the results of the regression analysis for job satisfaction, all body parts were statistically significant except elbow. It means that elbow was relatively low regarding sensitive for workers to feel about the job and accept it. The influence on the job satisfaction was highest in the shoulder, and back, knee, and neck were followed. Table 4.13 shows the results of the regression analysis.

Table 4.13 Regression model for job satisfaction

Variable	Estimate (95% CI)	*β*	*p*	Tolerance	VIF
Intercept	3.658 (3.461; 3.854)		.000		
Neck posture	-.006 (-.009; -.002)	-.091***	.005	.796	1.255
Back posture	-.009 (-.011; -.006)	-.228***	.000	.954	1.048
Wrist posture	-.005 (-.010; -.001)	-.072**	.014	.966	1.035
Shoulder posture	-.009 (-.011; -.008)	-.363***	.000	.699	1.431
Elbow posture	-8.211E-05 (-.002; .002)	-.003	.924	.826	1.210
Knee posture	-.005 (-.006; -.003)	-.186***	.000	.989	1.011

Note. *: $p < .1$, **: $p < .05$, ***: $p < .01$, $R^2 = .241$, $adj\text{-}R^2 = .236$.

For job stress, the results were similar with the job satisfaction. Every body part was significant except elbow. The wrist was also insignificant at the .05 level. It means that the posture of elbow and wrist were less influential than the posture of the neck, back, shoulder, and knee on the job stress. The influence on the job stress was highest in shoulder posture, and back, knee and neck were followed. The results of the regression analysis are shown in Table 4.14.

Table 4.14 Regression model for job stress

Variable	Estimate (95% CI)	β	p	Tolerance	VIF
Intercept	1.772 (1.539; 2.006)		.000		
Neck posture	.008 .003 .012	.106***	.001	.796	1.255
Back posture	.010 .008 .013	.235***	.000	.954	1.048
Wrist posture	.005 .000 .010	.053*	.076	.966	1.035
Shoulder posture	.009 .007 .012	.313***	.000	.699	1.431
Elbow posture	.001 -.001 .003	.023	.486	.826	1.210
Knee posture	.005 .003 .007	.176***	.000	.989	1.011

Note. *: $p < .1$, **: $p < .05$, ***: $p < .01$, $R^2 = .195$, $adj\text{-}R^2 = .190$.

4.3.8 Critical contributing factors for the working posture

To sum up the results, the contributing factors were as follows: age, height, BMI, medical history in upper arm, medical history in back, medical history in lower extremity, number of jobs per hour, rotation between jobs, whole body posture, static efforts, force acting on the upper extremity, repetitiveness in lower arm, workspace clearance, hand clearance, hand slipperiness, weight of heavy loads, visual demands, vertical height of the working point, horizontal distance to the working point, working surface, relative height according to the worker, length of tools, and force needed to push-pull.

These factors did not affect the posture of every body part. However, when a factor affects the posture of a specific body part, it anyhow affects the overall working posture consequently. Because the working posture is determined by combinations of the body parts and joints.

Among these contributing factors, the high influential factors-critical contributing factors-were vertical height of the working point, whole body posture, horizontal distance to the working point, relative height according to the worker, working surface, and worker's height. Broken down, these critical contributing factors were composed of four workplace-related factors and one posture-related factor in physical exposure factors and one individual factor.

Interestingly, worker's weight, handedness, vibration, fist hammering, and rotation period were revealed that had no influence on the working posture in this study.

4.4 Discussion

Working posture is one of the most important causal factors for WMSDs. However, as far as we know, no comprehensive study to reveal contributing factors for the working posture has been conducted until now. Justly, there was no single study that handled the field research data for this purpose.

The field research data has its advantages and disadvantages simultaneously. First, the biggest difference between field research data and experimental data is that truly realistic data can be gathered using field research data. Although, during our field research, observers might affect workers in doing their jobs, and the workers might do slightly different behavior compared with as usual. However, the gap between them is smaller in the field research than lab-based experimental research. While the field research has this advantage, the fact that reproducibility and repeatability cannot be guaranteed is a disadvantage. Moreover, controlling other confounding factors is not easy in the field research. Nonetheless, we tried to overcome this problem by gathering a large number of data many times for a longish period.

In this study, contributing factors for the working posture and their influences were grasped using the field research data. To this end, literature reviews were carried out firstly. By reviewing the previous literature, a candidate set of contributing factors was selected. Then we conducted statistical analyses including correlation analysis and linear multiple regression analysis. Through these steps, the final set of contributing factors for the working posture was obtained. Then, the relative influences of those factors were also analyzed.

The results of this study are expected to be used when setting the priority of intervention or change to improve the worker's working posture and perceived job satisfaction.

Chapter 5. Quantitative Models for Job Satisfaction and Job Stress

Various methods to measure a risk level of a job have been suggested by previous researchers. However, a method to quantify comprehensive risk level is needed. Because existing methods have their characteristics including both strength and weakness, and it is hard to apply the specific method to every context. Thus, this study intended to determine a quantification method for the risk level of a job regarding job satisfaction and job stress. In this regard, psychosocial factors such as job satisfaction and job stress were used as dependent variables. Hence, we proposed quantitative models for job satisfaction and job stress using existing ergonomic assessment methods. To this end, multiple linear regression analysis and machine learning techniques including neural network, support vector machine, and decision analysis were utilized.

Keywords: job satisfaction, job stress, ergonomic assessment method, regression analysis, machine learning technique

5.1 Introduction

5.1.1 Ergonomic assessment method

In the past decades, some researchers have sought to develop ergonomic assessment methods to analyze and evaluate jobs. RULA, REBA, quick exposure checklist (QEC), OWAS, and strain index (SI) are the representative ones.

The ultimate objective of these ergonomic assessment methods is to tell two thigs: whether an ergonomic intervention is necessary for a job (risk or no risk) (Li & Buckle, 1999). In addition to this, most of the methods provide the ergonomic risk level concept based on the experts' judgments and previous literature. By using this ergonomic risk level concept, action level categories can also be suggested. These concepts have been demonstrated to be very effective and efficient for quantifying the postural stress and preventing MSDs through many field researches (Kee & Karwowski, 2001).

Previous researchers have pointed out that diverse factors should be considered for more accurate and comprehensive ergonomic evaluation. Previous studies adopted '3-zone rating system' and 'traffic-light model' approach to quantifying the ergonomic risk level, developed by EN614-4 and Swedish National Board of Occupational Health (1998), respectively. However, these studies did not give a robust and concrete basis for the quantification of the ergonomic risk level. Table 5.1 contains the risk level and action level categories suggested in the previous studies.

Table 5.1 Risk level and action level categories in the previous studies

Method	Risk level	Action level category
RULA	From 1 to 7	From level 1 (acceptable) to level 4 (intervention required immediately)
REBA	From 1 to 15	From level 0 (negligible risk, action none necessary) to level 4 (very high risk, action necessary now)
OWAS	-	From class 1 (no need special attention) to class 4 (need immediate consideration)
QEC	From rating 0 to 176	From level 1 (acceptable) to level 4 (investigate and change immediately)
Rodgers' muscle fatigue assessment	From 1 (low) to 4 (very high)	-
NLE	From 0 to infinite	From low (LI < 1) to high (LI > 3)
SI	From rating 1 to 5	-
LUBA	Postural load index from 0 to 13	From category 1 (acceptable posture) to category 4 (action is required immediately)

As mentioned above, most of the researches and guidelines for the ergonomic risk level were developed based on solely literature reviews. Only a few studies conducted lab experiments including subjective evaluation or biomechanical experiment to calculate ergonomic risk level (Apostolico et al., 2014; Chung et al., 2003; Waters et al., 1993).

In addition, every assessment method has its strength and weakness. Hence, guidelines for 'when and how to choose an appropriate tool with

consideration of the context' have been suggested. However, it is not easy to decide which tool should be used pragmatically, because a job normally contains various properties simultaneously. Hence, practitioners cannot be sure to rely on which results when different methods indicate dissimilar results. To overcome this kind of weakness and limitation, a comprehensive scoring system for job evaluation is needed. Although the methods such as RULA, REBA, and OWAS have demonstrated predictive validity (Grieco, 1998; Moore & Garg, 1997), risk levels suggested by them do not have fine discrimination. They have only four ranges of action levels. These are not enough to prioritize implementation of the ergonomic interventions for the jobs. Accurate identification of 'at risk' jobs is one of the most critical issues for prevention of MSDs. Regarding the signal detection theory, false alarm or miss of the 'at risk' jobs could give inappropriate knowledge for prioritization of the interventions for the jobs.

In the previous studies, different assessment methods were considered simultaneously to compare the methods and investigate the agreement among results of the different methods. The 'score systems' adopted in some of the assessment methods are quite hypothetical, and the assessment results can only be interpreted or compared within the same system used (Li & Buckle, 1999).

In this respect, many researchers pointed out the limitations of the existing methods, and there have been many attempts to improve the postural analysis methods. Budnick (2013) reported that RULA has a strong focus on the only posture, but a weak focus on repetitiveness and duration. Kee and Karwowski (2001) noted the disadvantages of existing

methods: (1) not based on experimental data, (2) for specific application purposes, and (3) considered only a few representative joint motions.

With a close look at the development process of these ergonomic risk assessment methods, they were developed based on integrated models of the risk factors for MSDs which account for the role of physical exposures in the occurrence of MSDs (Jones & Kumar, 2010). Especially, calculation methods of the risk level were not proposed with concrete and logical grounds, and they were not data-driven developed. Even, the most widely used methods by practitioners such as RULA, REBA, QEC, and OWAS were not developed with any lab or field data. They were developed by referring previous literature and experts' opinions.

5.1.2 Job satisfaction and job stress

Despite a complex nature of job satisfaction, there is a clear consensus in the definition of job satisfaction. The consensus is that job satisfaction is an affective reaction to one's job (Locke, 1969; Weiss, 2002). Job satisfaction can be understood as a pleasurable emotional state resulting from the appraisal of one's job as achieving or facilitating the achievement of one's job values. Since a job is not perceived or experienced as such, it cannot initially be evaluated as a single unit. Overall job satisfaction is "the sum of the evaluations of the discriminable elements of which the job is composed" (Locke, 1969). Job satisfaction also has been used as a predictor for the mental health of the workers in the previous studies (Cooper et al., 1989).

Job satisfaction, the emotional reaction along the overall job, is also related to the job performance (Judge et al., 2001). Although the relationship between job satisfaction and job performance is not clear enough, it is obvious that there exists a significant relationship between them.

From a viewpoint of MSDs, job satisfaction is a significant notion. The relationship between job satisfaction and the development of MSDs have been revealed and supported by numerous existing studies (da Costa & Vieira, 2010; Linton, 2001; Magnusson et al., 1996; van der Windt et al., 2000). Hocking (1987) demonstrated that studies had found job satisfaction to correlate with the presence of MSDs better the ergonomic variables in their study. Moreover, it has been shown in the literature that job satisfaction to affect reports of body discomfort (Norman et al., 1998; Smith, 1997).

Job stress is a psychosocial factor that is highly related to the occurrence of WMSDs. There are some researches supporting that the prevalence rate of WMSDs increases as the workers get more stresses. Leino and Hänninen (1995) reported that excessive mental exertion is rather more influential than physical burden on the back and upper limb disorders. Bongers et al. (1993) also stated that the portion of WMSDs caused by physical factors is not higher than normally expected. For the measurement of the WMSDs, the prevalence rate is one of the most frequently used variables in the previous studies. Besides this, job stress is also one of the most influential factors for the WMSDs.

Nonetheless, existing ergonomic assessment methods such as RULA, REBA, OWAS, and QEC do not evaluate or assess the job satisfaction or job stress. These tools only focused on the physical conditions such as

working posture, repetitiveness, and excessive force. These tools have been utilized widely to evaluate the jobs ergonomically by the ergonomists and practitioners (Dempsey et al., 2005).

Hence, if the job satisfaction and job stress can be estimated by using the scores of ergonomic assessment methods, it can help practitioners to understand how the workers feel about their jobs. Moreover, a good grasp of the relationship between job satisfaction/stress and ergonomic assessment methods can be very meaningful with a view to MSDs prevention.

5.1.3 Research objectives

To sum up the issues mentioned above, an ergonomic risk level calculation method and quantitative models for job satisfaction and job stress need to be developed. In this regard, the followings were carried out in this study. (1) Ergonomic assessment methods were compared in terms of the risk level across specific context. (2) Ergonomic risk level was quantified using the results of ergonomic assessment methods and job satisfaction/stress. (3) Data-driven quantitative models for job satisfaction and job stress were proposed.

5.2 Methods

This study is three folds and flows as to conduct each sub-study. The following figure shows the overall research procedure (Figure 5.1). Detailed descriptions of each sub-study are explained in the following sections.

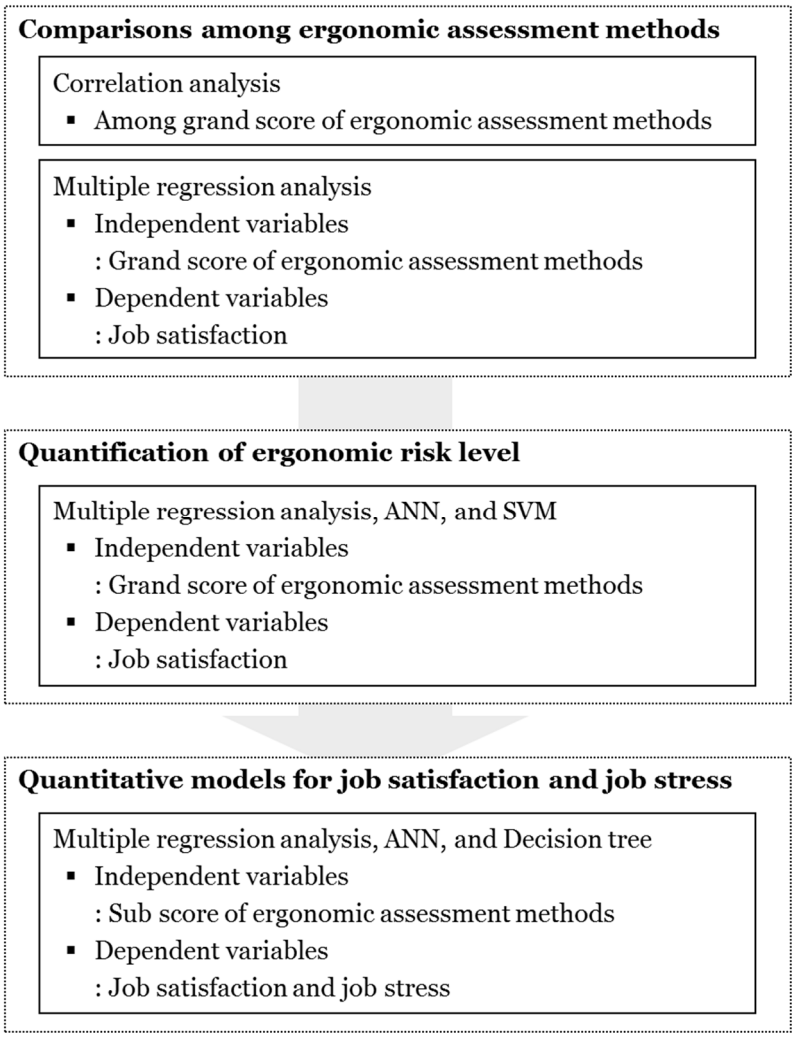

Figure 5.1 Research procedure of this study

5.2.1 Comparisons among ergonomic assessment methods

Ergonomic assessment methods were compared in terms of the risk level across specific context. The corresponding contexts were whole body posture and vibration exposure level. They were chosen from the contributing factors for the working posture presented in Chapter 4. To compare the evaluation results of the assessment methods. Two analyses were carried out. Firstly, correlation analysis was performed to understand the relationships among the results of the assessment methods. Secondly, multiple linear regression analysis was conducted. More detailed descriptions of the regression analysis are in the following sections.

5.2.1.1 Independent variables

Seven ergonomic assessment methods were considered, and they were as follows: RULA, REBA, OWAS, QEC, NLE, SI, and Rodgers' muscle fatigue assessment. The reason why we selected these methods were that they were most widely used methods by practitioners (Dempsey et al., 2005). In addition, they have their strength and weakness. Hence, previous studies suggested appropriate methods upon consideration of job characteristics. For example, when the worker is mainly using upper extremity during a job, it is better to adopt RULA than REBA, however, if a job needs usage of lower extremity too, then REBA is a better choice. Moreover, when a job has some risk factors such as vibration and postures like bending and twisting, QEC is more applicable.

To evaluate the jobs according to these methods, self-developed postural analysis software was used for more reliable and accurate analysis. Selection of the observed jobs and postures is obtained from a target postures. The target postures of the job were chosen based on the posture holding time or the level of the postural stress (McAtamney & Nigel Corlett, 1993). The posture to be assessed were those that are held for the greatest amount of the work cycle or those that the observer considers as stressful to the musculoskeletal system according to the ergonomic expertise. Total 942 jobs in an automobile assembly plant were analyzed. Not only final scores but also sub-scores of the methods were all evaluated and recorded. Table 5.2 shows the ergonomic assessment methods used in this study.

Table 5.2 Ergonomic assessment methods

Factors investigated	Description	Scale
RULA	Grand score of RULA	From 1 to 7
REBA	Grand score of REBA	From 1 to 15
OWAS	Grand score of OWAS	From 1 to 4
QEC	Grand score of QEC	From 0 to 176
SI	Grand score of SI	From 0 to -
Rodger's muscle fatigue assessment	Grand score of Rodger's muscle fatigue assessment	4-point scale
NLE	Lifting index (LI)	From 0 to -

5.2.1.2 Dependent variable

In this first sub-study, job satisfaction was used as a dependent variable. The reason why job satisfaction was chosen as a dependent variable is described in section 5.1.2 above.

5.2.1.2.1 Rating method

The job satisfaction was evaluated by adjusted magnitude estimation ranged from one to five. The higher score is, the higher satisfaction workers feel. We used the adjusted magnitude estimation because it could perform an effective assessment with high sensitivity and have many statistical applications so that many previous studies used this method (Han et al., 2000; Yun et al., 2001). The ratings of the dependent variable were based on short time exposure conditions due to the nature of the automobile assembly work. Such conditions often occur in various kinds of contemporary work in the construction industry, office environment, and agriculture (Bernard & Putz-Anderson, 1997).

5.2.2 Quantification of ergonomic risk level

In the second sub-study, the same variables were used as independent and dependent variables as in the first sub-study. Quantification of ergonomic risk level was tried using job satisfaction and a grand score of ergonomic assessment methods. However, in addition to the linear regression analysis, machine learning techniques were utilized.

5.2.2.1 Machine learning techniques

Lots of variables should be considered to choose appropriate method or technique for the model. First, the most common objective of the model is to maximize the accuracy of prediction. Second, robust of the model should be considered, too. A model with much more robust and slightly low accuracy can be better than the one with low robust. While more sophisticated techniques are being adopted to the predictive models, more positive benefits can be truly accomplished (Agha & Alnahhal, 2012). In this study, a statistical model such as linear regression analysis and machine learning techniques such as an artificial neural network (ANN), support vector machine (SVM), and decision tree analysis were performed.

5.2.2.1.1 Artificial neural network

One efficient way of solving complex problems is to "divide and conquer". A complex system could be disintegrated into simpler components to be able to understand it. In addition, simple components can be gathered to produce a complex system (Bar-Yam, 1997). Network is one approach to achieving this. There is a large number of different types of networks, but they all are characterized by the following elements: a set of nodes and connections between them.

The nodes can be seen as computational units. They receive inputs and process them to obtain an output. This processing might be very simple or quite complex. The information flows are determined by the connections between nodes. The connections can be bidirectional or unidirectional by directions of the flow between nodes.

One type of network is the nodes as 'artificial neurons'. These are called artificial neural networks. Neural networks classifier is a nonlinear classification method which mimics a human brain. An ANN consists of an input layer of neurons (or nodes, units), one or two (or even three) hidden layers of neurons and a final layer of output neurons (Wang, 2003). It contains a number of the perceptron, each of which has several input values and usually one output value. The output value is determined by a function of input values, called an activation function. The activation function can be a variety of functions such as step function, linear function, sigmoid function and so forth. The architecture of a neural network can be seen in Figure 5.2.

For supervised learning problems like classification, the weights of edges should be trained with training data. Back-propagation method can be used for this work (Hecht-Nielsen, 1989). In this study, the back-propagation method was used to determine the weights of edges. WEKA Version 3.8.0 (The University of Waikato, Hamilton, New Zealand) was used for ANN analysis.

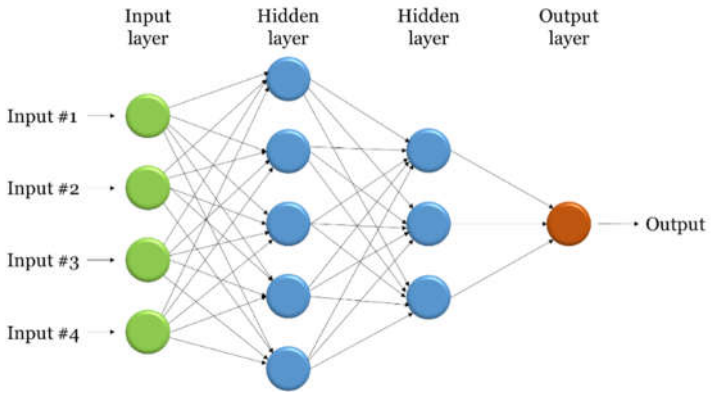

Figure 5.2 Architecture of a multilayer perceptron model

5.2.2.1.2 Support vector machine

SVM classifier is a pattern classification technique. It is a nonlinear binary classifier which finds the optimal decision hyperplane in a high-dimensional space (Boser et al., 1992; Vapnik, 2013). The reason why SVM is attractive is the characteristics of condensing information in the training data and providing a sparse representation by using a very small number of data points (SVs) (Girosi, 1998). MATLAB R2015b Version 8.6.0 (MathWorks, Natick, Massachusetts, United States). Figure 5.3 below illustrates an example of non-linear SVM.

Support vector machine for regression (SMOreg) was performed additionally for more accurate prediction. The SMOreg was conducted with nonlinear polykernels, and with algorithm 'RegSMOimproved', the most popular algorithm, suggested by Shevade et al. (2000).

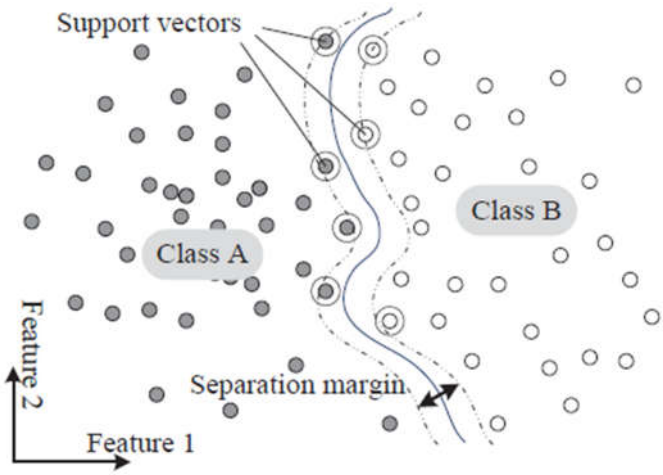

Figure 5.3 An example of non-linear support vector machine[1]

[1] Image source from: http://www.cse.wustl.edu/~jain/cse570-15/ftp/iot_ml/fig3.png

5.2.3 Quantitative models for job satisfaction and job stress

In the third sub-study, sub scores of ergonomic assessment methods were used as independent variables, not the grand scores. For dependent variables, job satisfaction and job stress were selected.

To develop quantitative models for job satisfaction and job stress, existing ergonomic assessment methods were reviewed. The reviewed methods were RULA, REBA, OWAS, QEC, NLE, SI, and Rodgers' muscle fatigue. Every method has its characteristics, and they are described briefly in the following paragraphs.

RULA should be used when the worker uses primarily the upper limb to perform the job, and RULA is not applicable for assessing MMH tasks. SI is appropriate for assessing any repetitive 'hand intensive' job. However, SI does not account for contact stress or hand-arm vibration. QEC considers various risk factors including vibration. Moreover, QEC considers not only working posture but also force and duration. REBA covers the whole body, and applicable to the posture which is static, dynamic, rapidly changing, or unstable. However, REBA focuses primarily on working postures and does not consider the duration of activity or vibration. Rodgers' muscle fatigue assessment also considers whole body areas and considers both duration or working postures. However, it is fairly difficult to assess a job using Rodgers' method, especially for the postural analysis. Finally, NLE considers only risk factors related to lifting tasks. It does not factor in vibration or non-lifting MSD hazards.

The grand scores of these methods are calculated using the subscores of each element such as body part and type of risk factor. We did not use both grand and first-level subscores except SI. Because the first-level subscore does not have enough information, and the grand score normally contains too much information to get together. For example, in the case of RULA, posture score A, posture score B, score C, score D, and grand score were not included in the model.

Elements firstly pooled from each method are as follows. From RULA, scores of neck, trunk, shoulder, elbow, wrist, twist in wrist, leg, force load, and muscles were pooled out. From REBA, scores of neck, trunk, shoulder, elbow, wrist, leg, force load, coupling, and activity were included in the model. From OWAS, scores of trunk, shoulder, leg, and force load were considered. From QEC, a score of neck, trunk, arm, hand, and others were used. LI was used from NLE, and SI score was used from SI.

Based on the characteristics of each method, the final candidates were selected. Among the elements from RULA and REBA, neck and trunk scores were gathered from RULA, and shoulder, elbow, wrist, leg, force load, coupling, and activity scores were from REBA. From OWAS, only leg score was used, and from QEC, workplace score including vibration, and work pace was included. Finally, LI from NLE and score of SI were included too. However, no element of Rodgers' muscle fatigue assessment was included in consideration of the difficulties in job evaluation using it.

5.3 Results

5.3.1 Comparisons among the ergonomic assessment methods

We conducted correlation analysis to find the relationships among the job evaluations scores by different assessment methods, and the results are contained in Table 5.3. As expected, there were significantly high correlations among pairs of RULA-REBA and REBA-OWAS. NLE had significant correlations with QEC, REBA, and SI. It seemed because those three methods all deal with MMH tasks, although the correlation coefficient between REBA and SI was low (r = .111). SI had significant correlations with RULA, REBA, and NLE. RULA and REBA both consider upper extremity including hand and wrist. Hence it is quite reasonable that the correlations between those two methods and SI were significant.

Table 5.3 Results of correlation analysis (Pearson's)

	RULA	REBA	OWAS	QEC	NLE	SI
RULA	1	.572**	.180**	.156**	.032	.111**
REBA		1	.341**	.253**	.074*	.155**
OWAS			1	-.011	-.039	.048
QEC				1	.198**	.033
NLE					1	.076*
SI						1

Note. *: $p < .05$, **: $p < .01$.

One of the main reasons why the outcomes were dissimilar between the methods came from the job characteristics. Since the objectives of each method are slightly different, the pattern of the outcomes is not same across the methods.

In the following sections, the results of regression analyses were investigated according to overall body posture and vibration exposure level.

5.3.1.1 The regression model according to the overall body posture

As mentioned above, we categorized all jobs into six groups including 'stand', 'stoop', 'squat', 'overhead', 'seat', and 'inside the vehicle'. We compared the job satisfaction prediction model of each group using multiple linear regression analysis. The grand scores of RULA, REBA, OWAS and QEC were used as independent variables.

For standing jobs, the regression model was statistically significant at the .05 level and significant variables were scores of RULA, REBA, and QEC ($adj\text{-}R2$ = .550, F (4, 384) = 119.640, p < .001). The standardized coefficients were as follows: RULA = -.150 (t = -3.501, p = .001), REBA = -.608 (t = -13.260, p < .001), OWAS = -.018 (t = -.487, p = .626), and QEC = -.087 (t = -2.412, p = .016). The OWAS score was determined as an insignificant variable. This result shows that OWAS is not a good assessment tool for standing jobs. In standing posture, workers generally have little postural problem on their back and leg, hence, the influence of the OWAS score may decrease. Because OWAS is deficient in evaluation of other risk factors.

In the case of jobs in stooping posture, the regression model was significant and the scores of REBA, OWAS and QEC were significant ($adj\text{-}R^2$ = .475, F (4, 228) = 53.433, p < .001). The standardized coefficients were as follows: RULA = -.051 (t = -.891, p = .374), REBA = -.606 (t = -10.192, p < .001), OWAS = -.105 (t = -2.154, p = .032), and QEC = -.118 (t = -2.417, p = .016). The score of RULA was not a significant variable in the model. This result shows that RULA is not a useful tool for evaluating the jobs in stooping posture. RULA is specialized in assessment of load on upper extremity. Hence, the fact that job satisfaction is more affected by load on lower back and lower extremity in stooping posture can be concluded.

When workers are in squatting postures, the regression model was not significant at the .05 level (F (4, 15) = 2.458, p = .091). It seems that those methods including RULA, REBA, OWAS, and QEC are not proper to assess the jobs in a squatting posture mainly.

In the case of overhead jobs, the significant independent variables were scores of RULA, REBA and QEC ($adj\text{-}R^2$ = .444, F (4, 188) = 39.389, p < .001). The standardized coefficients were as follows: RULA = -.206 (t = -3.204, p = .002), REBA = -.495 (t = -7.772, p < .001), OWAS = .000 (t = -.006, p = .995), and QEC = -.174 (t = -3.153, p = .002). The OWAS score was not a significant variable. In general, workers do overhead jobs in the posture of neck and back extensions. However, OWAS does not consider this neck and back extension postures.

In the case of jobs belong to the sitting posture group, the scores of RULA, REBA, OWAS and QEC were significant in the regression model ($adj\text{-}R^2$ = .670, F (4, 61) = 33.960, p < .001). The standardized coefficients were as follows: RULA = -.317 (t = -3.149, p = .003), REBA

= -.329 (t = -2.952, p = .004), OWAS = -.175 (t = -2.155, p = .035), and QEC = -.271 (t = -3.480, p = .001). Comparing with the overall regression model, the influence of the RULA score became fairly higher. Based on this result, when workers are in sitting posture, it can be noted that the influences of RULA and REBA become quite similar. It is thought because there is little problem on lower extremity in the sitting posture in general.

In the case of jobs taken inside the vehicle, the regression model contains scores of RULA, REBA and QEC as significant variables (*adj-*R^2 = .760, F (4, 36) = 32.680, p < .001). The standardized coefficients were as follows: RULA = -.227 (t = -2.567, p = .015), REBA = -.626 (t = -7.412, p < .001), OWAS = -.102 (t = -1.173, p = .249), and QEC = -.284 (t = -3.273, p = .002). The influence of QEC increased when compared with the overall regression model. It is regarded that postures like bending and twisting occur much frequently under this context. Hence, the influence of QEC which greatly deals with bending and twisting in neck and back becomes higher.

Comparisons of goodness-of-fit of the regression models indicated that the coefficients of determinations of 'stoop' and 'overhead' groups were remarkably lower than other groups such as 'inside the vehicle' and 'seat'. Moreover, the regression model was not significant for the 'squat' group. Therefore, a new method for quantifying job satisfaction is needed for more precise evaluation on the workload of the jobs in the postures such as stooping, overhead, and squatting. The standardized coefficients of all regression analyses are listed in Table 5.4.

Table 5.4 Standardized coefficients of each variable

Overall body posture	RULA	REBA	OWAS	QEC
Stand	-.150**	-.608**	-.018	-.087*
Stoop	-.051	-.606**	-.105*	-.118*
Squat	-.629*	-.049	-.030	-.313
Overhead	-.206**	-.495**	.000	-.174**
Seat	-.317**	-.329**	-.175*	-.271**
Inside the vehicle	-.227*	-.626**	-.102	-.284**
Overall	-.157**	-.575**	-.057*	-.138**

Note. *: $p < .05$, **: $p < .01$.

5.3.1.2 The regression model according to vibration exposure level

According to the vibration exposure level, we categorized the whole jobs into three groups: 'low', 'medium', and 'high'. The regression models for job satisfaction estimation were compared among the groups. Again, the grand scores of RULA, REBA, OWAS, and QEC were used as independent variables.

For the 'low' group, the regression model was significant with scores of RULA, REBA, and QEC as significant variables ($adj\text{-}R^2 = .579$, $F(4, 403) = 140.817$, $p < .001$). The standardized coefficients were as follows: RULA = -.231 ($t = -5.987$, $p < .001$), REBA = -.511 ($t = -11.949$, $p < .001$), OWAS = -.063 ($t = -1.798$, $p = .073$), QEC = -.180 ($t = -5.239$, $p < .001$).

In the case of jobs included in the 'medium' group, only REBA and QEC were significant at the .05 level ($adj\text{-}R^2 = .565$, $F(4, 270) = 89.839$, $p < .001$). The standardized coefficients were as follows: RULA = -.086

(t = -1.802, p = .073), REBA = -.658 (t = -13.005, p < .001), OWAS = -.036 (t = -.869, p = .386), QEC = -.107 (t = -2.577, p = .011).

When the vibration exposure level is high, the regression model was significant and the significant variables were scores of REBA and QEC ($adj\text{-}R^2$ = .499, F (4, 254) = 65.119, p < .001). The standardized coefficients were as follows: RULA = -.108 (t = -1.898, p = .059), REBA = -.575 (t = -9.483, p < .0041), OWAS = -.076 (t = -1.598, p = .111), and QEC = -.109 (t = -2.401, p = .017).

Interestingly, the regression model for the 'low' group only had RULA score as a significant predictor. It is thought because RULA does not consider vibration in any ways. The fact that RULA is not appropriate for evaluating jobs that have risk factors such as vibration is checked again. The standardized coefficients of all regression analyses are listed in Table 5.5.

Table 5.5 Standardized coefficients of each variable

Overall body posture	RULA	REBA	OWAS	QEC
Low	-.231**	-.511**	-.063	-.180**
Medium	-.086	-.658**	-.036	-.107*
High	-.108	-.575**	-.076	-.109*
Overall	-.157**	-.575**	-.057*	-.138**

Note. *: p < .05, **: p < .01.

5.3.2 Relationship between job satisfaction and ergonomic risk level

In summary, the best result among the statistical method and machine learning techniques was obtained by the SVM classifier. Hence, the relationship between job satisfaction and ergonomic risk level can be grasped quantitatively by using SVM classifier.

5.3.2.1 Results of regression analysis

According to the multiple linear regression analyses, the job satisfaction can be predicted by RULA, REBA, OWAS, QEC, and SI ($adj\text{-}R^2 = .552$, $F(5,936) = 72.348$, $p < .001$). The standardized coefficients were as follows: REBA = -.570 ($t = -19.836$, $p < .001$), QEC = -.139 ($t = -6.177$, $p < .001$), RULA = -.155 ($t = -5.837$, $p < .001$), SI = -.036 ($t = -1.636$, $p = .032$), and OWAS = -.058 ($t = -2.469$, $p = .014$). REBA, RULA, QEC, and SI were selected as predictors for job satisfaction. It seems that the source of data might affect the inclusion of SI, because the assembling was mainly done using both hand/wrist and forearms. Moreover, the results showed that the score of REBA, RULA, and QEC have higher influence on the overall job satisfaction.

5.3.2.2 Results of SVM classifiers

All seven variables were used for SVM classifier. Five folds cross-validation were used for all SVM classifiers. The best five results are presented in Table 5.6. The combination of RULA, REBA, OWAS, QEC, and SI was one of the best predictor set for job satisfaction prediction. It

seems that methods that have their strength were selected simultaneously as effective predictors. Since, RULA, REBA, and OWAS are postural based assessment methods; QEC is an overall exposure evaluation method; and SI is a forearm-focused tool. The highest accuracy for job satisfaction prediction was 64.3%. In the top five model, medium Gaussian SVM classifier showed the best accuracy.

Table 5.6 Results of SVM classifier

Elements	Classifier	Accuracy
RULA, REBA, OWAS, QEC, and SI	Medium Gaussian SVM	64.3
RULA, REBA, OWAS, QEC, and NLE	Medium Gaussian SVM	63.9
RULA, REBA, OWAS, QEC, and Rodgers' muscle fatigue assessment	Medium Gaussian SVM	63.8
RULA, REBA, OWAS, and QEC	Medium Gaussian SVM	63.7
RULA, REBA, OWAS, QEC, NLE, SI, and Rodgers' muscle fatigue assessment	Medium Gaussian SVM	63.5

5.3.2.3 Results of ANN analysis

For ANN analysis, we controlled the elements used as predictors. Table 5.7 shows the results of ANN analyses, the best result of each element set and the correlation coefficient are reported. An example of visualization of ANN model is illustrated in Figure 5.4.

For predicting job satisfaction, RULA, REBA, and QEC were all selected as the best elements set for the predictions. The accuracy was highest when every method is included.

Table 5.7 Results of ANN analyses

Elements	CC
RULA, REBA, OWAS, QEC, NLE, SI, and Rodgers' muscle fatigue assessment	.6797
RULA, REBA, OWAS, QEC, SI, and Rodgers' muscle fatigue assessment	.6670
RULA, REBA, OWAS, QEC, and hand	.6631
RULA, REBA, and QEC	.6500
RULA, REBA, OWAS, QEC, SI, and Rodgers' muscle fatigue assessment	.6499

Note. CC denotes correlation coefficient.

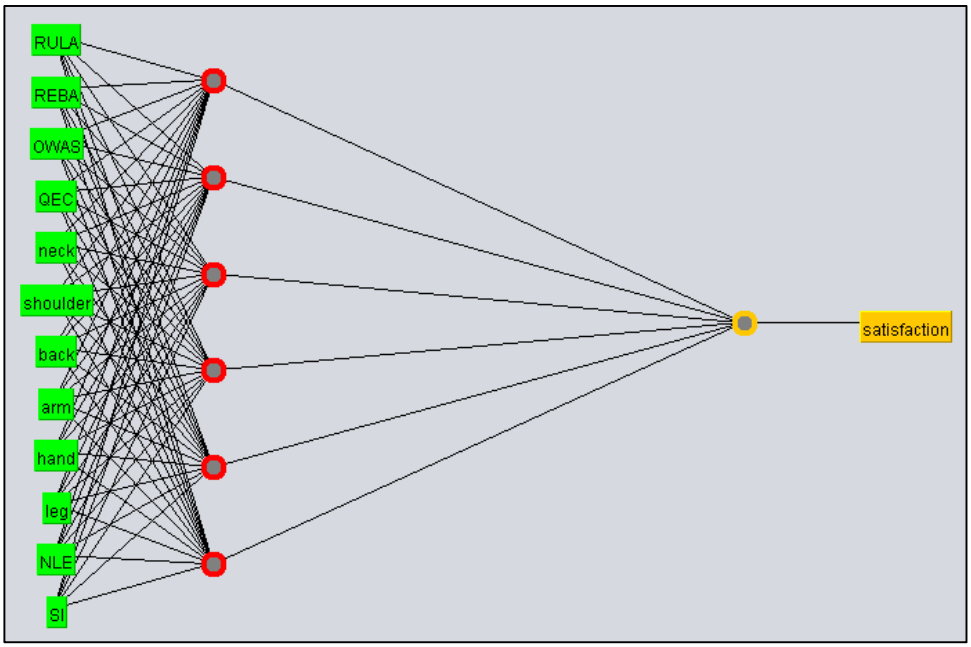

Figure 5.4 Visualization of ANN model for job satisfaction

5.3.3 Quantitative models for job satisfaction and job stress

In section 5.3.2 above, we proposed a method to quantify the ergonomic risk level in terms of job satisfaction using the grand scores of the assessment methods. In this section, sub scores of existing ergonomic assessment methods were used as independent variables for more accurate job satisfaction and job stress estimations. They were utilized as predictors for job satisfaction and job stress estimations. Whole independent variables included in the model are explained in section 5.2.3.

To sum up the results in the following sections, the accuracy of the prediction was highest in the decision tree analysis with 83.7%.

5.3.3.1 Regression analysis

First, a multiple linear regression analysis was conducted with the job satisfaction as a dependent variable. The results of the regression analysis showed a significant model with fairly high coefficient of determination ($adj\text{-}R^2$ = .796, F (13, 928) = 283.924, p < .001). Multicollinearity between independent variables was checked, and every independent variable had VIFs less than 10 and high tolerance. All statistics including standardized coefficients are listed in Table 5.8.

SI score, NLE's LI, and REBA's activity score were not statistically significant at the .05 level. According to the results, the influence of each variable on the job satisfaction was the highest in QEC's workplace score.

REBA's shoulder and coupling scores, and RULA's trunk and neck scores were also influential.

Table 5.8 Multiple regression analysis for job satisfaction

Variable	Estimate (95% CI)	*β*	*p*	Tolerance	VIF
Intercept	5.440 (5.127; 5.752)		.000		
RULA's trunk score	-.102 (-.130; -.074)	-.115	.000**	.812	1.231
REBA's shoulder score	-.107 (-.131; -.082)	-.141	.000**	.789	1.267
REBA's elbow score	-.100 (-.153; -.047)	-.057	.000**	.941	1.062
REBA's wrist score	-.038 (-.072; -.005)	-.035	.025*	.908	1.101
REBA's leg score	-.120 (-.165; -.074)	-.078	.000**	.934	1.071
REBA's coupling score	-.133 (-.169; -.098)	-.112	.000**	.932	1.073
REBA's force load score	-.113 (-.160; -.065)	-.078	.000**	.768	1.301
REBA's activity score	-.260 (-.524; .004)	-.029	.054	.983	1.017
QEC's workplace score	-.054 (-.056; -.051)	-.694	.000**	.622	1.607
SI score	.000 (-.005; .005)	.002	.917	.920	1.087
RULA's neck score	-.065 (-.087; -.043)	-.089	.000**	.915	1.093
NLE's LI	.003 (-.023; .030)	.004	.805	.825	1.212
OWAS's leg score	-.015 (-.046; .016)	-.014	.339	.946	1.058

Note. *: $p < .05$, **: $p < .01$, $R^2 = .799$, *adj-*$R^2 = .796$.

Second, using the job stress as a dependent variable, a multiple linear regression analysis was conducted. The results of the regression analysis showed a significant model with fairly high coefficient of determination ($adj\text{-}R^2$ = .756, F (13, 928) = 225.294, p < .001). Multicollinearity between independent variables was checked, and every variable had VIFs less than 10 and high tolerances. All statistics including standardized coefficients are listed in Table 5.9.

Compared with the case of the job satisfaction, REBA's elbow, wrist, leg scores were also insignificant, in addition to SI score, NLE's LI, and REBA's activity score. The pattern in the influence of each variable on the job stress was similar to the case of job satisfaction.

Table 5.9 Multiple regression analysis for job stress

Variable	Estimate (95% CI)	β	p	Tolerance	VIF
Intercept	.279 (-1.116; .675)		.166		
RULA's trunk score	.069 (.034; .105)	.068	.000**	.812	1.231
REBA's shoulder score	.039 (.008; .070)	.045	.013*	.789	1.267
REBA's elbow score	.046 (-.020; .113)	.023	.173	.941	1.062
REBA's wrist score	-.029 (-.072; .013)	-.023	.176	.908	1.101
REBA's leg score	.050 (-.008; .108)	.028	.093	.934	1.071
REBA's coupling score	.112 (.067; .157)	.081	.000**	.932	1.073
REBA's force load score	.073 (.013; .133)	.044	.017*	.768	1.301
REBA's activity score	.362 (.028; .697)	.035	.034*	.983	1.017

Table 5.9 Multiple regression analysis for job stress

Variable	Estimate (95% CI)	β	p	Tolerance	VIF
QEC's workplace score	.070 (.066; .074)	.785	.000**	.622	1.607
SI score	.006 (.000; .012)	.031	.064	.920	1.087
RULA's neck score	.030 (.002; .057)	.035	.035**	.915	1.093
NLE's LI	-.001 (-.035; .032)	-.002	.932	.825	1.212
OWAS's leg score	.024 (-.015; .063)	.020	.231	.946	1.058

Note. *: $p < .05$, **: $p < .01$, $R^2 = .759$, $adj\text{-}R^2 = .756$.

5.3.3.2 Decision tree analysis

All 12 variables were used as predictors for decision tree analysis. Five folds cross-validation were adopted for all analysis. The best five results for job satisfaction and job stress are presented in Table 5.10. In general, the combination of RULA's neck, trunk scores / REBA's shoulder, elbow, wrist, leg, coupling, force load, and activity score / QEC's workplace score was the best predictors for the dependent variables. The best results had in common that they all used these elements as predictors. Interestingly, the best predictor set was same as the predictor set for the best regression model presented in the above section.

The accuracy was highest for job satisfaction prediction in average. The highest accuracy for job satisfaction was 83.7%. For job stress, the accuracy was between 70.6% and 70.8%.

Table 5.10 Results of decision tree analysis

Response	Elements	Classifier	Accuracy
Job satisfaction	RULA's neck, trunk scores / REBA's shoulder, elbow, wrist, leg, coupling, force load, and activity score / QEC's workplace score	Medium Tree with PCA	83.7
	Same as the top / NLE's LI	Medium Tree	83
	Same as the top / NLE's LI + SI score	Medium Tree	83
	Same as the top / SI score	Medium Tree	83
	Same as the top / NLE's LI / SI score + OWAS' leg score	Medium Tree	82.9
Job stress	RULA's neck, trunk scores / REBA's shoulder, elbow, wrist, leg, coupling, force load, and activity score / QEC's workplace score	Simple Tree	70.8
	Same as the top / OWAS' leg score	Simple Tree	70.8
	Same as the top / NLE's LI / SI score	Simple Tree	70.8
	Same as the top / NLE's LI / SI score / OWAS' leg score	Simple Tree	70.8
	Same as the top / SI score	Simple Tree	70.6

5.3.3.3 ANN analysis

For ANN analysis, we controlled the set of elements used as predictors. Table 5.11 shows the results of ANN analysis including correlation coefficients. The best result of each element set and the correlation coefficient were reported.

To predict job satisfaction and job stress, RULA's neck, trunk scores, REBA's shoulder, elbow, wrist, leg, coupling, force load, and activity score, and QEC's workplace score were all selected as the best element set. For both job satisfaction and stress, the accuracy was highest when this element set was included in predictors. In the case of job satisfaction, NLE's LI was added to this element set, and OWAS' leg score was included in the element set for job stress.

Table 5.11 Results of ANN analysis

Response	Elements	CC
Job satisfaction	RULA's neck, trunk scores / REBA's shoulder, elbow, wrist, leg, coupling, force load, and activity score / QEC's workplace score / NLE's LI	.8524
	Same as the top / SI score	.8454
	Same as the top except NLE's LI	.8416
	Same as the top / SI score / OWAS' leg score	.8415
	Same as the top except NLE's LI / SI score	.8228
Job stress	RULA's neck, trunk scores / REBA's shoulder, elbow, wrist, leg, coupling, force load, and activity score / QEC's workplace score / OWAS' leg score	.8076
	Same as the top / SI score / NLE's LI - OWAS' leg score	.7837
	Same as the top except OWAS' leg score	.7826
	Same as the top except OWAS' leg score / SI score	.7802
	Same as the top / SI score / NLE's LI	.7572

Note. CC denotes correlation coefficient.

5.4 Discussion

Abounding studies have been done on the ergonomic evaluation of jobs or works. In these efforts, various ergonomic assessment methods were developed. These methods including RULA, REBA, OWAS, QEC, etc. are still widely used by both academic researchers and practitioners. Although those methods have their strength and weakness, it was verified and proved that they are effective and pragmatic to estimate the ergonomic risk level with a view to MSDs prevention by many researches.

Although, the importance of job satisfaction job stress has been pointed out and reported in the previous studies, far too little attention has been paid to investigate the relationship between these factors and ergonomic risk level. Hence, these studies tried to figure out the relationship between the ergonomic risk level calculated by the existing methods and job satisfaction. To this end, regression analysis and machine learning techniques including ANN analysis and SVM classifier. In this study, the relationship between only job satisfaction and ergonomic risk level was investigated. Additionally, more analysis on the job stress also can be carried out in further study.

Job satisfaction and job stress are not easy to measure due to their inherent and subjective nature. However, they can be predicted through models such as linear regression, neural network, SVM, and decision tree using objectively measurable variables. Subscores of existing ergonomic assessment methods were used as inputs due to their ease to be measured and objective nature in the evaluation. A comparison was made among the techniques for predicting the job satisfaction and job stress. By considering predictability (*adj-*R^2 and accuracy), the linear

regression analysis and decision tree analysis showed quite similar performance. However, neural network model showed relatively bad performance than those two models.

In this study, whole data was gathered by field researches. Total 942 jobs in an automobile assembly plant were analyzed and evaluated through work site investigation. Due to the nature of the field research data, it was not well balanced in terms of a sample size of the groups by job characteristics such as whole body posture, vibration exposure level, etc. However, from the naturalness perspective, it can be stated that highly realistic and useful data was used in this study.

Nonetheless, this study also has the following limitation. The field research was conducted only in an automobile plant. Although the automobile assembly plant has some representative properties, the results of this study cannot be directly adopted to other work sites or industries. Most of the jobs were cyclic work and the portion of sitting posture was quite low. Hence, further study should be carried out to verify and generalize our results.

Chapter 6. Ergonomic Problems and Interventions in an Automobile Assembly Plant

Ergonomic interventions were suggested in previous studies to prevent musculoskeletal disorders of workers. However, no single study tried to find ergonomic problems and suggest interventions at an automobile assembly plant in South Korea. Hence, we did a field research as a case study in an automobile assembly plant to grasp the ergonomic problems in detail. After the field investigations, appropriate and pragmatic interventions were developed. Moreover, a follow-up study was carried out to examine the effectiveness of the interventions applied to the work site. According to the results of this study, ergonomic approach actually works in the real world setting effectively regarding working posture and musculoskeletal disorders.

Keywords: ergonomic problem, ergonomic intervention, working posture, musculoskeletal disorders, follow-up study, automobile assembly plant

6.1 Introduction

6.1.1 Ergonomic problem

MSDs have been a major problem in industrialized countries. Studies on the MSDs have been conducted by many researchers and institutes, and it is known that MSDs occur due to diverse factors such as job-related factors, personal factors, and psychosocial factors.

To be specific, previous investigations into the cause of MSDs have identified three categories of risk factors: (1) biomechanical exposures, (2) psychosocial stressors, and (3) individual risk factors (Bongers et al., 2002).

Biomechanical exposures include factors such as poorly designed work sites or workplaces, repetitive motion, excessive forces, and deviations from neutral body alignments (National Research Council and the Institute of Medicine, 2001). Psychosocial stressors include factors such as high-perceived workplace stress, low-perceived social support, low perceived job control, and time pressure (Bongers et al., 2002; Huang et al., 2003). Individual factors include gender, age, negative stress reactions, unsatisfactory rest time, and additional workload (Bergqvist et al., 1995; Fredriksson et al., 1999).

Ergonomic problems in work sites are highly related to workers' MSDs. Therefore, to determine the ergonomic problems, we should consider the risk factors for the MSDs. Using the information on the ergonomic problems, applicable ergonomic intervention should be developed and implemented to the work sites.

6.1.2 Ergonomic intervention

A considerable amount of studies has tried to suggest interventions have focused on modifying one or the other of the categories of risk factors. Especially, most of them focused on modifying either biomechanical exposures or psychosocial stress in the workplace (Lincoln et al., 2000; Piligian et al., 2000).

MSDs prevention is imperative, and previous studies have been conducted to achieve this objective. Interventions for MSDs can be classified into three groups: (1) primary, (2) secondary, and (3) tertiary interventions (Rubenowitz, 1997). Primary intervention is the one against presumed causative occupational exposure factors. Secondary intervention directs towards the individual worker to allay symptoms or strengthen the resistance to harmful exposures. Tertiary intervention is rehabilitation act designed to bring a patient with MSD back to work (Rubenowitz, 1997). However, the classification between primary, secondary and tertiary interventions is often not very clear cut. Thus, Bongers et al. (2006) divided the interventions into following two groups of primary/secondary and secondary/tertiary interventions.

The interventions also can be categorized into two types: (1) ergonomic intervention, and (2) job stress management (Feuerstein et al., 2004). Ergonomic interventions are one of the well-known ways of prevention of MSDs (Denis et al., 2008). Ergonomic interventions aim to change the mechanical exposure of workers and thereby improve their musculoskeletal health (Westgaard & Winkel, 1997).

In this study, we focused on the ergonomic interventions, especially, primary/secondary ergonomic interventions. The primary/secondary

interventions aim to (1) reduce awkward postures, (2) minimize the need to use excess force, (3) reduce highly repetitive movement, (4) reduce the period of time spent in one position, and (5) ensure sufficient rest/recovery periods (Piligian et al., 2000).

In general, practitioners tend to focus on surveillance and identification of problematic jobs so as to decide whether ergonomic interventions are needed, and if this is the case, whether the interventions are effective (Li & Buckle, 1999). Several academic reviews have been conducted on ergonomic interventions to prevent MSDs in the workplace (Denis et al., 2008; Karsh et al., 2001; Kennedy et al., 2010; Kilbom, 1988; Rivilis et al., 2008; Snook, 1988; Westgaard & Winkel, 1997). These previous studies aimed to verify whether or not the proposed interventions were effective in preventing MSDs.

To measure the effectiveness of the ergonomic interventions, a follow-up study, a type of longitudinal studies, should be carried out, because the comparison of the working conditions before and after an intervention can be performed through the follow-up study.

Furthermore, from the viewpoint of cost-benefit, previous literature measured effectiveness by incidence rate, the number of MSDs, lost work days, restricted days, workers' comp costs, cost per claim and so on (Goggins et al., 2008). However, this study did not consider cost-benefit perspective.

As mentioned above, a variety of factors were used as dependent variables for assessing the effectiveness of the interventions. They were incidence rate and the number of MSDs, job stress, job satisfaction, etc. Nonetheless, we analyzed the effectiveness with focusing on the working

posture of the workers. The reason why we set working posture as a key dependent variable is as follows. (1) Working posture is one of the most crucial factors to MSDs. (2) It can be objectively measured compared with other factors. (3) By analyzing the working posture, effects of the interventions can be observed immediately.

To gather the data needed to determine ergonomic problems and develop ergonomic interventions, a case study was conducted. More detailed explanations on the case study are described in the next section.

6.1.3 Case study

The automobile manufacturing industry is one of the largest revenue-generating industry in an advanced country such as South Korea. Moreover, automobile assembly plant has a complex nature including various kinds of jobs such as pressing, painting, assembling, and even office work.

In this complex circumstance, automobile assembly plants are facing much difficulty in providing good working conditions to their workers. The prevalence of MSDs in automobile manufacturing industry is relatively higher than other manufacturing industry. Automobile and trailer manufacturing have been the most frequently reported industries for MSDs in South Korea (Ahn et al., 2002). It seems because of the long-serving employment, higher labor intensity, and large exposure population. Moreover, there are many jobs that use the whole body of the workers, and the prevalence of musculoskeletal symptom of the workers in the automobile industry is not limited to a specific body part

(Kim, 2005). However, a follow-up study on MSDs in the automobile industry have not been conducted so far, especially in South Korea (Heo et al., 2007). Only cross-sectional studies were performed due to its nature that is easy to implement, even though, it is not effective to grasp the dynamic course of the work site. Thus, in this study, a follow-up approach was used for a better comparison.

The case study took place in a large-sized automobile manufacturing company in South Korea. This company produces various kinds of automobiles in terms of size (mini, mid-sized, and full-sized) and purpose (sedan and sports utility vehicle). We conducted thorough work site investigations on the whole assembly lines in the plant. The investigations were done for seven times, from the year 2007 to 2015.

6.1.4 Research objectives

The objective of this study is three folds: (1) ergonomic problems in the plant were determined through an investigation of the plant, (2) appropriate ergonomic interventions were developed for each ergonomic problem, and (3) effectiveness of the ergonomic interventions was measured by analyzing the working postures and ergonomic risk levels.

6.2 Ergonomic Intervention Development

6.2.1 Development process of ergonomic intervention

The development process of ergonomic intervention is as follows. (1) Preliminary analyses: defining the scope of the problems in the work situation and orienting the data collection in next step. (2) The diagnostic step: the step that finds causes for the identified problems, causes to which the changes should be directly related. (3) The solution development step: solutions to change the work situation are developed (Denis et al., 2008). Rubenowitz (1997) suggested that for developing ergonomic interventions, problem analysis, data collection including job situation at the workplace, implementation and follow-up should be well performed.

Denis et al. (2008) proposed better characterization of each of these three major steps in the intervention process: (1) Investigation of the characteristics of the work: information on the nature of the tasks (cyclic or varied) and on the general layout of the workstation where the work is done (stationary workstation or variable environment). (2) The implemented changes: the changes implemented in the workplace. (3) The evaluation of the intervention: the change follow-up process to demonstrate the impacts or utility of the intervention.

Most previous studies tried to improve the work situation by referring and adapting standard such as NIOSH lifting guidelines, workstation guidelines, technical guidelines, etc. In these cases, standards were often used as a basis, and modified in relation to the needs of the situation (Denis et al., 2008).

Others tried to develop a new design to change the work situation since it was difficult to solve the problems by applying the conventional standards. Moreover, solution development needs more comprehensive and broader insight than the application or adaptation of existing standards.

Information considered to develop the interventions in the previous studies can be categorized into three groups: (1) activity sector (construction; industrial environment; health care; office work; others), (2) type of work (MMH; visual display unit work; assembly, sewing, packaging, quality control; construction work; trade-related technical work; driving; operating machinery; others), and (3) job characteristics (nature of the jobs; workstation layout).

For more realistic interventions, the more adapted approach is needed (Buchholz et al., 1996; Denis et al., 2008; Kemmlert, 1995; Wickström et al., 1996). Additionally, there was very little existing documentation about job or task characteristics being considered in developing interventions. The choice of appropriate intervention process is so important, and characteristics of the job should be considered for this (Denis et al., 2008).

Consequently, in this study, we investigated more information on the job characteristics for more detailed job analysis and more appropriate interventions.

6.2.2 Categorization of ergonomic intervention

Interventions suggested in the previous literature were classified as shown in Table 6.1. As mentioned in section 6.1.2 above, ergonomic interventions can be largely classified into two groups: primary/secondary and secondary/tertiary in terms of the characteristics of themselves.

Some researchers suggested terminologies like 'multiple interventions', 'multiple approaches', and 'multiple components' for applying two or more interventions to one ergonomic problem (Bongers et al., 2006; Karsh et al., 2001; Lincoln et al., 2000). However, this study aimed to classify the interventions into exclusive subgroups. Hence, we did not contain 'multiple' concept in the classification of the interventions.

Table 6.1 Classification of interventions in the previous studies

Classification	Reference
1. Workstation redesign **2.** Education **3.** Physiotherapy **4.** Work organization	Kilbom (1988)
1. Environment **2.** Physical layout (workplace; adjustments or repositioning) **3.** Equipment	Denis et al. (2008)

Table 6.1 Classification of interventions in the previous studies

Classification	Reference
(personal protection; mechanical aids; storage; adjustable tables/chairs; office accessories/computing; tools/machine) **4.** Training **5.** Work organization (temporal aspects; policies/procedures; process) **6.** Rehabilitation	
1. Back belt use **2.** Ergonomic or lifting training **3.** Examined tools or technologies **4.** Exercise **5.** Job redesign **6.** Multiple interventions	Karsh et al. (2001)
1. Engineering controls **2.** Administrative controls **3.** Multiple components	Lincoln et al. (2000)
1. Modification of the existing workstations **2.** Stretching exercises	Feuerstein et al. (2004)
1. Materials handling (fewer handling actions) **2.** Workstation design (efficient, easier work) **3.** Physical environment (safe comfortable space) **4.** Welfare facilities (restful conditions) **5.** Work organization (effective teamwork) **6.** Other daily life aspects (stable daily life)	Kogi (2006)

Table 6.1 Classification of interventions in the previous studies

Classification	Reference
1. Work organization (task rotation or task enrichment, work-rest schedules, management engagement) **2.** Individual (workstyle/work techniques, cognitive approach) **3.** Multiple approaches (workstation redesign, ergonomic task force establishment, training, and restricted duty provisions)	Bongers et al. (2006)

6.3 Research Methodology

6.3.1 Research procedure

Total 1,098 jobs were investigated for three objectives: to find ergonomic problems, to suggest ergonomic interventions, and to figure out the effectiveness of the interventions on the working posture. During the investigation, one worker for each job was also interviewed and surveyed.

The research procedures can be seen in Figure 6.1. (1) Thorough investigations were conducted to gather all information on the jobs. (2) Based on the investigation results, ergonomic problems were identified and categorized. (3) To resolve the problems, ergonomic interventions were developed, and some of them were applied to the plant. (4) For a follow-up study, working postures and ergonomic risk levels before and after intervention were compared.

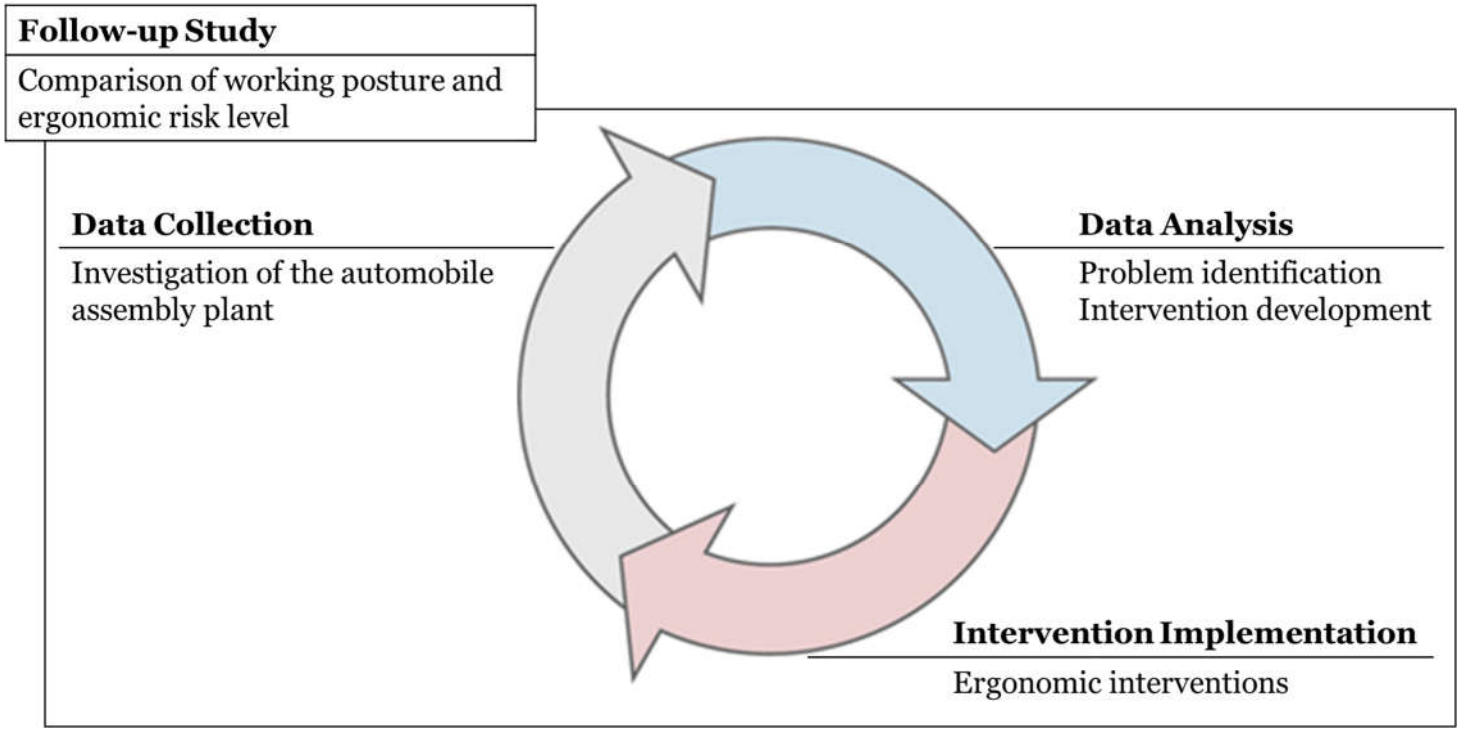

Figure 6.1 Overall research procedure

6.3.2 Investigation of the automobile assembly plant

Data on the risk factors and working posture were gathered through field investigation and survey. The field investigation took place in a large-sized automobile assembly plant in South Korea. Thorough investigations on the whole assembly lines in the plant were conducted. Total 1,098 jobs and a same number of workers were investigated from the year 2007 to 2015 over seven times (2007: 122 jobs, 2009: 34 jobs, 2010: 164 jobs, 2012: 149 jobs, 2013: 480 jobs, 2014: 39 jobs, 2015: 110 jobs).

About 11,000 people are employed at this plant, working in 12 divisions or department. Each division or department is composed of teams, and jobs belong to the team. Most of the employees rotate between the jobs in each team while working. However, some of them do not rotate because of health problems such as the pain in certain body parts.

The risk factors considered in this study could be grouped into four types including individual factors, physical exposure factors, and environmental factors.

Individual factors include worker's physical features such as height, weight, body shape, and medical history. Gender, age, handedness, and seniority (years of service) were also included. Physical exposure factors include job cycle time, working time per day, visual demands, the number of jobs per hour, rotation between jobs, weight of heavy loads, vertical height of the working point, horizontal distance to the working point, and information on tools. Environmental factors are composed of illumination and temperature

6.3.3 Identification of ergonomic problems

A general survey and direct observation of the plant were conducted to find the major ergonomic problems in the work site. Direct observation was conducted because of the advantages such as 'non–intrusive' characteristics and the general survey were used to understand the detailed information on the job characteristics and workers. The methodologies used to grasp each ergonomic problem are described in Table 6.2.

Table 6.2 Methods used to investigate major ergonomic problems

Problems	Methods
Bad tool or machine usability	▪ Direct observation of workers. ▪ Working posture analysis using recorded video. ▪ Measurement of the weight of the tool. ▪ Interview with the workers.
Contact stress	▪ Direct observation of workers.
Excessive force by the job characteristics	▪ Direct observation of workers. ▪ Measurement of the weight and force. ▪ Interview with the workers.
Noise	▪ Direct observation of workers. ▪ Interview with the workers.
Bad visibility	▪ Direct observation of workers. ▪ Interview with the workers.

Table 6.2 Methods used to investigate major ergonomic problems

Problems	Methods
	▪ Working posture analysis using recorded video.
Poor rack design	▪ Direct observation of workers. ▪ Measure the vertical and horizontal distance with a tapeline. ▪ Working posture analysis using recorded video.
Poor work site layout	▪ Direct observation of workers. ▪ Interview with the workers. ▪ Working posture analysis using recorded video.
Poor workstation design	▪ Measure the vertical and horizontal distance with a tapeline. ▪ Working posture analysis using recorded video.
Short rest	▪ Direct observation of workers. ▪ Interview with the workers.
Unnecessary movement	▪ Direct observation of workers. ▪ Interview with the workers.
Vibration	▪ Direct observation of workers.

6.3.4 A follow-up study

Control of background factors is one of the most crucial principles when conducting a follow-up study. If the intervention aims at one or a few risk factors, then another causal, effect modifying or confounding factors must be controlled (Kilbom, 1988). Thus, in this study, the

effectiveness of the interventions was analyzed with only the jobs with the similar working situations except the targeting intervention.

To determine the effectiveness of the interventions, several methods were used in previous studies. Kilroy and Dockrell (2000) used RULA's grand score, the prevalence of symptoms, and subjective body discomfort. Yeow and Nath Sen (2003) performed Wilcoxon signed test on Likert scale ratings of work-related problems before and after ergonomic interventions.

In this study, we decided to use the angles of the body joints as the elements of the working posture and grand scores of RULA, REBA, and OWAS as dependent variables. The grand scores of those ergonomic assessment methods denote the ergonomic risk level, and postural stress can be measured by analyzing the working posture. Among various ergonomic assessment methods, the reasons why those methods were chosen were as follows. They are still most frequently and widely used by practitioners in industry and even academia. Although RULA and REBA have some limitations, they remain a useful tool in the occupational ergonomist's toolbox with proper training in its application and interpretation. According to the results of a survey of ergonomic assessment method usage, ergonomists in the United States answered that they use RULA (51.6%), OWAS (21.4%), and REBA (17.9%) in the order of frequency (Dempsey et al., 2005).

To this end, the working postures before and after intervention were recorded and analyzed. In industrial ergonomics, intervention should be measured in quantitative or qualitative manners (Park, 2006). In this regard, working posture is one of the most effective measures of the effectiveness of the interventions applied to the work site. Moreover, the

working posture has several advantages: (1) it can be measured objectively, and (2) the improvements can be observed immediately. However, continuous recording of each worker was impractical; therefore, video recording was event-driven (i.e. workers were recorded performing a work task, and recording continued until several representative cycles of the task were completed). Subsequent viewing of the recorded video allowed tasks to be broken down into components, which were analyzed using RULA, REBA, and OWAS.

Paired-t tests were conducted for the comparisons. A statistical package (IBM SPSS Statistics Version 21, IBM Corp., Armonk, NY, United States) was used with a significance criterion of $p < .05$ for all statistical analyses. For the graph and charts, Excel 2016 (Microsoft, Albuquerque, NM, United States) was used.

6.4 Results

6.4.1 Job description

This study was conducted in the automobile assembly plant in South Korea which has full facilities to produce complete vehicles. The plant is organized into several divisions and departments based on the company's own standards as following; (1) press division, (2) body division, (3) paint division, (4) chassis assembly division, (5) trim assembly division, (6) engine assembly division, (7) material logistics department, (8) quality inspection department, (9) knocked-down (KD) assembly departments, and (10) others. The job characteristics of each division and department were fairly different in material, tool handling, working postures, job cycle time, and environmental factors. Among the divisions and departments, the job characteristics of some divisions and characteristics of the workers are described below.

6.4.1.1 Job characteristics of the divisions and departments

In the press division, the manufacturing process begins to produce body panels of different parts and components of the vehicle. It has rather varied job cycle time in each job task compared with other divisions because of various production speeds for different panels. The working posture in the press division and other most divisions is most likely standing posture with working height between workers' knee and shoulder; average height of the working point of 68.3 to 108.6cm from the floor and average horizontal distance to the workstation from 31.9 to 48.8cm.

Workers in the body division build body shells of vehicles which are required to be carried and connected to heavy and large components using semi- or fully-automated machines. In this division, the weight of heavy loads is also heavier than those in other divisions with a longest average cycle time of jobs. The average height of the working point is 88.6 to 122.7cm from the floor with the average horizontal distance to the working point of 45.8 to 60.0cm.

While painting vehicles is conducted by automatic painting machines, in the paint division, the rest jobs such as pre-cleaning, sanding, cleaning, and finishing jobs are solely dependent on workers to perform tasks manually with long average job cycle time as the body division. The workers have to stretch their arms further to inspect and perform the tasks on the roof, side, joint connection, and others; consequently, the average horizontal distance to the working point is the longest in the whole divisions investigated (48.6 to 56.9cm). The average height of the working point is 92.3 to 132.5cm. Most jobs in the painting division are performed at the height between workers' knee and shoulder.

The chassis assembly division starts from building the frame of chassis to assembling the chassis with the body of the vehicle. Once the frame is built, other components such as engine, power train, etc. are mounted and assembled before the body is mounted on it. This division has much prolonged overhead works with arm elevation and neck extension; therefore, the number of jobs that the work is performed above the shoulder is the largest in this division. The average height of the working point is the highest from 118.6 to 138.0cm with the average horizontal distance to the working point from 46.6 to 59.9cm.

In the trim division, interior and exterior components are assembled on the body of the vehicle before and after installation on the chassis. There are a number of components and parts to be installed and assembled in the vehicle. This leads to various working postures compared with other divisions. For example, working on engine compartment requires stoop posture to reach inside the vehicle, and installing components inside the vehicle requires kneeling or floor sitting with neck flexion. The average height of the working point is 91.5 to 123.1cm from the floor with the average horizontal distance to the working point of 43.2 to 56.0cm.

Workers in the engine assembly division use various hand tools with different torque to assemble many small parts on engines. According to the engine type and specification, the height of the working point and horizontal distance to the working point are slightly varied with different hand tools. Accordingly, the most working postures are standing with working height between knee and shoulder. Each task is aligned along the conveyor in a narrow and small space to minimize the walking distance. However, on this account, worse working postures appear in this division. Moreover, the manually handled components are quite heavy to assemble them on the engine (MMH is needed in 14.0% of the jobs). The average height of the working point is 90.7 to 120.5cm from the floor with the average horizontal distance to the working point of 35.9 to 49.0cm.

6.4.1.2 Characteristics of the workers

In this study, the average age of the 1,098 workers was 44.0 years old (*SD* 8.6). Their average height was 171.4cm (*SD* 7.2). Among them, the

proportion of right-handed person was 79 percent while that of the left-handed person was only 6 percent; 15 percent of ambidextrous person. The average working experience of the workers in the company was 7.9 (*SD* 6.9). Eighty-eight percent of them rotated between the jobs within each team in the division or department every one or two hours; whereas the rest did not because of insufficient skills, health problems or unwillingness.

6.4.2 Ergonomic problems

The number of jobs with ergonomic problems is listed in Table 6.3. About 61.77% of jobs had ergonomic problems in some ways. All ergonomic problems were analyzed by its characteristics including factors mentioned above. Through these analyses, more detailed subclasses of ergonomic problems were identified. Then, ergonomic problems and the detailed subclass of ergonomic problems were grouped by their properties.

Moreover, the outcome of each ergonomic problem along the body parts was investigated. The outcomes were identified with three types. Based on the critical risk factors for MSDs, force, posture, and repetitiveness were chosen as the types of the outcomes. Force means that excessive force is needed to finish the job, posture means that awkward posture appeared while doing the job, and repetitiveness means that excessive force or awkward posture repeatedly appears in working process.

Table 6.3 Number of jobs investigated and with ergonomic problems

Year	Jobs investigated	Jobs with ergonomic problems
2007	122	70
2009	34	21
2010	164	105
2012	149	80
2013	480	300
2014	39	26
2015	110	73
TOTAL	1,098	675

6.4.2.1 Ergonomic problems

Ergonomic problems were classified into 12 groups: (1) bad tool or machine usability, (2) contact stress, (3) excessive force by the job characteristics, (4) noise, (5) bad visibility, (6) poor rack design, (7) poor work site layout, (8) poor workstation design, (9) short rest, (10) unnecessary movement, (11) vibration, and (12) others.

Bad tool or machine usability contains problems caused by a bad hand tool or machine that workers use until job done. Contact stress means that any boy contact stress with vehicle body or material appears. Excessive force by job characteristics means that high force is needed for finishing a job. Noise mainly occurred by tools and machines. Bad visibility causes awkward working posture and eye fatigue to do work right. Poor rack, work site, and workstation design cause various kinds of problems. They cause many postural stresses in various body parts including lower back, neck, hands, and upper arms. Short rest is also a

major problem in the plant. The unnecessary movement appears in several work sites. Vibrations caused by various kinds of hand tools and machines affect workers' health. Other problems included bad workplace such as engine room, legroom beneath the steering wheel, and bad working surface.

6.4.2.2 Subclass of ergonomic problems

For more detailed categorization, a subclass of ergonomic problems was identified by analyzing work site, job characteristics, and workers. Then, the subclass of the ergonomic problems was regrouped according to their properties. The subclass of ergonomic problems was classified into eight groups: (1) job characteristics, (2) hand tool or machine, (3) workstation, (4) workspace, (5) working surface, (6) rack, (7) work site, and (8) environment. Detailed subclass of ergonomic problems and the group they belong to are listed in Table 6.4. The number of jobs where each subclass of ergonomic problem occurred was also included in Table 6.4.

Table 6.4 The subclass of ergonomic problems

Subclass of ergonomic problems	
Bad tool usability	Heavy weight of tools
	Inappropriate shape of tools
	Bad grip of tools
Contact stress	Sharp parts
	Engine room
	Long distance to workstation
	High height of workstation
	High height of supporter
	Reverse side of a door
	Flank side
	Narrow space
	Inside the vehicle
	Non-locking of vehicle doors
Excessive force by the job characteristics	High torque demanded
	Weight bearing
	Push or pull
	Grasping finger force
	Fist hammering
	Open or close (trunk, hood, etc.)
	Pinch grip
	Heavy loads
Noise	Noise
Bad visibility	Screened space
	Bad lighting
Poor rack design	Wide range of rack height
	Low rack height

Table 6.4 The subclass of ergonomic problems

Subclass of ergonomic problems	
	High rack height
Poor work site layout	Inefficient layout or limitation on space
Poor workstation design	Long distance to workstation
	Short distance to workstation
	High work-surface height
	Low work-surface height
	Wide range of work-surface height
Short rest	Long work cycle
Unnecessary movement	Unautomated production line floor
Vibration	High torque demanded
Working surface	Lower side
	Flank side
	Upper side
	Reverse side of a door
Workspace	Legroom
	Engine room
	Inside the vehicle
	Narrow space

Due to the nature of the automobile assembly plant, job characteristics was the most occurred subclass. Ergonomic problems contained in the job characteristics were those occurred when assembling materials of the automobiles. Excessive force on the fingers and heavy loads are needed for assembling materials and MMH tasks. Moreover, long job cycle time induces fatigue with short rest time.

The problems related to the workstation and the rack were also identified. The vertical height of the workstation or the rack and horizontal distance to the workstation or the rack induced many ergonomic problems. Workers should do overhead jobs with a high working point, and their lower back should be bent with a low working point. They should stretch their arms with far workstation or rack.

Hand tools or machines used in the work site were the third most appeared subclass. The inappropriate shape and heavy weight of tools and machines led to the postural stress and fatigue in workers' body parts, especially in hands and fingers.

The next subclass was about the overall work site. Inefficient layout and unautomated production line floor gave rise to unnecessary walking and raised the fatigue in the lower extremity.

The last subclass was environmental factors including noise and bad lighting. Noise was mainly generated by vibrations of tools or machines and also by a conveyor belt of the assembly line. Intensive and continuous noise can harm workers' hearing. Moreover, cognitive performance can be hampered during exposure to the noise and vibration (Ljungberg & Neely, 2007).

6.4.2.3 Outcomes of the ergonomic problems on the body parts

In this study, due to the nature of the automobile assembly plant, force and repetitiveness appeared simultaneously in most cases. Almost all jobs were cyclic work with conveyor belt assembly lines, and the average

job cycle time was less than two minutes. Thus, repetitiveness came on with force in the majority of cases.

The Outcomes of ergonomic problems on the body parts are described in Table 6.5. The total number of reported outcomes was 2,043 cases. Among the various problems, the 'excessive force by the job characteristics' showed the largest number of outcomes with 831 cases. The second largest was 'poor workstation design' of 567 cases. The third and fourth largest problems were 'workspace' and 'bad tool usability' with 225 and 150 cases respectively. These were the main problems that need to be further investigated.

In the 'excessive force by the job characteristics', more than half of them, which are 611 cases, were related to the hand with mostly due to force and repetitiveness. It is obvious that most of the jobs demanding force are conducted by hands due to the characteristics of manufacturing plant. In the subclass of the problem, the largest number of cases were from grasping finger force of 271 cases followed by high torque demanded (213 cases) and heavy loads (103 cases). The majority of cases in the grasping finger force and high torque demanded affected hands with force and repetitiveness whereas the heavy loads did more on the elbow and back with force. Furthermore, this problem reported the largest number of outcomes in the hand and elbow throughout all problems. In this problem, 57% of the cases were related to the force, and about 35% of the cases were related to the repetitiveness unlikely that other problems were mostly related to the posture. This is because the problem itself is directly related to the force exertion, which is caused by distinct characteristics of each job.

The second problem, 'poor workstation design' reported more than half of the cases from the height of workstations. The number of cases in the subclass of the problems related to the height such as high, low, and a wide range of height of workstations was more than double of the number of cases in the short and long distance to workstations. The high height of workstation in which 185 cases were reported, had outcomes mostly in the shoulder, neck, and elbow with 78, 38, and 29 cases, respectively. On the other hand, more than half of the cases in the low height of workstation were reported from the back: more than 59% of the cases in this subclass of the problem. In this problem, the number of outcomes n the body parts such as the neck, shoulder, back, and low extremity was the largest throughout all the problems. Most outcomes of this problem were related to the posture of body parts with 84%. In this problem and subclass of the problem, this is because workers have to fit their body to the poor and non-adjustable workstation with uncomfortable and awkward working postures.

In the third largest problem 'workspace', the subclass of the problem was related to regions of assembly work such as the reverse side of a door, legroom, engine room, inside the vehicle etc. In this problem, the inside the vehicle, flank side, and reverse side of a door were the dominant subclass of the problem with 50, 48, and 38 cases in total 225 cases of the problem. The body part back and neck were the area where over 57% of the cases were reported. In addition, almost 80 % of the total cases were also posture type in this problem. Since the subclasses of the problems were related to the regions of assembly, it is expected that they caused various postural problems to workers such as bending and twisting of neck, body, and arms.

The fourth largest problem 'bad tool usability' had three subclasses of the problems: the inappropriate shape of tools, the heavy weight of tools, the bad grip of tools in descending order of the number of outcomes respectively. The inappropriate shape of tools had 96 cases mostly on the hand with the posture. The total number of outcomes on the hand was 121 and more than 80% of the cases. In this problem, almost 50% of the total cases were related to the posture. Since most of the tools are used and operated by hands, it showed a large number of outcomes on the hand, especially with the posture. This is expected that the subclasses of the problems lead to wrist flexion, extension or ulnar/radial deviation when using most of the tools.

The number of outcomes from the remainder was accounted for 13% of the total number of outcomes. Although they are small numbers, it is worthwhile to investigate the size and order of the outcomes in each problem and its largest subclass of the problem. They are listed in descending order with the numbers of outcomes in parenthesis as follows: 'vibration'/high torque demanded (79/79); 'contact stress'/ long distance to workstation (65/27); 'unnecessary movement'/ unautomated production line floor (41/41); 'poor work site layout'/ inefficient layout or limitation on space (34/34); 'poor rack design'/low rack height (31/21); 'bad visibility'/screened space (15/9); 'noise'/noise (4/4); 'short rest'/long work cycle (1/1). Among the above, the problem 'noise' had the subclass of the problem as noise. This is a special case in which the subclass of the problem, noise was derived from different characteristics of jobs such as large vibration, pressing work, welding work and etc.

Table 6.5 Ergonomic problems and its outcomes along the body part

Ergonomic problem	Subclass of ergonomic problems	Outcomes in the body part																	
		Neck			Upper arm			Lower arm			Hand			Back			Lower extremity		
		F	P	R	F	P	R	F	P	R	F	P	R	F	P	R	F	P	R
Bad tool usability	Heavy weight of tools	0	0	0	0	0	0	15	0	1	15	1	3	0	0	0	0	0	0
	Inappropriate shape of tools	0	6	0	0	1	0	2	3	0	14	56	13	0	1	0	0	0	0
	Bad grip of tools	0	0	0	0	0	0	0	0	0	7	6	6	0	0	0	0	0	0
Contact stress	Sharp parts	0	0	0	0	0	0	0	0	0	5	0	4	0	0	0	0	0	0
	Engine room	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0	0
	Long distance to workstation	0	0	0	1	1	0	1	2	0	0	0	0	1	4	0	15	2	0
	High height of workstation	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
	High height of supporter	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Reverse side of a door	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	Flank side	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	Narrow space	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Inside the vehicle	0	1	0	0	1	0	0	0	0	0	0	0	0	2	1	5	2	2

Table 6.5 Ergonomic problems and its outcomes along the body part

Ergonomic problem	Subclass of ergonomic problems	Outcomes in the body part																	
		Neck			Upper arm			Lower arm			Hand			Back			Lower extremity		
		F	P	R	F	P	R	F	P	R	F	P	R	F	P	R	F	P	R
	Non-locking of vehicle doors	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1
Excessive force by the job characteristics	High torque demanded	0	2	0	5	0	1	17	0	3	84	21	75	1	0	1	1	1	1
	Weight bearing	0	0	0	7	0	0	14	0	1	14	1	11	3	1	0	0	0	0
	Push or pull	0	0	0	6	0	0	22	0	6	8	0	7	11	0	0	0	0	0
	Grasping finger force	0	0	0	4	0	0	4	0	0	125	16	114	1	5	0	0	1	1
	Fist hammering	0	0	0	1	0	0	1	0	0	38	1	33	0	0	0	0	0	0
	Open or close (trunk, hood, etc.)	0	0	0	5	1	0	8	0	5	6	1	6	1	0	0	0	0	0
	Pinch grip	0	0	0	2	0	0	1	0	0	9	6	7	0	0	0	0	0	0
	Heavy loads	0	2	0	8	0	0	25	4	1	16	3	9	24	4	1	2	0	4
Noise	Noise	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	1
Bad visibility	Screened space	0	5	0	0	0	0	0	0	0	1	1	1	0	1	0	0	0	0
	Bad lighting	0	3	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0

Table 6.5 Ergonomic problems and its outcomes along the body part

Ergonomic problem	Subclass of ergonomic problems	Outcomes in the body part																	
		Neck			Upper arm			Lower arm			Hand			Back			Lower extremity		
		F	P	R	F	P	R	F	P	R	F	P	R	F	P	R	F	P	R
Poor rack design	Wide range of rack height	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
	Low rack height	0	0	0	0	0	0	4	0	0	0	0	0	4	13	0	0	0	0
	High rack height	0	0	0	2	2	0	1	2	0	0	0	0	1	0	0	0	0	0
Poor work site layout	Inefficient layout or limitation on space	0	1	0	0	0	0	3	0	0	0	0	1	1	1	0	0	0	27
Poor workstation design	Long distance to workstation	0	2	0	2	2	0	7	15	1	3	4	4	2	26	1	4	3	1
	Short distance to workstation	0	2	0	2	2	0	7	15	1	3	4	4	2	26	1	4	3	1
	High work-surface height	0	38	0	7	78	1	2	29	0	1	11	0	0	9	0	1	8	0
	Low work-surface height	2	32	0	1	2	0	1	7	0	3	2	2	2	116	0	6	16	3
	Wide range of work-surface height	0	3	0	0	5	0	0	5	0	1	2	2	0	9	2	0	3	1
Short rest	Long work cycle	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Unnecessary	Unautomated production line	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	1	37

Table 6.5 Ergonomic problems and its outcomes along the body part

Ergonomic problem	Subclass of ergonomic problems	Outcomes in the body part																	
		Neck			Upper arm			Lower arm			Hand			Back			Lower extremity		
		F	P	R	F	P	R	F	P	R	F	P	R	F	P	R	F	P	R
movement	floor																		
Vibration	High torque demanded	0	0	0	1	0	0	9	0	4	33	3	27	0	0	0	0	1	1
Working surface	Lower side	0	3	0	0	0	0	0	0	0	0	2	0	2	7	0	2	0	0
	Flank side	1	15	0	1	2	0	1	2	0	2	1	2	0	19	0	0	2	0
	Upper side	0	16	0	1	5	0	0	1	0	0	3	0	1	6	0	0	1	0
	Reverse side of a door	1	16	1	0	3	0	1	0	0	0	2	0	0	8	0	1	4	1
Workspace	Legroom	0	2	0	0	0	0	0	1	0	0	0	0	0	8	0	0	1	0
	Engine room	0	1	0	0	0	0	0	2	0	0	0	0	0	8	0	2	1	0
	Inside the vehicle	0	1	0	1	3	0	0	1	0	1	1	1	1	9	1	5	16	9
	Narrow space	0	3	0	0	0	0	0	0	0	4	3	3	0	0	0	0	0	0

Note. F denotes excessive force; P denotes awkward posture; R denotes repetitiveness.

6.4.3 Ergonomic intervention and related problems

6.4.3.1 Suggested ergonomic interventions

Ergonomic interventions were derived from the analysis of the ergonomic problems. Based on the results of analysis, the interventions tried to eliminate the detailed subclass of ergonomic problems. The ergonomic interventions suggested in this study were divided into two groups: (1) engineering, and (2) administrative interventions. The engineering interventions are mainly related to the workplace improvements such as adjusting workstation height or distance, improving the tool, and so on. The administrative interventions include work organization improvements, education, training, and medical treatments.

The whole ergonomic interventions developed in this study can be classified into eight groups, and they were as follows. (1) Workstation: adjusting the height of the workstation or distance to the workstation. (2) Rack or boxes for materials: adjusting the height of rack or boxes and improving the shape or functions. (3) Hand tool: improving shape, weight, and others, or providing additional ones. (4) Equipment: function improvement or installation of additional equipment. (5) Work site: revision of overall layout and environmental conditions. (6) Auxiliary equipment: provision of guards, chairs, and others. (7) Job modification: adjusting working method, rescheduling or re-divide jobs, and improving the specification of parts. (8) Education or training: in working methods or ergonomics. The whole ergonomic interventions suggested in this study are described in Table 6.6, and this table also includes expected effects of each intervention.

Table 6.6 Developed ergonomic interventions and its expected effects

Ergonomic intervention			Expected effects
Workstation	Height	Adjust floor height (upward/downward/subdivision) by installing toehold	Relaxation in back flexion; prevention of stretch of upper arm for overhead job
		Adjust workstation height (upward/downward) by installation of height adjustable electric lift	As above
		Install a workstation when there's no workstation	Relaxation in back flexion; prevention of squatting posture
	Distance	Adjust the slope of the floor	Relaxation in back flexion; prevention of stretch upper arms too far
		Adjust the angle between workstation and floor	As above
		Install a toehold on the floor	As above
Rack	Height	Adjust rack height (upward/downward) by installation of height-adjustable electric lift	Relaxation in back flexion when reaching to the bottom inside of the rack
	Shape or function	Automation of materials or parts supply by tilting the rack	Relaxation in back flexion when reaching to the end inside of the rack
		Change the direction of part loading	Make it easy to lift parts in the rack

Table 6.6 Developed ergonomic interventions and its expected effects

Ergonomic intervention			Expected effects
		Make easily movable by installation of the device (pusher); enlargement of wheels	Decrease power needed to push or pull the rack
		Automation of rack supply	No need for workers to push or pull the rack
Hand tool	Shape	Add an auxiliary handle to the impact tool	Lessen the shock to the hands caused by rebound and vibration
		Change the type of tool into appropriate type in-line, pistol, right angle, or adjustable type	Prevention of awkward posture of wrists and fingers (flexion or extension)
		Improve grip comfort by adjusting the circumference of the handle; adding a handle if there is no one	Decrease load in fingers to grip and operate the tools
		Optimize the area of the contact surface	Decrease power to insert or assemble the parts
		Chang the form factors of tools position/length of the trigger; length of the tool; angle between handle and tool	Decrease load in fingers or wrists by prevention of awkward posture of wrists and fingers (flexion or extension)
		Make connection between hose and tool flexible	Decrease power to operate and move the tools, in particular, working points are

Table 6.6 Developed ergonomic interventions and its expected effects

Ergonomic intervention			Expected effects
			diverse
	Weight	Provide lighter tools	Reduce load on hands and wrist during operation of tools
		Reduce the weight of the cables of tools by installing spring balance or hoist equipment	Reduce load on hands and wrist caused by cables during operation of tools
	Others	Adjust positions of the cables	Minimize work interruption caused by the connected cables
		Adjust the tension of the trigger	Minimize the power needed in fingers to operate the tools
		Install light to the tools	Prevention of the awkward posture to have a good look when it is dark
		Adopt oil pulse tool	Decrease vibration and noise caused by the tools
		Attach Velcro tape to pen and tool	Decrease hand fatigue while holding a pen; remove unnecessary walking
		Make fluids be spread uniformly by improving mouth of the container	Reduce hand fatigue to control the spread volume of the fluids

Table 6.6 Developed ergonomic interventions and its expected effects

Ergonomic intervention			Expected effects
		Attach vibration-proof pad to the tool	Lessen the shock to the hands caused by vibration
	Supplement	Provide batting glove	Lessen the shock to the hands caused by fist hammering
		Provide rubber/urethane/plastic hammer	As above
		Apply impact tool	As above
		Apply tool or jig for pushing	Reduce the hand stress caused by pinch grip
Equipment	Function	Minimize of equipment failure (hoist, rail, etc.)	Get rid of the body stress caused by equipment failures
		Install ergonomic chair to synchronized dolly	Workers can take rest effectively on the chair
		Synchronize equipment with assembly line	Reduce the stress to adjust the equipment to appropriate place
		Improve usability of handling equipment by adopting power grip; adjusting the length of the handle; adjusting the position of buttons or	Decrease load in hands to grip and operate the tools

Table 6.6 Developed ergonomic interventions and its expected effects

Ergonomic intervention		Expected effects
	triggers	
	Install aids to back up a forklift (rear-view camera)	Prevention of twisting of back or neck when looking back
	Improve own functions of equipment or machine itself	Minimize the awkward posture and musculoskeletal load
Supplement	Install a hoist or a lift for helping MMH tasks	Remove MMH task
	Install a lift for adjusting height	Remove awkward posture such as back flexion
	Adopt conveyor system to floor	Remove unnecessary walking; minimize the burden on the lower extremities
	Install a dolly synchronized with assembly line	As above
	Install pressing-in equipment	Minimize the finger fatigue for the job
	Equipment for semi-automation of jobs (panel loading; roof sealing; nut assembly; oil injection)	Reduce the power in hands and fingers for the jobs

Table 6.6 Developed ergonomic interventions and its expected effects

Ergonomic intervention			Expected effects
Work site	Overall layout	Provide ample work site by changing position of workstation, rack, and equipment; extension of the workplace	Remove awkward posture caused by small workplace
		Establish passage for part racks such as pallet rail	
	Environmental condition	Dust cleaning	Cleaning bad air by removing dust from materials
		Change the position of light source	Remove awkward posture caused by bad lighting
Additional equipment	Guards	Provide guards wrist; belly/side; knee; hip; neck; arm; fingers	Lessen the shock or fatigue caused by awkward posture or excessive force
		Provide gloves with higher frictional force	Reduce power needed in pinch grip
		Provide vibration-proof gloves	Lessen the shock or fatigue caused by vibration
		Provide wire mesh gloves	Prevention of cut from sharp parts
	Chair	Provide a low chair	Prevention of squatting posture

Table 6.6 Developed ergonomic interventions and its expected effects

Ergonomic intervention			Expected effects
		Provide a standing chair	Minimize the burden of lower extremities
		Provide a chair with backrest	Workers can take rest or do the jobs with remaining seated
	Others	Install the mirror or display	Remove neck twisting to see rear side
		Attach tool/part pouch to waist of workers	Remove unnecessary walking; decrease hand fatigue while holding it
		Provide lubricant oil	Help with assembling parts
		Install a wastebasket at the bottom	Remove unnecessary walking
		Spread a mat for fatigue prevention	Decrease fatigue in lower extremities
		Install a handle on the tray	Minimize stress in fingers and wrists
Job modification	Working method	Encourage to follow operation standards do work at the regular position; use installed equipment or machine	Balance the burden among body parts

Table 6.6 Developed ergonomic interventions and its expected effects

Ergonomic intervention		Expected effects
	Change the working position for better posture divide into left and right sides for preventing job inside a vehicle; make workers do jobs inside a vehicle	Improve working posture at better working position
	Change working method for less stress or fatigue push rather than batting or pulling; use right and left hands in turn; do tentative assembly before full assembly; use both hands when MMH; divide and move; work with one leg supported inside the vehicle	Improve working posture; lessen fatigue in certain body part
	Change order of jobs (workers)	Make it easier to do jobs
	Change arrangement of parts in the rack locate parts with low demand at the bottom	Minimize of back flexion to pick up
Job rescheduling	Reduce rotation cycle	Balance physical stress among body parts through job rotation
	Rotation between directions of the work left and right side	As above (especially between left and right body parts)
	Rotation between divisions if needed	As above

Table 6.6 Developed ergonomic interventions and its expected effects

Ergonomic intervention		Expected effects
Job redistribution	Divide a job into two jobs left/right; top/bottom; front/rear	It makes rotation scheduling effective
	Do job in pairs (two workers)	Avoid “do extremely hard work and take a rest”
	Rearrange the jobs add more workers for the division; change the order; change the division	If additional worker is needed, Assign more worker to the job
	Assign workers with considering the anthropometric data of workers (height; painful body parts; etc.)	Minimize of awkward posture caused by inappropriate work-surface height
Specification improvement	Alter properties of parts shape, material, handle, coupling	Reduce stress on fingers and hands
	Install an oven to heat parts for easy assembly	As above
	Quality control of parts or materials defective management, reduce dust occurrence, the degree of equal painting	General improvements
	Provide materials in order of the assembly line	Remove unnecessary walking

Table 6.6 Developed ergonomic interventions and its expected effects

Ergonomic intervention			Expected effects
		Reduce a unit of box packing	Remove MMH (heavy weight load)
Education or training	in working method	Education on operation standards	Follow working standards
		Training on new equipment or machines	Follow working standards
	in Ergonomics	Education on musculoskeletal stretching	Minimize ergonomic burden by stretching and effective relaxation
		Education on wrist exercises before work	As above
		Education on general ergonomics and occupational safety	Help to avoid harmful action or posture

As described in Table 6.1, Denis et al. (2008) classified interventions into six groups: environment, physical layout, equipment, training, work organization, and rehabilitation. Compared with Denis et al. (2008)'s study, we did not suggest interventions in work organization and rehabilitation.

6.4.3.2 Appropriate ergonomic interventions for the ergonomic problems

Ergonomic interventions were developed after analyzing the ergonomic problems. Detailed ergonomic problems and appropriate interventions are listed up in Table 6.7.

In this study, we firstly consider interventions that can resolve the ergonomic problems directly. For example, 'adjusting floor height upward by installing toehold or electric lift' can resolve the 'low height of the working point' directly. Interventions that can resolve the problems indirectly such as 'providing guards including gloves, protectors, supporters', 'minimization of equipment failure', and 'dust cleaning' were suggested after agonizing over the direct interventions.

Table 6.7 Ergonomic problems and appropriate ergonomic interventions

Ergonomic problems		Ergonomic interventions
Job characteristics	High force on the fingers	Hand tool (shape; weight; others; supplement), Equipment (supplement), Work site (overall layout), Additional equipment (guards), Job modification (working method; specification improvement)
	High torque demanded	Hand tool (shape; others; supplement), Additional equipment (guards), Job modification (specification improvement)
	Fist hammering	Hand tool (supplement), Additional equipment (guards), Job modification (working method; specification improvement)
	Heavy loads	Rack (height; shape or function), Equipment (function; supplement), Work site (overall layout), Additional equipment (guards), Job modification (working method; job rescheduling; job redistribution; specification improvement)
	Push or pull	Rack (shape or function), Equipment (function; supplement), Additional equipment (guards)
	Weight bearing	Equipment (function; supplement), Additional equipment (guards), Job modification (specification improvement)
	Pinch grip	Rack (shape or function), Hand tool (shape; supplement), Equipment (supplement), Additional equipment (guards), Job modification (working method)
	Open or close (trunk, hood, etc.)	Equipment (function; supplement), Additional equipment (guards), Job modification (working method)
	Sharp parts	Additional equipment (guards), Education or training (in working method)
	Long work cycle	Job modification (working method; job rescheduling; job redistribution; specification improvement), Education or training (in working method)

Table 6.7 Ergonomic problems and appropriate ergonomic interventions

Ergonomic problems		Ergonomic interventions
	Non-locking of vehicle doors	Additional equipment (others), Job modification (working method; specification improvement)
Workstation	Low height of the working point	Workstation (height; distance), Hand tool (shape; others), Equipment (function; supplement), Work site (overall layout), Additional equipment (guards), Job modification (job redistribution)
	High height of the working point	As above
	Wide range of height	As above
	Short distance to workstation	Workstation (distance), Hand tool (shape; others), Equipment (function; supplement), Work site (overall layout), Additional equipment (guards)
	Long distance to workstation	As above
Bad tool usability	Inappropriate shape of tools	Hand tool (shape; supplement), Equipment (function)
	Heavy weight of tools	Hand tool (shape; weight; others; supplement), Equipment (function; supplement), Work site (overall layout)
	Bad grip of tools	Hand tool (shape; others; supplement), Equipment (function), Additional equipment (guards), Job modification (working method)
Work site	Unautomated production line floor	Equipment (supplement), Work site (overall layout), Additional equipment (others), Job modification (job redistribution)
	Inefficient layout or limitation on space	Work site (overall layout), job modification (working method; job redistribution)
Working surface	Flank side	Hand tool (shape), Equipment (supplement), Additional equipment (guards)

Table 6.7 Ergonomic problems and appropriate ergonomic interventions

Ergonomic problems		Ergonomic interventions
	Reverse side of a door	Hand tool (supplement), Equipment (supplement), Additional equipment (guards)
	Upper side	Hand tool (shape), Equipment (supplement), Additional equipment (guards; chair; others)
	Lower side	Hand tool (supplement), Equipment (supplement), Additional equipment (guards)
Workplace	Inside the vehicle	Hand tool (others), Equipment (function), Additional equipment (guards), Job modification (working method; job rescheduling; job redistribution), Education or training (in working method)
	Engine room	Workstation (height; distance), Hand tool (shape; supplement), Additional equipment (guards), modification (working method)
	Legroom	Hand tool (shape), Equipment (function; supplement), Additional equipment (guards)
	Narrow space	Hand tool (shape), Equipment (supplement), Work site (overall layout), Additional equipment (guards), Job modification (working method; job redistribution; specification improvement)
	Screened space	Additional equipment (others)
	High height of supporter	Workstation (height; distance), Hand tool (shape), Work site (overall layout), Additional equipment (guards), Job modification (working method)
Rack	Low height	Rack (height; shape or function), Hand tool (shape; supplement), Equipment (function; supplement), Work site (overall layout), Additional equipment (guards), Job modification (job redistribution)
	High height of rack	As above
	Wide range of height	As above

Table 6.7 Ergonomic problems and appropriate ergonomic interventions

Ergonomic problems		Ergonomic interventions
Environment	Bad lighting	Hand tool (others), Additional equipment (others), job modification (working method; job redistribution)
	Noise	Hand tool (supplement; others)

6.4.4 A follow-up study

Workplace analysis identified the need for a significant number of ergonomic changes, and appropriate changes were carried out within the financial constraints of the company. Among suggested interventions, total 27 interventions were adopted to 77 jobs at the automobile assembly plant. The interventions and the number of jobs implemented are listed in Table 6.8. The implemented interventions were about hand tool, job modification, workstation, rack, and additional equipment. The comparisons before and after interventions were conducted regarding working posture and ergonomic risk level. Total 77 pairs of jobs were compared to grasp the effectiveness of the interventions. The results are reported according to the type of intervention in the following sections.

Table 6.8 The number of jobs implemented in the plant

Ergonomic intervention		Number of jobs
Workstation	Height	6+4
	Distance	0
Rack	Height	7
	Shape or function	2
Hand tool	Shape	7+3
	Weight	0
	Others	2+1+1
	Supplement	5+3+2
Equipment	Function	0
	Supplement	3+2
Work site	Overall layout	0
	Environmental condition	0
Additional equipment	Guards	6
	Chair	1+1
	Others	3+1+1
Job modification	Working method	9+3
	Job rescheduling	2
	Job redistribution	0
	Specification improvement	1+1
Education or training	in working method	0
	in Ergonomics	0

6.4.4.1 Workstation

Interventions about workstation could be divided into two groups: 'adjust workstation height (upward/downward)' and 'adjust floor height (upward/downward/subdivision)'. All interventions were about the vertical height rather than the horizontal distance. Two examples of this type of interventions are illustrated in Figure 6.2.

According to the results, only difference in back flexion was statistically significant (t = 3.876, df = 9, p = .004). The degree of back flexion decreased from 21.02 to 10.72 degree. Moreover, decreases were observed in the angles of neck flexion and knee flexion. It means that by adopting this intervention, there is no need to flex the trunk too much to reach to the lower point. The whole changes in the working posture along the body parts are charted in Figure 6.3. Figure 6.4 illustrates the decrease in the degree of back flexion as a consequence of the interventions.

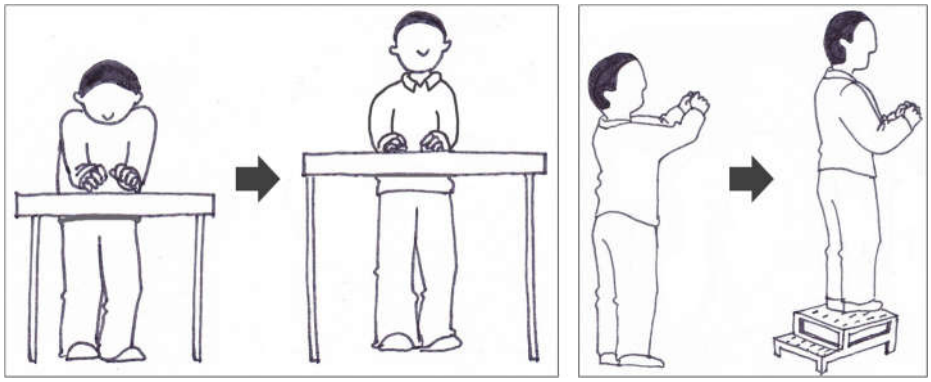

Figure 6.2 Adjusting the height of the workstation

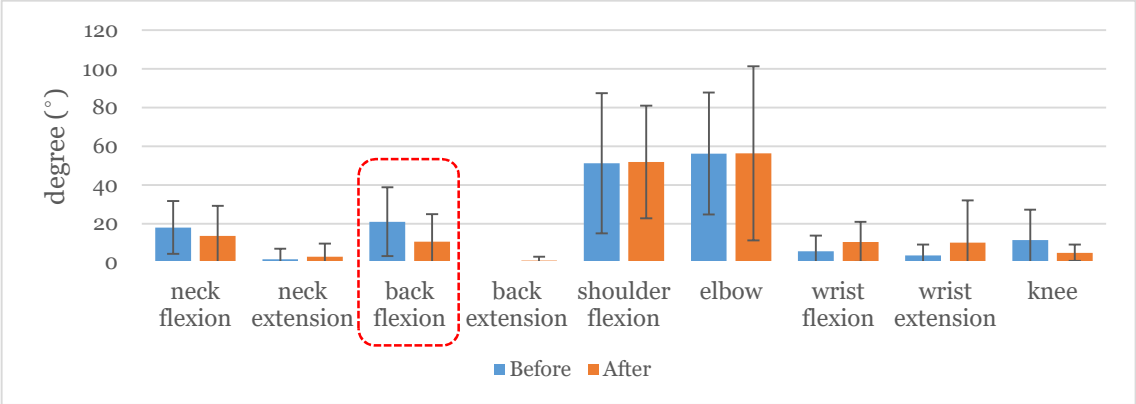

Figure 6.3 Changes in the working posture - workstation

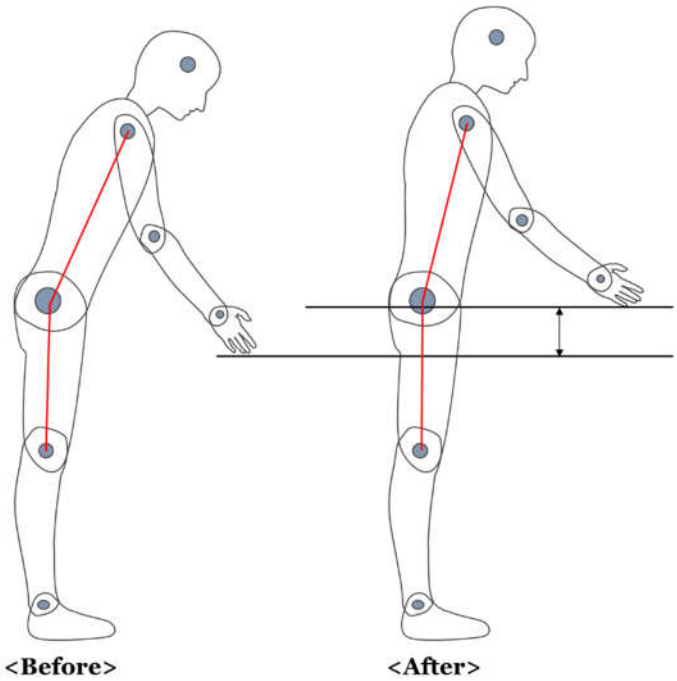

Figure 6.4 Decrease in the degree of back flexion

Differences in the ergonomic risk level according to the assessment methods were not statistically significant. However, the scores were consistently lower after the interventions in average (Figure 6.5).

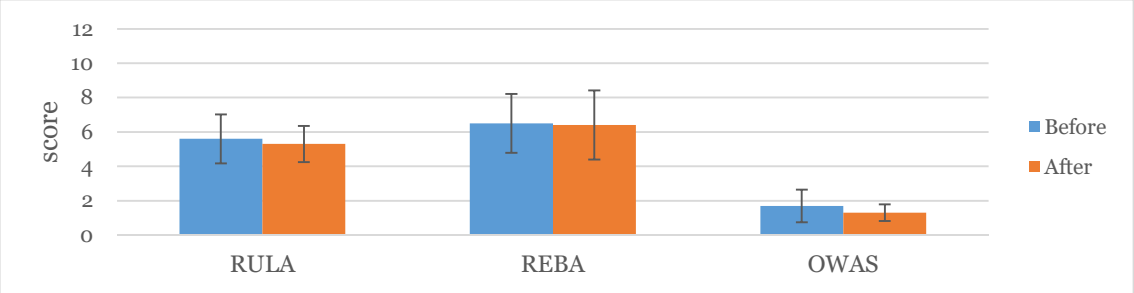

Figure 6.5 Changes in the ergonomic risk level - workstation

6.4.4.2 Rack

Interventions related to the rack were about the rack height and function. Most of interventions were implemented to make too low height of racks or material boxes higher. Significant differences appeared in neck flexion (t = 3.156, df = 8, p = .013), back flexion (t = 4.785, df = 8, p = .001), and shoulder flexion (t = 2.931, df = 8, p = .019). Although, the differences were not significant, the angles decreased in elbow flexion and wrist flexion (Figure 6.6).

It was similar to the case of the workstation, and the effects were more dramatic in the case of the rack. It is thought that with lower height of rack, workers should flex their trunk more to reach the lowest point of the rack which is normally the floor level. Figure 6.7 illustrates the decreases in the degree of the neck, back, and shoulder flexion.

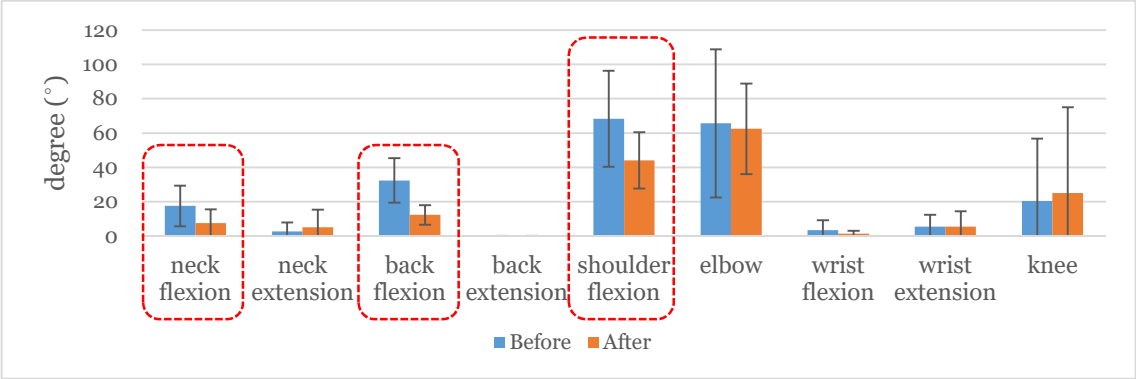

Figure 6.6 Changes in the working posture - rack

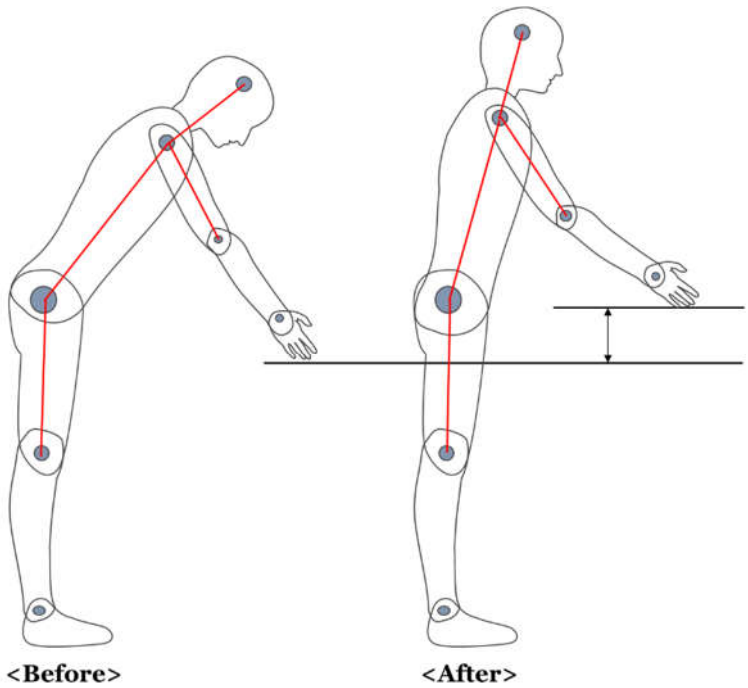

Figure 6.7 Decreases in the degree of neck, back, and shoulder flexion

Differences in the ergonomic risk level were significant in RULA score (t = 2.600, df = 8, p = .032) and REBA score (t = 5.292, df = 8, p = .001) (Figure 6.8). The results can be inferred that improvements of the rack height can reduce the ergonomic risk levels effectively.

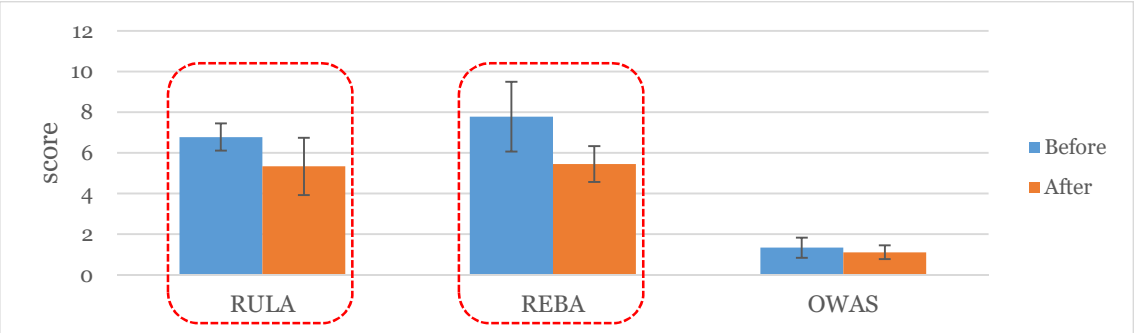

Figure 6.8 Changes in the ergonomic risk level - rack

6.4.4.3 Hand tool

Interventions about hand tool were implemented in various ways. Firstly, the shapes of tools were changed into more appropriate forms, and secondly, if needed, new hand tools were provided to the workers. An example of this type of interventions is illustrated in Figure 6.9.

The significant effects of changing form factors or type of tools were observed in only elbow flexion (t = 2.860, df = 9, p = .019). In the case of changing the pistol type tools to right angle type, the need to stretch arms to the far point can be eliminated. It seemed that improvements on hand tools did not affect the posture of the neck or back significantly (Figure 6.10). Moreover, in the posture of the wrist, all angles of flexion,

extension, and radial extension became smaller than before interventions. Figure 6.11 illustrates the decreases in the degree of shoulder and elbow flexion.

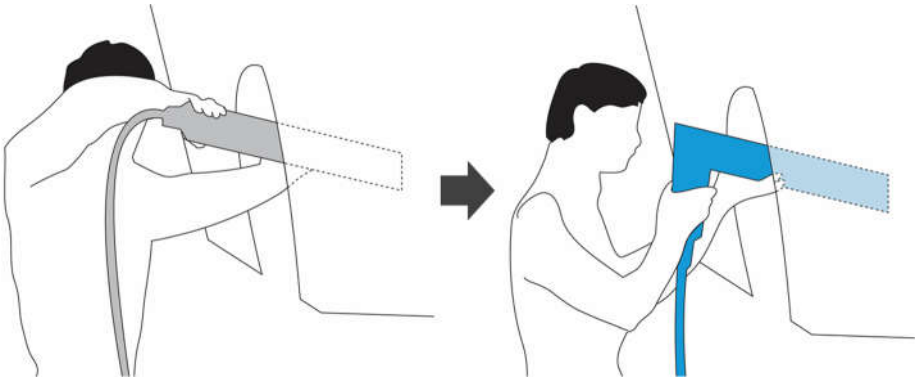

Figure 6.9 An example of tool shape

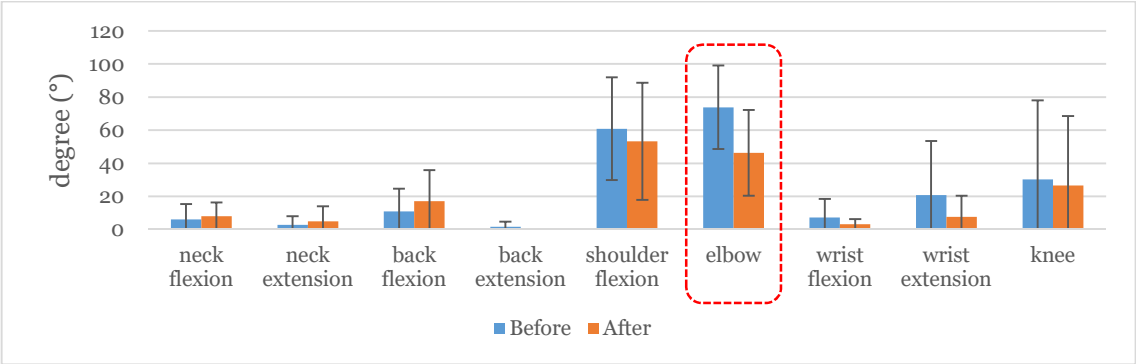

Figure 6.10 Changes in the working posture - tool shape

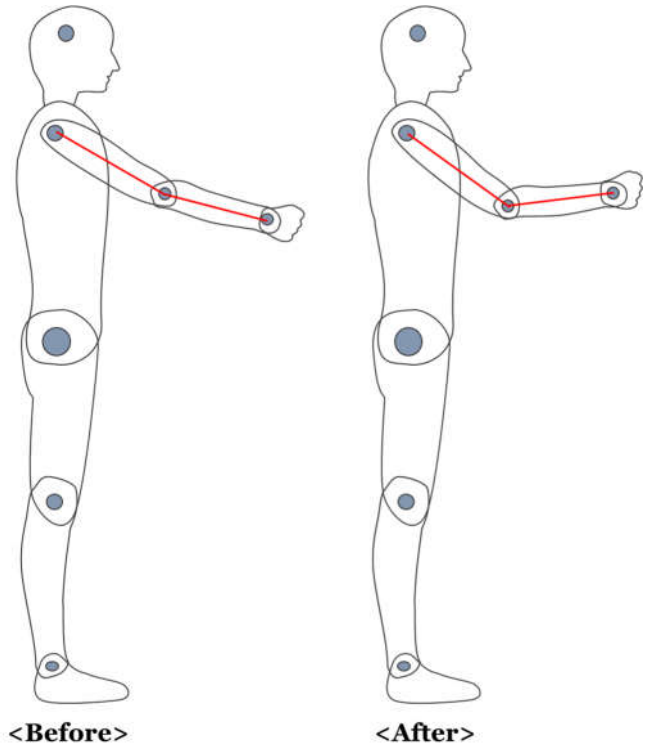

Figure 6.11 Decreases in the degree of elbow and shoulder flexion

Differences in the grand score of the assessment methods regarding the ergonomic risk level were significant in only RULA score (t = 2.283, df = 9, p = .048). However, both REBA and OWAS score decreased too (Figure 6.12).

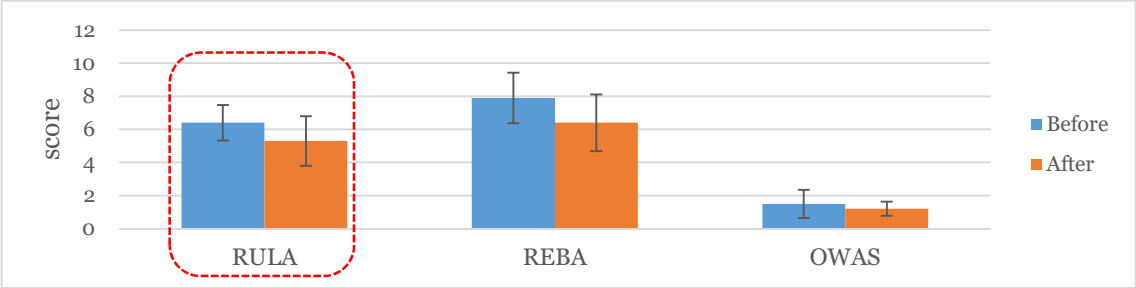

Figure 6.12 Changes in the ergonomic risk level - tool shape

In the case of providing new tools, there was no statistically significant difference. With a closer look at the data, the small sample size might work. The angles of the shoulder flexion, elbow flexion, wrist flexion, wrist extension, and wrist radial extension all decreased (Figure 6.13). Especially, a provision of the tool for push-in helps workers in force perspective rather than in posture perspective. Hence, the difference regarding the posture might not reflect the improvements.

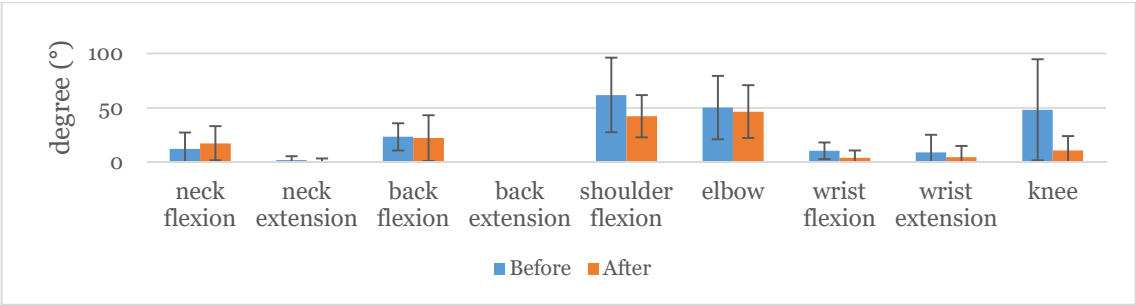

Figure 6.13 Changes in the working posture - new tool

No statistically significant difference was obtained in the ergonomic risk level. Although the grand score declined in every method, however, none of them was significant (Figure 6.14).

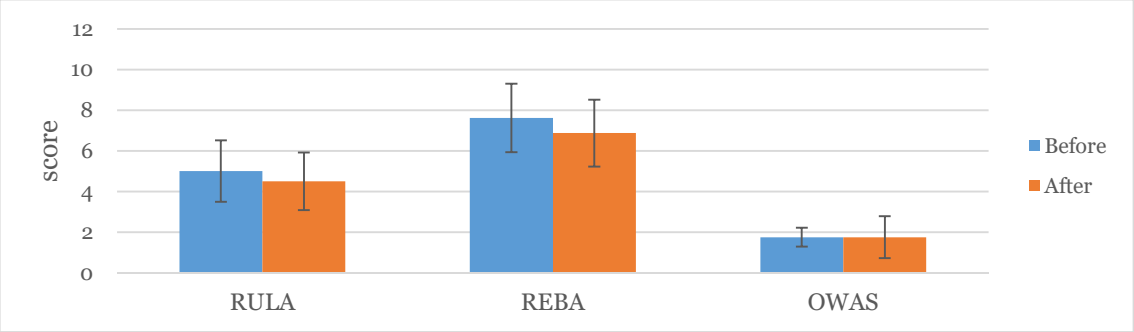

Figure 6.14 Changes in the ergonomic risk level - new tool

6.4.4.4 Equipment

Interventions related to the equipment were mainly about adopting new equipment such as a hoist, manipulator, and synchronized dolly. These kinds of equipment can help both in terms of force and posture when doing MMH or lifting tasks. An example of the installation of hood or trunk lifter is shown in Figure 6.15.

According to the results, there was no significant difference in any angle of body joint and ergonomic risk level. However, the degree of neck flexion, back flexion, elbow flexion, and wrist extension declined (Figure 6.16-17).

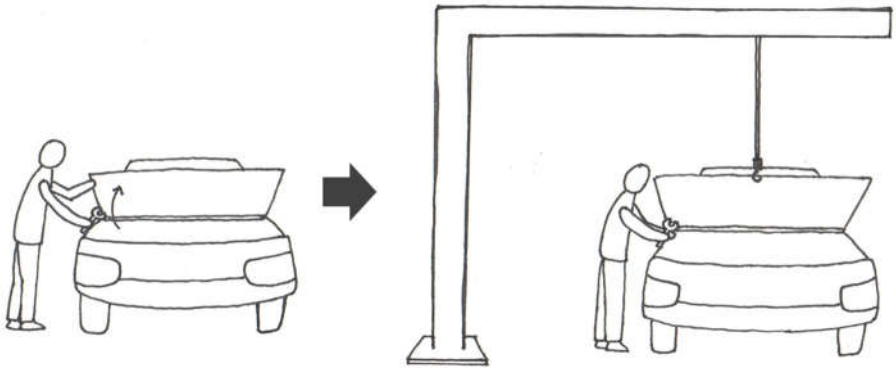

Figure 6.15 An example about hood/trunk lifter installation

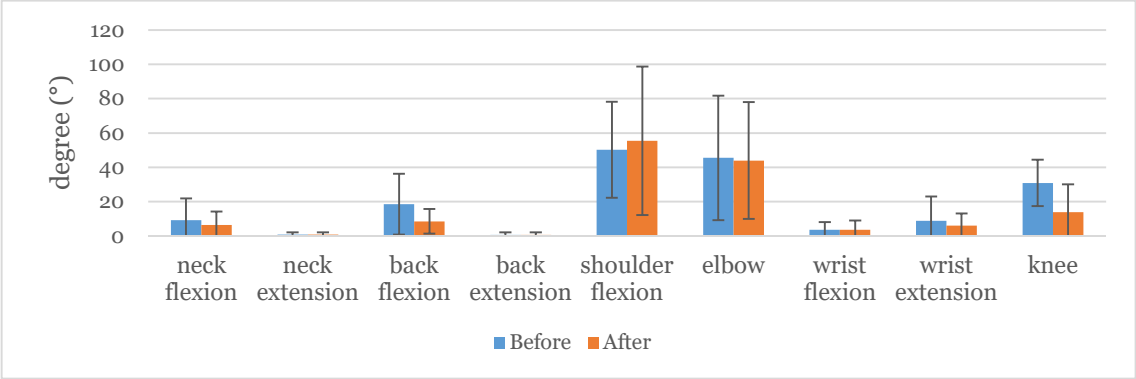

Figure 6.16 Changes in the working posture - equipment

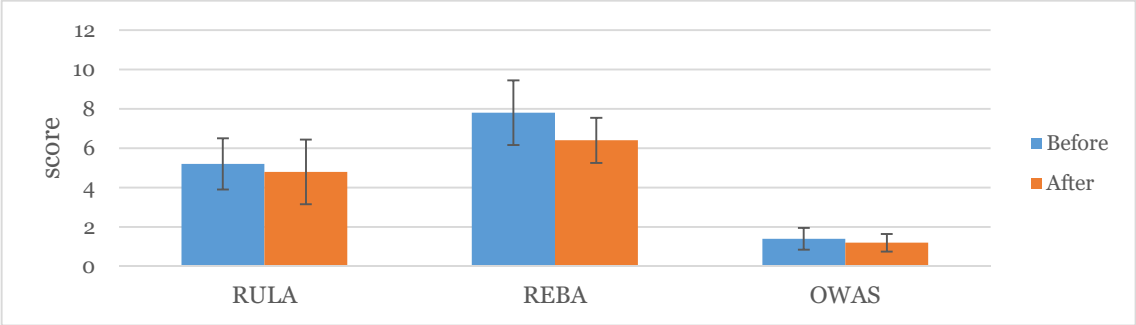

Figure 6.17 Changes in the ergonomic risk level - equipment

6.4.4.5 Additional equipment

Implemented interventions about additional equipment were divided into two categories: (1) provision of guards for the wrist, back, and neck, and (2) provision of the chair. In the case of the guards for protection, none of the angles and scores vary significantly along the body parts. Although the most angles and scores decreased, angles of the neck extension and wrist extension became higher than before the interventions. It is thought that with the guards, workers set their mind at ease on the one hand (Figure 6.18-19).

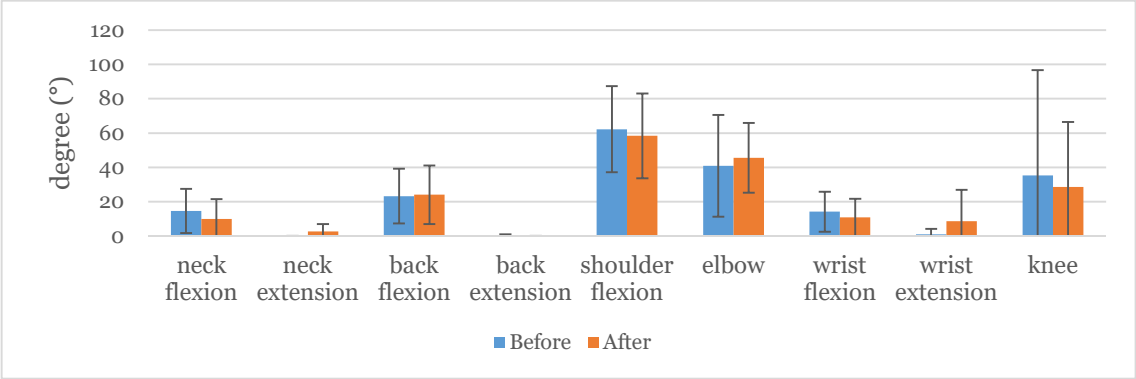

Figure 6.18 Changes in the working posture - provision of guards

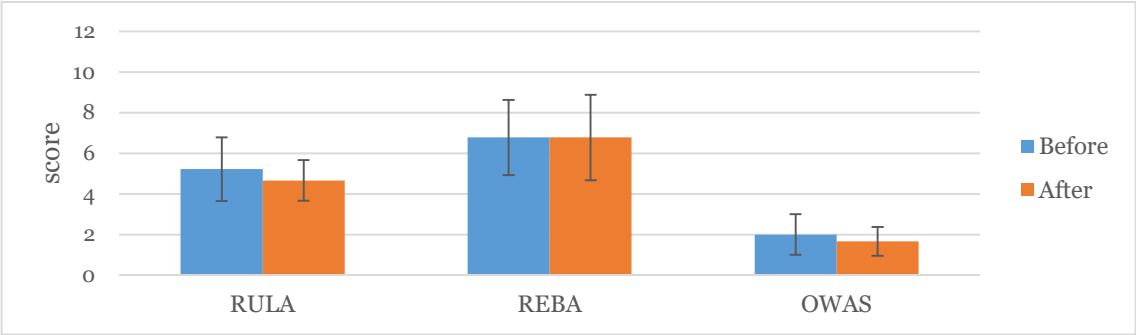

Figure 6.19 Changes in the ergonomic risk level - provision of guards

In the case of the provision of chairs, the overall body posture changed directly, from standing or squatting to seating. With a closer look at the angle of the knee, the degree decreased in the jobs with squatting posture, however, in the jobs with standing posture, the degree rather increased. According to the results in the ergonomic risk level, although

they were not significant, every score decreased after providing the chairs (Figure 6.20-21).

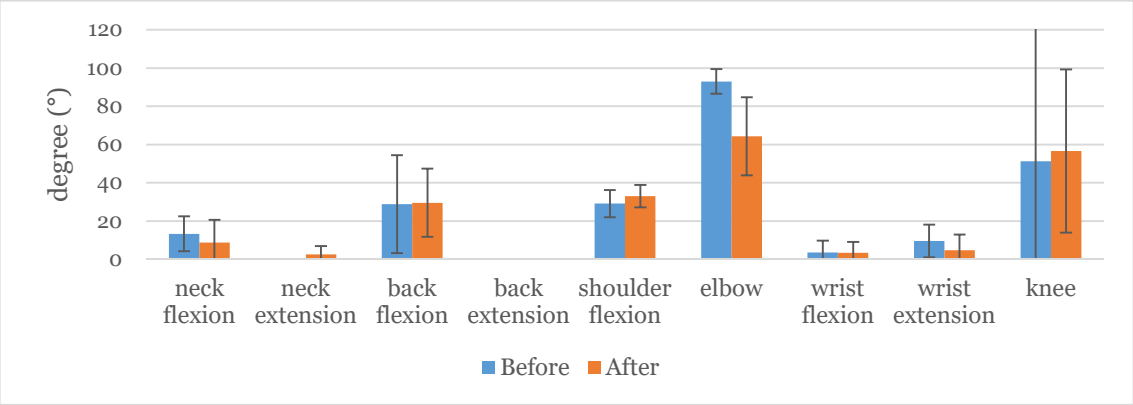

Figure 6.20 Changes in the working posture - provision of chairs

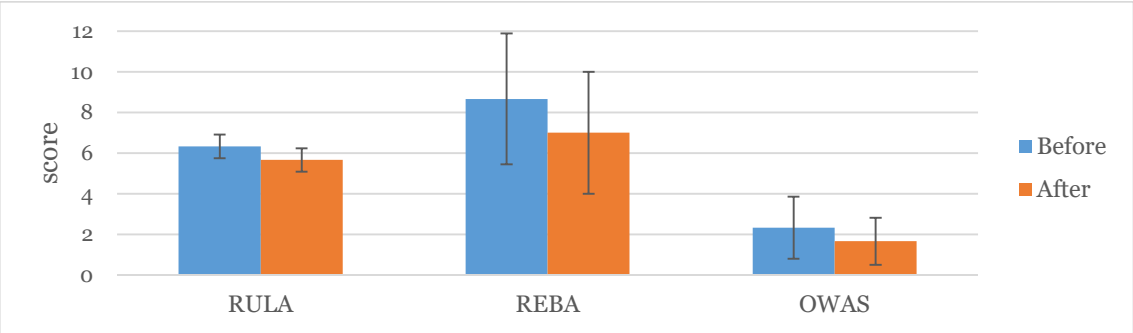

Figure 6.21 Changes in the ergonomic risk level - provision of chairs

6.4.4.6 Job modification

Interventions about job modification can be categorized into three groups: working method, job rescheduling, and specification improvement. Implementing job rescheduling and specification improvement did not affect the working posture in this study. Hence, we only analyzed the results of the interventions of working method. Figure 6.22 shows an example that changed working method is adopted to do jobs whose working surface is rear side.

There were significant differences in back flexion (t = 2.946, df = 11, p = .013), neck flexion (t = 2.315, df = 11, p = .041), and shoulder flexion (t = 2.228, df = 11, p = .048). Moreover, although it was insignificant, the degree of the posture decreased in wrist extension and knee flexion (Figure 6.23). Figure 6.24 illustrates that the decreases in the back, neck, and shoulder flexion. It can be observed that the average posture changed to more comfort state in the neck, back, shoulder, and elbow.

In terms of the ergonomic risk level, the grand score of RULA (t = 3.924, df = 11, p = .002) and REBA (t = 2.545, df = 11, p = .027) significantly decreased (Figure 6.25).

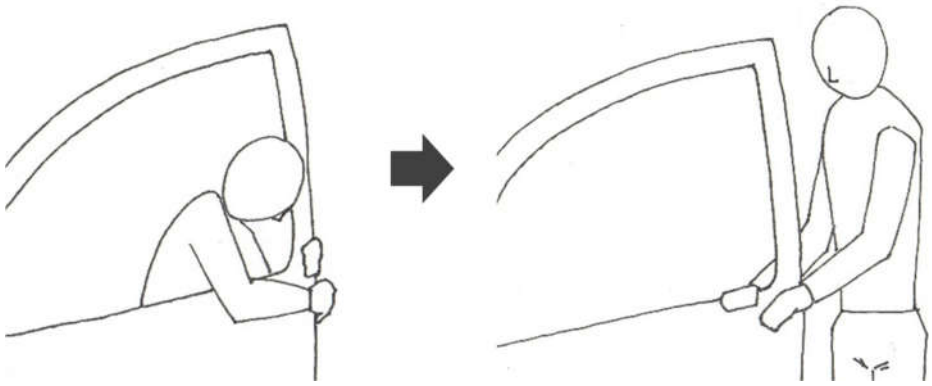

Figure 6.22 Change in working method to do rear-side jobs

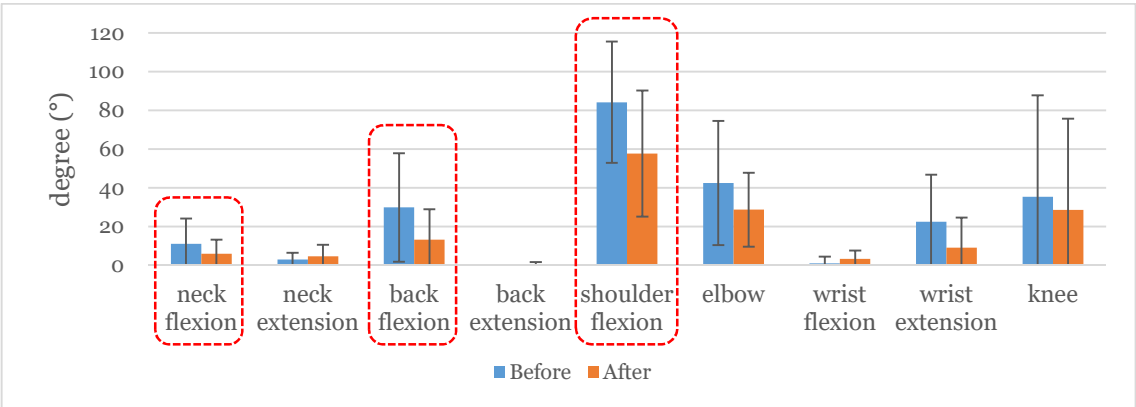

Figure 6.23 Changes in the working posture - job modification

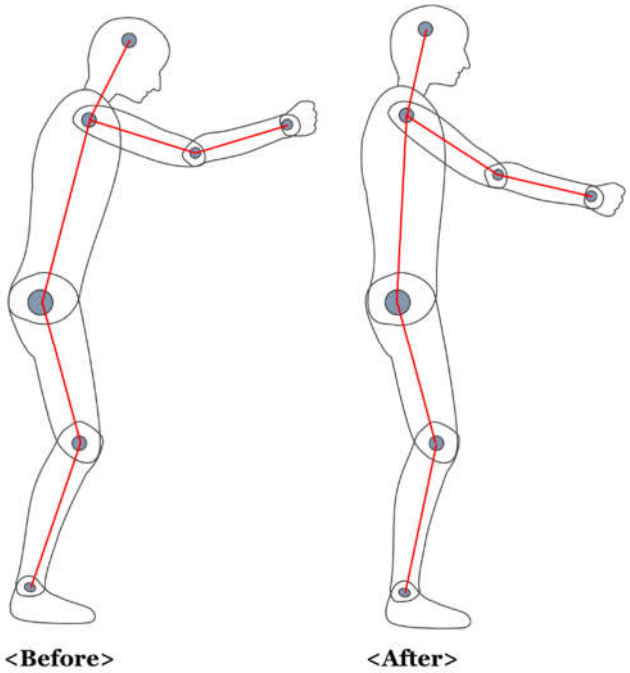

Figure 6.24 Decreases in the neck, back, shoulder, elbow flexion

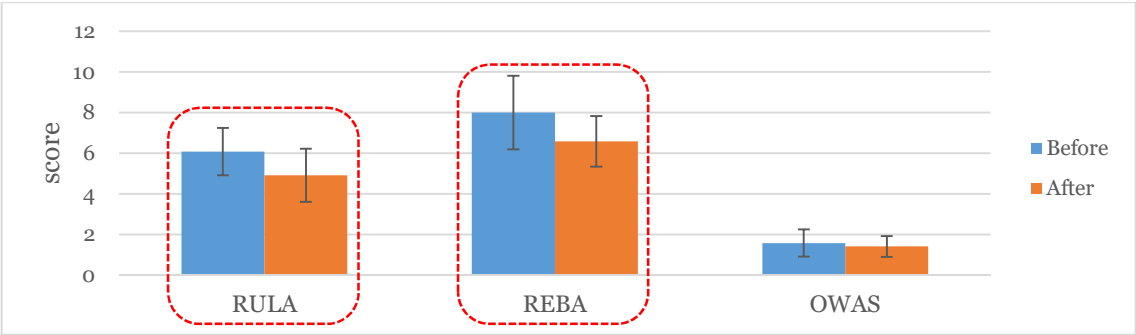

Figure 6.25 Changes in the ergonomic risk level - job modification

In a modification of working methods, the differences were generally huger than other interventions. It is thought that one of the reason is that we analyzed the effectiveness of the interventions based on the working posture. Normally, improving the working methods might directly affect the workers' posture. Hence, dramatic change was observed in this kind of interventions.

6.5 Discussion

Traditional ergonomic interventions in the industry have focused on *microergonomics* that mainly considered the workstation or physical environment for individual workers (Hendrick & Kleiner, 2005). Although it is still effective, the microergonomic approach has some disadvantages in not considering a context of information, procedures, constraints, incentives, authority, status, and expectations that arise from human organizations. To overcome these disadvantages, in recent decades, there have been emphasized on a *macroergonomic* approach that also considers work systems in a larger perspective. The macroergonomic interventions and improvements also focus on larger social and organizational factors including actions such as increasing employee involvement (Imada & Feiglstok, 1990).

Participatory ergonomics, a method whereby employees are centrally involved from the beginning, is one of the most commonly used methods for taking a macroergonomic approach (Wickens et al., 1998).

However, the reality in South Korea is that many plants were not constructed considering ergonomics or human factors from the beginning. Moreover, they have not been well managed and controlled. Hence, in this study, we adopted the microergonomic approach rather than macroergonomic approach. In addition, to take the advantages of the participatory ergonomics, we designed this study with practitioners in the automobile assembly plant from the very beginning and during whole investigations.

This study aimed to figure out the ergonomic problems in an automobile assembly plant and develop the appropriate interventions.

To this end, we carried out thorough investigations of the work site seven times. Through a direct survey and field measurements, various kinds of ergonomic problems were found. Then, the outcomes of the problems were analyzed from the force, posture, and repetitiveness perspective along the body parts. To resolve the ergonomic problems, appropriate interventions were derived and suggested. Lastly, the effectiveness of the interventions was examined based on the working posture and ergonomic risk level calculated by RULA, REBA, and OWAS.

In the previous literature, ergonomic interventions were suggested to deal with the ergonomic problems at the work site including factory, office, and etc. (Caroly et al., 2010; Denis et al., 2008; Goggins et al., 2008; Gravina et al., 2007; Kilbom, 1988; Mahmud et al., 2012; Pillastrini et al., 2010; Rubenowitz, 1997; Silverstein & Clark, 2004; Westgaard & Winkel, 1997). The efficacy and usefulness were verified and validated by this literature. Karsh et al. (2001) conducted a systematic review to grasp the efficacy of the ergonomic interventions. To this end, He examined the following six types of ergonomic interventions: (1) provision of a back belt, (2) training, (3) change in tools or a single technology, (4) exercise, (5) job design, and (6) multiple components. According to the results of his study, 84% of all of the studies found some positive results, although the majority had mixed results.

Despite many attempts to reveal the effectiveness of the ergonomic interventions, there were a few studies that had a rigorous methodology regarding study design. The studies conducted under laboratory settings could not reflect all the variables in the real world, and it is not quite high quality regarding the reality and pragmaticality. When a study was

carried out under the real field setting, a company that is willing to allow research to be conducted within its walls is often unlikely to allow 'control' groups.

This study tried to overcome this practical problem mentioned above and has its contributions from an empirical perspective. We conducted pre-intervention phase, intervention phase, and post-intervention phase iteratively. Through this procedure, the quasi-control study could be conducted. Although the ergonomic interventions were developed by the ergonomic approach in academic articles and textbooks, their usefulness and efficacy were not verified well enough in the real world setting. The results of this study proved usefulness and effectiveness of ergonomic interventions from ergonomic standpoint by performing a follow-up study targeting to an automobile assembly jobs.

The data dealt with in this study were only about the automobile assembly jobs. Automobile assembly plant contains various kinds of jobs in terms of job characteristics and has some representative properties of a manufacturing industry. However, the results of this study cannot be generalized or adapted to every kind of jobs or industries. When looking into the relative frequency of an overall body posture evaluated in this study is as follows: stand (41.3%), stoop (24.7%), squat (2.1%), overhead (20.5%), seat (7.0%), and inside the vehicle (4.4%). The ratio of the jobs in sitting posture and squatting was relatively low. Hence, ergonomic problems and interventions related to specific conditions might be pooled out and derived. In this regard, further studies dealing with jobs that have different properties and conditions need to be done shortly.

Chapter 7. Developments of Working Postural Analysis System and WMSDs Management System

For effective work-related musculoskeletal disorders management on a work site, it is crucial that a manager grasps the current state of the work-related musculoskeletal disorders. To understand the dynamic state of the work-related musculoskeletal disorders, whole information on both work site and workers should be managed well. Hence, for figuring out realistic ergonomic problems and developing appropriate interventions, effective and efficient management of the information should be undertaken.

In this study, two desktop application systems were developed. One was a working a postural analysis system, and the other was a web-based database system for work-related musculoskeletal disorders management. These two systems are expected to help and satisfy both practitioners and academic researchers regarding pragmaticality and efficiency.

Keywords: work-related musculoskeletal disorder, working posture analysis system, web-based, management system

7.1 Introduction

7.1.1 Motivation of the study

In South Korea, work site investigation in terms of ergonomics and MSDs should be conducted every three years, and it's regulated by Korean occupation safety and health acts. Hence, every company in S. Korea investigates work site every three years at least. However, the work site investigation has several critical limitations in general.

First, the investigation was considered as a one-time event. In most cases, gathered and analyzed data were used in the right investigation only. Thus, continuous tracking or follow-up cannot be measured. Even though, a follow-up study, a type of longitudinal study, should be conducted to identify the dynamic course of the status of the work site and the effectiveness of interventions.

Second, the gathered data was not analyzed quantitatively and reliably. When assessing the working posture, angles between body parts including joints should be measured to adopt the ergonomic assessment methods such as RULA, REBA, and OWAS. Undergoing this process, results could differ according to the observers or analyzers.

Finally, a proper platform for various application such as data sharing, job rotation scheduling, and high accessibility did not exist.

Regarding these limitations, a web-based database system and working postural analysis software can resolve the problems and help to manage the whole information related to the work site investigation and

management. With these systems, a virtuous circle can be created from the ergonomics point of view.

In previous studies, a sort of motion analysis system was used to analyze the working posture. With those systems, the motion can be captured automatically by tracking markers attached on bony landmarks of the subject. However, this kind of system is difficult to use in the real field research, because of the following reasons. There are so many obstructions to capture the markers such as bad lighting and obstacles. Workers usually feel uncomfortable with those markers on their bodies, and it is practically hard to let them do their jobs with those markers.

Hence, in this study, we developed (1) a working postural analysis system, and (2) a web-based database system for the whole related information. The postural analysis system also provides the results of the previous ergonomic assessment methods including RULA, REBA, and OWAS. The database system provides a function to calculate job rotation scheduling for better job rotation from human factors perspective.

7.1.2 Expected effects

In the development process, we took into account the practicality of the systems especially, when assuming that they are used by practitioners with a little expertise of ergonomics or human factors. By adopting the developed two systems, several advantages can be achieved.

The advantages of the postural analysis system are as follows: (1) more accurate and reliable data can be obtained, (2) results of the ergonomic assessment methods including RULA, REBA, and OWAS can be calculated with a minimal effort, and (3) the system can be easily used due to its high intuitiveness and operational simplicity.

The expected effects of the database system are as in the following. (1) Every information and data can be effectively and easily managed. It can be stored with using Microsoft Excel spreadsheet, and loaded by many optional variables. (2) The whole system can be accessed by various conditions including desktop PC and mobile device via the internet. (3)

These two systems help in managing musculoskeletal disorders of the workers in the work site such as plants, business areas, and even offices. They also can be used to figure out the hazard factors in work site and to develop appropriate interventions. Furthermore, the implementation process of those interventions can be tracked, and their effectiveness can be grasped easily. Eventually, the work site can be intervened and improved by adopting these systems, and the workers in the plant can do their jobs with higher job satisfaction and lower job stress.

7.1.3 Aim of the study

The objectives of the study are twofold. First, we developed a working postural analysis system that includes measuring angles of the joints and calculation of ergonomic assessment methods. Second, we

developed the MSD management system with a web-based platform. This system helps in managing whole information related to the work site investigations and ergonomic interventions.

7.2 System Development and Specifications

7.2.1 Working postural analysis system

The working postural analysis system is composed of three modules including a control module, angle measurement module, and advanced analytics module. Each module is explained sections below.

The information on the working posture is used to determine the ergonomic assessment methods including RULA, REBA, and OWAS. The reason why these methods were chosen among various tools is that these methods are mainly based on the working posture.

Every method has its strong point and blind spot. From this point of view, RULA, REBA, and OWAS were regarded most effective to evaluate the overall working posture. Moreover, these were the most representative tools and have been used by practitioners until now. A tool like 'Rodgers' muscle fatigue assessment' considers not only posture, but also force and repetitiveness, so we decided that this kind of tools not be appropriate for adopting to the postural analysis system.

7.2.1.1 Control module

The control module is shown in Figure 7.1. In this module, users basically choose a video or a picture to analyze, and the video can be played and paused. The data on the features for measuring the angle of each joint and the results can be saved as a CSV format file, and also can be loaded by using this CSV file. With capturing function, every capture of each frame which was evaluated can be captured automatically.

Moreover, several adjustments are available including play speed, features' size and color.

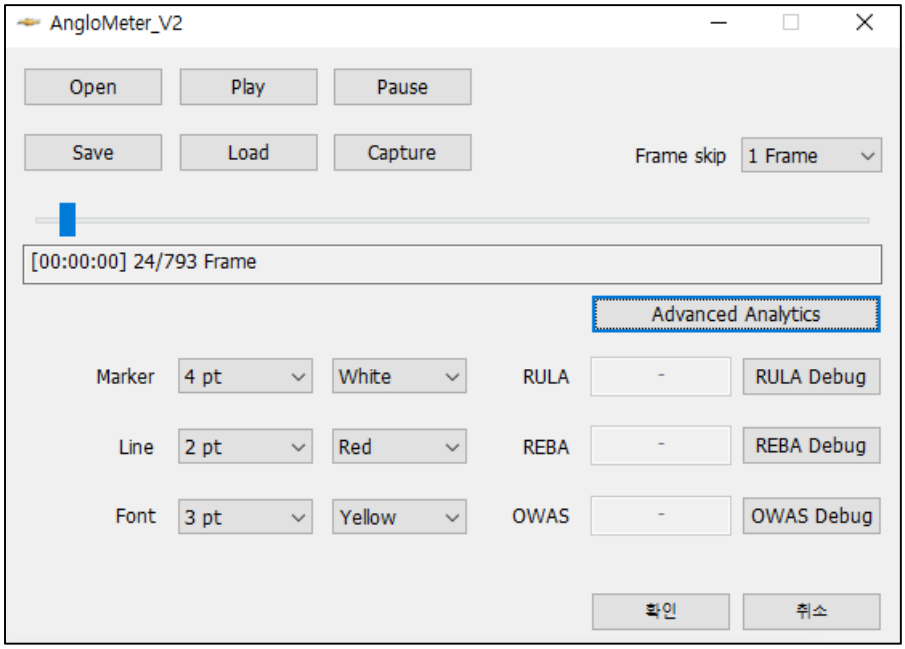

Figure 7.1 Control module

7.2.1.2 Angle measurement module

In angle measurement module, 15 features can be marked on each frame. With these features, angles of the joints are measured. To grasp the working posture, observers point the bony landmarks including head, shoulder, elbow, wrist, low back, knee, and ankle from the sagittal plane. Those features are used to measure the angle of each joint of worker's body.

Adding to this basic function, 'neutral' button was added in this module. Using this button, every joint is assumed as a neutral state in a specific frame. This function was added to avoid underestimation or overestimation of the angles. The underestimation or overestimation may appear without this function. Because when a workers' posture is in all neutral state, the features should be pointed on the frame to distinguish the neutral state in work cycle from the rest time. To avoid this kind of annoyingness, the 'neutral' button was added. The control module is shown in Figure 7.2.

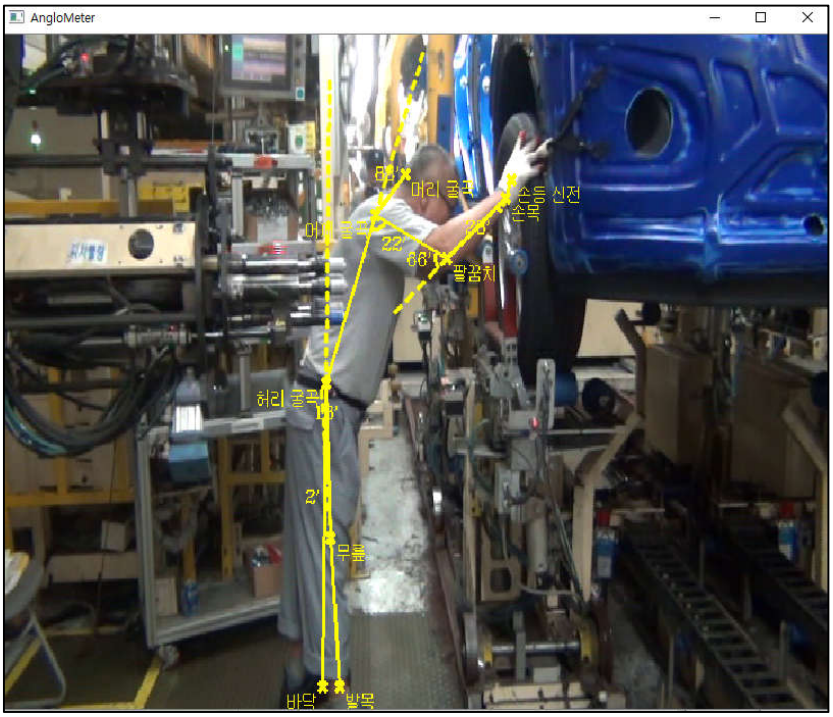

Figure 7.2 Angle measurement module

7.2.1.3 Advanced analytics module

The advanced analytics module is shown in Figure 7.3. The questions were derived to calculate RULA, REBA, and OWAS. They can be divided into two groups: (1) common questions for each job, and (2) individual questions for each frame. Items in the common questions are about the factors which are same in one job. The items are a coupling state, the weight of heavy loads, the force needed, static posture, and repetitiveness. Items in individual questions are about the factors which may vary along each frame or moment. The items are state of the neck, upper arm, lower arm, wrist, low back, and leg. These common and individual questions are all used to calculate the results of RULA, REBA, and OWAS.

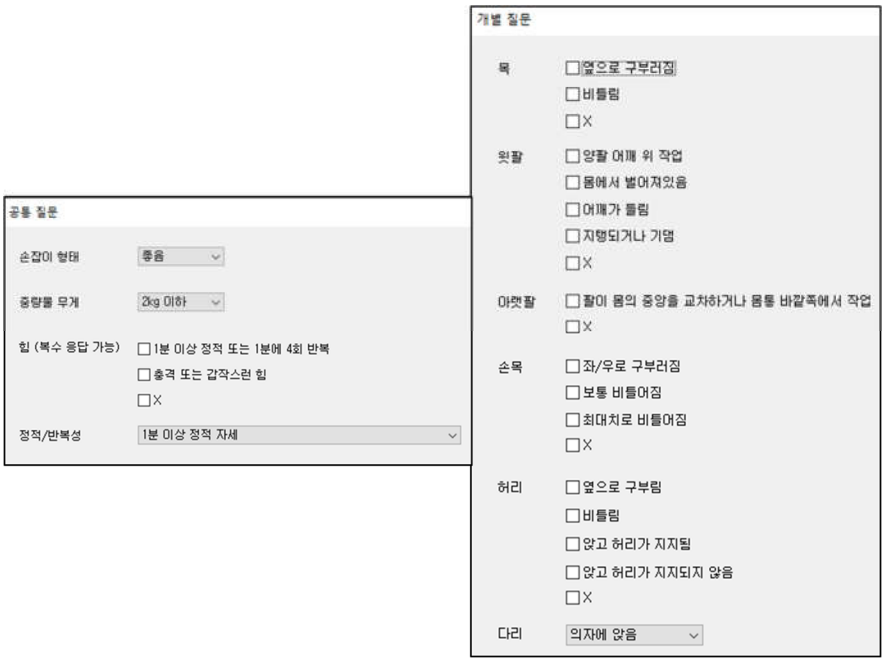

Figure 7.3 Advanced analytics module

7.2.2 A database system for MSDs management

The database system for MSDs management was developed with a web-based platform. Therefore, this system can be accessed from everywhere where internet access is available.

The MSDs managing database system contains three modules: data input module, result output module, and a job rotation scheduling module. Each module is explained sections below. Moreover, with a consideration of usage by practitioners, we differentiate accessibility in each module according to the authority.

7.2.2.1 Data input module

There are five parts in the data input module, and they are as follows: (1) job-related information, (2) worker's personal factors, (3) ergonomic problems, (4) ergonomic interventions, and (5) information on tracking interventions. All data can be uploaded by using Microsoft Excel spreadsheet. With the uploading function, all data can be uploaded into the database at a time. Figure 7.4 and Figure 7.5 show examples of job-related information input and worker's personal factors.

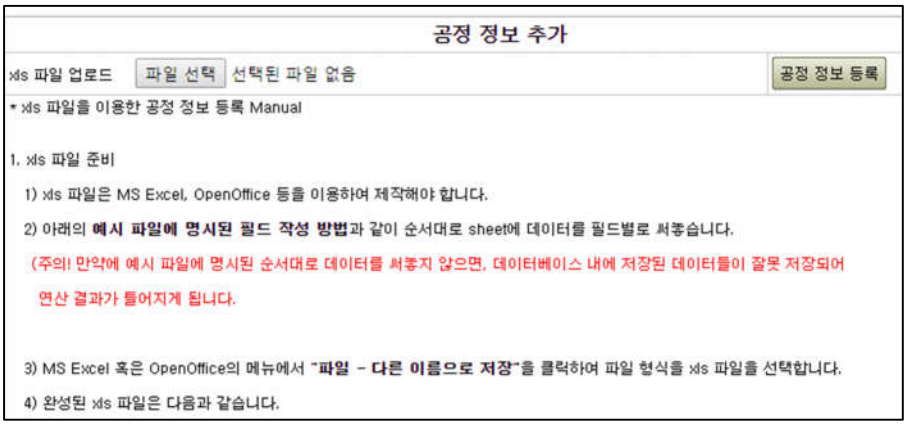

Figure 7.4 Data input module: job information input

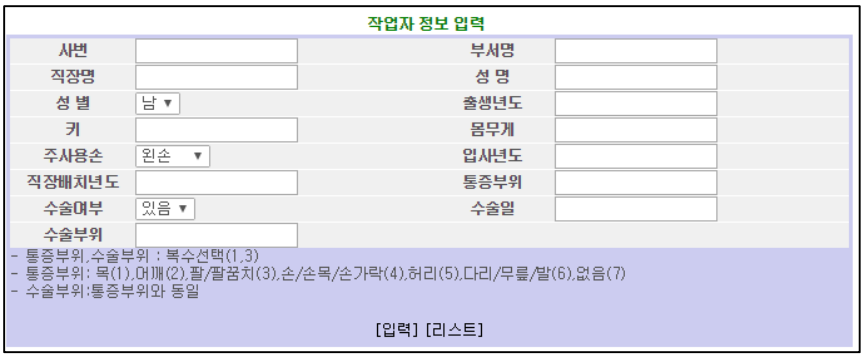

Figure 7.5 Data input module: worker's personal factors

The job-related information includes job characteristics, working posture, psychosocial factors, environmental factors, and information on investigations such as year and type of investigation, investigator, and key index for the database system. In addition, the analysis results of the ergonomic assessment methods such as QEC, SI, RULA, REBA, OWAS, design ergonomics worksheet (DEW), global ergonomics screening tool (GEST), NLE LI, and Rodgers' muscle fatigue assessment are also included. In particular, results of the postural analysis were also added.

Workers' personal factors include name, height, handedness, age, gender, weight, years of service and medical history. The information on workers is connected to the job-related information for better understanding of the whole work site status.

Ergonomic problems also can be uploaded and saved to the database system. The uploaded problems can be connected to the job-related information also. By utilizing this, whole problems can be listed up and be seen at a glance. Moreover, which job has which problems can be easily understood and tracked. These functions are also available to the intervention part.

Finally, information on tracking interventions can be managed. By using this part, the status of work sites before-and-after the intervention can be compared and understood.

7.2.2.2 Result output module

In result output module, whole data and information achieved by investigations can be searched and checked. There are largely two parts in this module, and they are (1) job-related information management, and (2) intervention follow-up management.

In job-related information management part, the results can be inquired by key index, year or type of investigation, department, division, and job. The result output module is shown in Figure 7.6.

Figure 7.6 Result output module

The raw data can be checked on the website, and downloaded as an Excel spreadsheet. Moreover, the data can be reported as a pdf file. Figure 7.7 shows an example of the detailed report page. The uploaded data can be modified on the web page itself.

1.조사 대상 작업 개요

부서명	직장명	공정명	JPH	작업시간(S)	로테이션주기/공정수
부평FAM1엔진부	엔진조립직	피스톤 압입공정	60	50초	1hr / 6개 공정

2.작업조사 일반사항

작업자세	서서 작업	중량물 물품명(무게)	실린더 헤드(7.8kg)
주작업위치	무릎~가슴(90~120cm)	중량물 빈도	30회 / 1hr
비틀림 부위	없음	밀기/당기기 유무	없음
반복성 부위	없음	수동백업렌치 사용유무	없음
위험요인	부자연스런 자세 / 과도한 힘	사용공구(무게)	없음

3.신체부위별 부담요소

	자세	힘	반복	비틀림	기타 부담 요인	부담여부
목	V				접촉 스트레스	123
허리	V				작업공간	1
어깨					진동	
팔/팔꿈치	V	V			손망치 작업	
손목/손가락	V	V			조명	
다리/무릎/발목					온도	

기타부담요소	시간이 부족함

4.평가도구별 유해요인 분석

사전평가 도구A	높음	사전평가 도구B	보통	JSI(손/손목부담)	-

평가 도구	평가 내용	평가 결과	결과 해결 및 조치수준
OWAS	전반적인 자세 요소	1/4	작업자세에 아무런 조치도 필요치 않음
RULA	상지 관련 요소	2/4	계속 추적 관찰 요함
REBA	전반적인 자세 요소	1/4	수용 가능한 작업
QEC	작업자/조사자 주관적 평가	2/4	지속적 관찰 요망

부하 수준		목	어깨	허리	팔	손/손목	다리
신체부위별 자세/힘 부하 정도	종합	낮음	낮음	낮음	낮음	낮음	낮음
	힘	낮음	낮음	낮음	낮음	낮음	낮음
	시간	낮음	낮음	낮음	낮음	낮음	낮음
	빈도	보통	낮음	낮음	낮음	보통	보통

Figure 7.7 An example of the detailed report page

In intervention follow-up management part, the intervention applied to the work site can be inquired by key index, year or type of investigation, department, division, job, and year of intervention applied. Screenshot of this page is shown in Figure 7.8, and Figure 7.9 shows an example of the follow-up management.

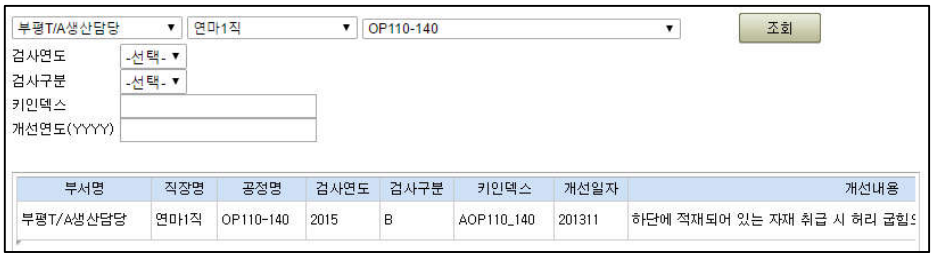

Figure 7.8 Intervention follow-up management page

Figure 7.9 An example of the follow-up management

7.2.2.3 Job rotation scheduling module

Job rotation scheduling module provides the optimal job rotation scheduling with considering job characteristics and worker's characteristics. The job characteristics include the height of the working point, the level of MMH, and workload on body parts evaluated by using Rodgers' muscle fatigue assessment. Worker's characteristics include

painful body parts and height. The algorithm for the optimal job rotation scheduling was adopted from Song et al. (2016)'s study.

To conduct job rotation scheduling, the division that a manager wants to rotate should be selected. Then the targeting jobs and workers should be checked. This process is shown in Figure 7.10.

부서명	직장명	공정명	작업자수	선택
권상현 부서	상현 직장	상현 공정 1	1	☑
권상현 부서	상현 직장	상현 공정 2	1	☑
권상현 부서	상현 직장	상현 공정 3	1	☑
권상현 부서	상현 직장	상현 공정 4	1	☑
권상현 부서	상현 직장	상현 공정 5	1	☐
권상현 부서	상현 직장	상현 공정 6	1	☐
권상현 부서	상현 직장	상현 공정 7	1	☐

작업자명	통증 및 산재부위	주 사용손	나이	키	몸무게	선택
고영진 (상현 공정 6)	2, 4	오른손	52세	173cm	69kg	☐
김기욱 (상현 공정 1)	5	오른손	57세	163cm	65kg	☐
전용구 (상현 공정 5)	4	오른손	53세	174cm	73kg	☐
조경희 (상현 공정 2)	2,4	오른손	56세	173cm	74kg	☑
최동철 (상현 공정 7)	7	양손	51세	172cm	65kg	☑
최정호 (상현 공정 4)	4	오른손	54세	170cm	72kg	☑
홍성래 (상현 공정 3)	2, 4	오른손	55세	170cm	73kg	☑

- 통증부위: 목 (1), 어깨 (2), 팔/팔꿈치 (3), 손/손목/손가락 (4), 허리 (5), 다리/무릎/발 (6), 없음 (7)

scheduling 결과 조회

Figure 7.10 Conducting the job rotation scheduling

After choosing the jobs and workers, adopted algorithm for the optimal rotation scheduling is performed. The results contain an order of jobs for each worker, total workload when rotating in existing order, total workload when rotating with the optimal order, and the rate of

improvement. An example of the result of the job rotation scheduling is shown in Figure 7.11.

번호	공정 이름
1	상현 공정 1
2	상현 공정 2
3	상현 공정 3
4	상현 공정 4

작업 순환 결과

작업자	Rotation 1	Rotation 2	Rotation 3	Rotation4
조경희	4	3	4	3
최동철	3	4	3	4
최정호	2	1	2	1
홍성래	1	2	1	2

작업 순환 효과
현행 로테이션 점수 : 4.5 점
스케줄링 로테이션 점수 : 3 점
현행 대비 개선효과 : -33.33 %

작업 순환 효과(기존로직)

한 작업만 수행했을 때 부하 점수	순서대로 작업을 바꿀 때 부하 점수	작업순환 스케줄링 적용 시 부하 점수	개선 정도
25.5	4.5	3	-33.33

Figure 7.11 Result of the job rotation scheduling

7.3 Discussion

For effective MSDs management on a work site, it is crucial that managers grasp the current state of the MSDs. To understand the state of the MSDs, whole information on both work site and workers should be handled well. This information must be acquired to get realistic ergonomic problems, and develop appropriate ergonomic interventions.

With a closer look at the process, several important acts should be conducted for the MSDs management. First, whole data and information on the investigation should be documented. The documents should contain information on jobs, workers, multimedia files, analysis results, problems, and interventions. Information on the jobs should include job characteristics, the burden of body parts, and environmental factors. Information on workers should include gender, age, height, weight, handedness, and years of service. Multimedia files should include video files of working postures and pictures of the workplace. Analysis results are derived by using various ergonomic assessment methods such as RULA, REBA, OWAS, and so on. Problems should contain all problems occurring at the work site. Interventions should include not only appropriate interventions but also the effectiveness of the interventions.

For continuous management of this information, a systematic framework such as database system could be very advantageous. By using the database system, proactive handling can be adopted adequately. Appropriate proactive handling can be developed with the knowledge about characteristics of jobs and workers. Moreover, the optimal job rotation scheduling can be derived with this knowledge.

As mentioned above, a tracking management or a follow-up study is a necessary condition for good MSDs management system. Thus, this study focused on facilitating this function. Hence, we developed a web-based database system to guarantee this purpose. We also considered practicability, usability, and accessibility in the development process. By adopting this database system, there are some following expected advantages.

First, not only all data but also the relationships among them can be grasped. Jobs that have a common problem can be easily checked, and the factors derive this problem can be understood effectively. It is the same in the case of interventions.

Second, continuous data management is available with a follow-up study, and objectivity and reliability with statistical analysis can also be grasped. Moreover, financial effects including compensation cost reduction for MSDs and safety accident, a decrease of job time and failure rate and non-financial value including an increase in job satisfaction and a decrease in pain or fatigue during job done can be created.

Third, the work site can be investigated from various points of view by utilizing various assessment methods. With these nine ergonomic assessment methods, the more comprehensive analysis is possible, and more thorough investigation of the problems can be conducted.

Finally, an optimal job rotation scheduling can be brought out with focusing on the working postures. With this optimal job rotation scheduling, total stress on workers' body can be reduced when compared with existing job rotation.

A working postural analysis system was developed, and this system has some advantages. Angles of the joints can be measured quantitatively and objectively. The result of the working postural analysis system can be applied to the various area. It is automatically used to calculate the previous ergonomic assessment methods such as RULA, REBA, and OWAS. Moreover, the angles can also be used to other methods that handle about the angles of body joints.

Nonetheless, this postural analysis system has some disadvantages. The angles of each joint are measured from the sagittal plane only. Hence, flexion or extension of the neck, low back, upper arm, the elbow can be measured. However, the degree of twisting cannot be measured precisely with this system. Though we added some additional questions that deal with this kind of information, it is still not perfect.

Chapter 8. Conclusion

8.1 Review of Findings

This dissertation aims to resolve four research questions proposed in Chapter 1. To this end, five somewhat independent studies were conducted, and a variety of findings were taken.

First, an overview study of the systematic reviews on the risk factors for the WMSDs was conducted. Through the overview, numerous risk factors and concepts that belong to the factors were pooled out and classified by their characteristics. Final categories were individual factors, psychosocial factors, and physical exposure factors. After collecting and classifying these factors, the associations between the risk factors and WMSDs were reported along the body part. The major risk factors were figured out by our overview study.

Second, a study was carried out to understand the contributing factors for working posture. In this regard, a candidate set of the contributing factors was made through literature reviews. By performing a field research, data on the factors included in the candidate set and working postures was gathered. After analyzing the whole data, the contributing factors for the working posture were figured out, and their influences on the working posture were grasped, consequently.

Third, quantification methods for job satisfaction and job stress were proposed. To enhance the credibility of the method, various kinds of techniques including regression analysis, ANN analysis, SVM classifier, and decision tree analysis were used and compared.

Fourth, a case study targeting an automobile assembly plant in South Korea was conducted. Through the investigations on the work site, ergonomic problems that might induce MSDs were found. Additionally, appropriate ergonomic interventions were suggested for each problem. Then, the effectiveness of interventions applied to the work site was evaluated by comparing the working postures and ergonomic risk levels before and after interventions. In evaluating the ergonomic risk level, ergonomic assessment methods such as RULA, REBA, and OWAS were used. Through the follow-up study, it was confirmed that ergonomic interventions acquired by ergonomic approach really work in the real world setting regarding working posture and ergonomic risk level.

Lastly, a postural analysis system and a web-based database system for MSDs management were developed. Those systems are both pragmatic and easy to use. They are expected that can help both practitioners and academic researchers.

8.2 Limitations and Future Works

In this dissertation, job satisfaction and job stress were used as dependent variables with assuming that these psychosocial factors are one of the most critical factors for the prevalence of WMSDs. It is quite clear that these factors are very important from ergonomics or occupational safety perspectives. However, other factors, more directly related to the WMSDs, such as prevalence rate or occurrence rate of the WMSDs can be better dependent variables than job satisfaction and job stress in some ways. Thus, a study that collects the prevalence rate of the WMSDs in a work site and uses this variable as a dependent variable could help to get much more trustworthy results that are directly related to the WMSDs.

Analysis schemes for working posture used in this dissertation have some limitations. First, the working posture was evaluated by measuring the degree of each joint angle. The existing analysis schemes do not propose quantitative criteria on this subject. However, we only considered the angles to the frontal plane and did not consider the angles to the sagittal plane. Hence, if the degrees of back's side bending or neck's side bending are included into our models, the goodness-of-fit of the models can be much better than now.

Second, the working posture of a job was evaluated with targeting one specific moment in the job, because this approach is recommended by earlier researchers. However, for diversified jobs, only one moment is not enough to get accurate analysis results. To get rid of this kind of bias, sampling techniques or whole analysis on every second can be adopted.

This dissertation took a field research at an automobile assembly plant to collect practical and realistic data. Hence, the results of this thesis cannot be directly adapted to all kinds of conditions and work sites. In the near future, further studies that concern the other types of data should be done.

References

Agha, S.R., & Alnahhal, M.J. (2012). Neural network and multiple linear regression to predict school children dimensions for ergonomic school furniture design. *Applied Ergonomics, 43*(6), 979-984.

Ahn, Y.-S., Choi, Y.-H., Kang, S.-K., & Chung, H.-K. (2002). Analysis of work-related musculoskeletal disease by approved Korea labor welfare corporation in 1999. *Annals of Occupational and Environmental Medicine, 14*(2), 154-168.

Apostolico, A., Cappetti, N., D'Oria, C., Naddeo, A., & Sestri, M. (2014). Postural comfort evaluation: experimental identification of Range of Rest Posture for human articular joints. *International Journal on Interactive Design and Manufacturing (IJIDeM), 8*(2), 109-120.

Ariëns, G., van Mechelen, W., Bongers, P., Bouter, L., & van der Wal, G. (2001). Psychosocial risk factors for neck pain: a systematic review. *American Journal of Industrial Medicine, 39*(2), 180.

Armstrong, T. (1986). Upper-extremity posture: definition, measurement and control. *The ergonomics of working postures*, 59-73.

Armstrong, T.J., Foulke, J.A., Joseph, B.S., & Goldstein, S.A. (1982). Investigation of cumulative trauma disorders in a poultry processing plant. *The American Industrial Hygiene Association Journal, 43*(2), 103-116.

Asundi, K., Odell, D., Luce, A., & Dennerlein, J.T. (2010). Notebook computer use on a desk, lap and lap support: effects on posture, performance and comfort. *Ergonomics, 53*(1), 74-82.

Bar-Yam, Y. (1997). *Dynamics of complex systems*. Reading, MA, United States: Addison-Wesley.

Baty, D., Buckle, P., & Stubbs, D. (1986). Posture recording by direct observation, questionnaire assessment and instrumentation: a comparison based on a recent field study. In N. Corlott & J.

Wilson (Eds.), *The ergonomics of working postures* (pp. 283-292). London, England: Taylor and Francis.

Bergqvist, U., Wolgast, E., Nilsson, B., & Voss, M. (1995). Musculoskeletal disorders among visual display terminal workers: individual, ergonomic, and work organizational factors. *Ergonomics, 38*(4), 763-776.

Bernard, B.P., & Putz-Anderson, V. (1997). Musculoskeletal disorders and workplace factors: a critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back *DHHS (NIOSH) Publication* (Vol. 97-141).

Bongers, P., Ijmker, S., Van den Heuvel, S., & Blatter, B. (2006). Epidemiology of work related neck and upper limb problems: psychosocial and personal risk factors (part I) and effective interventions from a bio behavioural perspective (part II). *Journal of Occupational Rehabilitation, 16*(3), 272-295.

Bongers, P.M., de Winter, C.R., Kompier, M.A., & Hildebrandt, V.H. (1993). Psychosocial factors at work and musculoskeletal disease. *Scandinavian journal of work, environment & health*, 297-312.

Bongers, P.M., Kremer, A.M., & Laak, J.t. (2002). Are psychosocial factors, risk factors for symptoms and signs of the shoulder, elbow, or hand/wrist?: A review of the epidemiological literature. *American Journal of Industrial Medicine, 41*(5), 315-342.

Boser, B.E., Guyon, I.M., & Vapnik, V.N. (1992). *A training algorithm for optimal margin classifiers*. Paper presented at the Fifth annual workshop on Computational learning theory, PA, United States.

Bouter, L.M., & van der Wal, G. (2001). Psychosocial risk factors for neck pain: a systematic review. *American Journal of Industrial Medicine, 39*, 180-193.

Buchholz, B., Paquet, V., Punnett, L., Lee, D., & Moir, S. (1996). PATH: a work sampling-based approach to ergonomic job analysis for construction and other non-repetitive work. *Applied Ergonomics, 27*(3), 177-187.

Buckle, P., Stubbs, D., & Baty, D. (1986). Musculo-skeletal disorders (and discomfort) and associated work factors. *The ergonomics of working postures*, 19-30.

Budnick, P. (2013). The trouble with RULA. from http://www.ergoweb.com/news/detail.cfm?id=2705Ergowb

Burgess-Limerick, R., Plooy, A., & Ankrum, D.R. (1998). The effect of imposed and self-selected computer monitor height on posture and gaze angle. *Clinical Biomechanics, 13*(8), 584-592.

Burgess-Limerick, R., Plooy, A., Fraser, K., & Ankrum, D. (1999). The influence of computer monitor height on head and neck posture. *International Journal of Industrial Ergonomics, 23*(3), 171-179.

Burström, L., Nilsson, T., & Wahlström, J. (2015). Whole-body vibration and the risk of low back pain and sciatica: a systematic review and meta-analysis. *International Archives of Occupational and Environmental Health, 88*(4), 403-418.

Caroly, S., Coutarel, F., Landry, A., & Mary-Cheray, I. (2010). Sustainable MSD prevention: Management for continuous improvement between prevention and production. Ergonomic intervention in two assembly line companies. *Applied Ergonomics, 41*(4), 591-599.

Chung, M.K., Lee, I., & Kee, D. (2003). Assessment of postural load for lower limb postures based on perceived discomfort. *International Journal of Industrial Ergonomics, 31*(1), 17-32.

Cook, C., Burgess-Limerick, R., & Papalia, S. (2004). The effect of upper extremity support on upper extremity posture and muscle activity during keyboard use. *Applied Ergonomics, 35*(3), 285-292.

Cooper, C.L., Rout, U., & Faragher, B. (1989). Mental health, job satisfaction, and job stress among general practitioners. *Bmj, 298*(6670), 366-370.

Corlett, E.N., & Bishop, R. (1976). A technique for assessing postural discomfort. *Ergonomics, 19*(2), 175-182.

Corlett, E.N., Wilson, J.R., & Manenica, I. (1985). *Ergonomics of*

working postures: models, methods and cases. Paper presented at the The First International Occupational Ergonomics Symposium, Zadar, Yugoslavia.

da Costa, B.R., & Vieira, E.R. (2010). Risk factors for work-related musculoskeletal disorders: a systematic review of recent longitudinal studies. *American Journal of Industrial Medicine, 53*(3), 285-323.

David, G., Woods, V., Li, G., & Buckle, P. (2008). The development of the Quick Exposure Check (QEC) for assessing exposure to risk factors for work-related musculoskeletal disorders. *Applied Ergonomics, 39*(1), 57-69.

Davis, K.G., & Heaney, C.A. (2000). The relationship between psychosocial work characteristics and low back pain: underlying methodological issues. *Clinical Biomechanics, 15*(6), 389-406.

Delleman, N.J., & Dul, J. (2002). Sewing machine operation: workstation adjustment, working posture, and workers' perceptions. *International Journal of Industrial Ergonomics, 30*(6), 341-353.

Dempsey, P.G., McGorry, R.W., & Maynard, W.S. (2005). A survey of tools and methods used by certified professional ergonomists. *Applied Ergonomics, 36*(4), 489-503.

Dendamrongvit, T. (2002). *Development of a posture prediction model.* (Master of Science), Oregon State University.

Denis, D., St-Vincent, M., Imbeau, D., Jetté, C., & Nastasia, I. (2008). Intervention practices in musculoskeletal disorder prevention: A critical literature review. *Applied Ergonomics, 39*(1), 1-14.

Faucett, J., & Rempel, D. (1994). VDT-related musculoskeletal symptoms: Interactions between work posture and psychosocial work factors. *American Journal of Industrial Medicine, 26*(5), 597-612.

Feuerstein, M., Nicholas, R.A., Huang, G.D., Dimberg, L., Ali, D., & Rogers, H. (2004). Job stress management and ergonomic intervention for work-related upper extremity symptoms. *Applied Ergonomics, 35*(6), 565-574.

Foreman, T., & Troup, J. (1987). Diurnal variations in spinal loading and the effects on stature: a preliminary study of nursing activities. *Clinical Biomechanics, 2*(1), 48-54.

Fransson-Hall, C., Karlquist, L., Gloria, R., Wiktorin, C., Kilbom, Å., Winkel, J., & Group, S.M.S. (1991). Portabel ergonomisk observationsmetod (PEO) *Stockholmsundersökningen 1* (pp. 91-103).

Fredriksson, K., Alfredsson, L., Köster, M., Thorbjörnsson, C.B., Toomingas, A., Torgén, M., & Kilbom, A. (1999). Risk factors for neck and upper limb disorders: results from 24 years of follow up. *Occupational and environmental medicine, 56*(1), 59-66.

Genaidy, A., Al-Shedi, A., & Karwowski, W. (1994). Postural stress analysis in industry. *Applied Ergonomics, 25*(2), 77-87.

Genaidy, A.M., Guo, L., Eckart, R., & Troup, J.D.G. (1993). *A postural stress analysis system for evaluating body movements and positions in industry*. Paper presented at the Ergonomics Society Conference, Edinburgh, Scotland.

Gilleard, W., & Smith, T. (2007). Effect of obesity on posture and hip joint moments during a standing task, and trunk forward flexion motion. *International Journal of Obesity, 31*(2), 267-271.

Girosi, F. (1998). An equivalence between sparse approximation and support vector machines. *Neural computation, 10*(6), 1455-1480.

Goggins, R.W., Spielholz, P., & Nothstein, G.L. (2008). Estimating the effectiveness of ergonomics interventions through case studies: implications for predictive cost-benefit analysis. *Journal of Safety Research, 39*(3), 339-344.

Gravina, N., Lindstrom-Hazel, D., & Austin, J. (2007). The effects of workstation changes and behavioral interventions on safe typing postures in an office. *Work: A Journal of Prevention, Assessment & Rehabilitation, 29*(3), 245.

Green, R., Briggs, C., & Wrigley, T. (1991). Factors related to working posture and its assessment among keyboard operators. *Applied Ergonomics, 22*(1), 29-35.

Grieco, A. (1998). Application of the concise exposure index (OCRA) to tasks involving repetitive movements of the upper limbs in a variety of manufacturing industries: preliminary validations. *Ergonomics, 41*(9), 1347-1356.

Grimes, P., & Legg, S. (2004). Musculoskeletal disorders (MSD) in school students as a risk factor for adult MSD: a review of the multiple factors affecting posture, comfort and health in classroom environments. *Journal of the Human-Environmental System, 7*(1), 1-9.

Hadler, N.M. (2005). *Occupational Musculoskeletal Disorders*. Alphen aan den Rijn, The Netherlands: Lippincott Williams & Wilkins.

Hartvigsen, J., Lings, S., Leboeuf-Yde, C., & Bakketeig, L. (2004). Psychosocial factors at work in relation to low back pain and consequences of low back pain; a systematic, critical review of prospective cohort studies. *Occupational and environmental medicine, 61*(1), e2.

Haslegrave, C.M. (1994). What do we mean by a 'working posture'? *Ergonomics, 37*(4), 781-799.

Hauke, A., Flintrop, J., Brun, E., & Rugulies, R. (2011). The impact of work-related psychosocial stressors on the onset of musculoskeletal disorders in specific body regions: A review and meta-analysis of 54 longitudinal studies. *Work & Stress, 25*(3), 243-256.

Hecht-Nielsen, R. (1989). *Theory of the backpropagation neural network*. Paper presented at the Neural Networks, 1989. IJCNN., International Joint Conference on.

Hedge, A., Morimoto, S., & Mccrobie, D. (1999). Effects of keyboard tray geometry on upper body posture and comfort. *Ergonomics, 42*(10), 1333-1349.

Heinsalmi, P. (1986). Method to measure working posture loads at working sites (OWAS). In E. N. Corlett, J. Wilson & I. Manencia (Eds.), *The ergonomics of working postures* (pp. 100-104). London, England: Taylor & Francis.

Hendrick, H.W., & Kleiner, B. (2005). *Macroergonomics: theory,*

methods, and applications. Florida, United States: CRC Press.

Heo, J., Park, S., & Song, C. (2007). A Study on the Improving Product Usability Applying the Kano's Model of Customer Satisfaction *Human-Computer Interaction. Interaction Design and Usability* (pp. 482-489): Springer.

Higgins, J.P., & Green, S. (2008). *Cochrane handbook for systematic reviews of interventions* (Vol. 5). New Jersey, United States: Wiley Online Library.

Hignett, S., & McAtamney, L. (2000). Rapid entire body assessment (REBA). *Applied Ergonomics, 31*(2), 201-205.

Hocking, B. (1987). Epidemiological aspects of" repetition strain injury" in Telecom Australia. *The medical journal of Australia, 147*(5), 218-222.

Hooftman, W.E., van der Beek, A.J., van de Wal, B.G., Knol, D.L., Bongers, P.M., Burdorf, A., & van Mechelen, W. (2009). Equal task, equal exposure? Are men and women with the same tasks equally exposed to awkward working postures? *Ergonomics, 52*(9), 1079-1086.

Hoogendoorn, W., Bongers, P., De Vet, H., Ariens, G., Van Mechelen, W., & Bouter, L. (2002). High physical work load and low job satisfaction increase the risk of sickness absence due to low back pain: results of a prospective cohort study. *Occupational and environmental medicine, 59*(5), 323-328.

Hoogendoorn, W.E., van Poppel, M.N., Bongers, P.M., Koes, B.W., & Bouter, L.M. (2000). Systematic review of psychosocial factors at work and private life as risk factors for back pain. *Spine, 25*(16), 2114-2125.

Huang, G.D., Feuerstein, M., Kop, W.J., Schor, K., & Arroyo, F. (2003). Individual and combined impacts of biomechanical and work organization factors in work-related musculoskeletal symptoms. *American Journal of Industrial Medicine, 43*(5), 495-506.

Imada, A., & Feiglstok, D. (1990). An organizational design and management approach for improving safety. *Human factors in organizational design and management—III*, 479-482.

Jaffar, N., Abdul-Tharim, A.H., Mohd-Kamar, I.F., & Lop, N.S. (2011). A literature review of ergonomics risk factors in construction industry. *Procedia Engineering, 20*(0), 89-97.

Jakob, M., Liebers, F., & Behrendt, S. (2012). The effects of working height and manipulated weights on subjective strain, body posture and muscular activity of milking parlor operatives–Laboratory study. *Applied Ergonomics, 43*(4), 753-761.

Jakob, M.C., Liebers, F., & Behrendt, S. (2009). The influence of varying working heights and weights of milking units on the body posture of female milking parlour operatives. *Agricultural Engineering International: the CIGR Ejournal, 11*, 1–10.

Jones, T., & Kumar, S. (2010). Comparison of ergonomic risk assessment output in four sawmill jobs. *International Journal of Occupational Safety and Ergonomics, 16*(1), 105-111.

Judge, T.A., Thoresen, C.J., Bono, J.E., & Patton, G.K. (2001). The job satisfaction–job performance relationship: A qualitative and quantitative review. *Psychological bulletin, 127*(3), 376.

Juul-Kristensen, B., Fallentin, N., & Ekdahl, C. (1997). Criteria for classification of posture in repetitive work by observation methods: A review. *International Journal of Industrial Ergonomics, 19*(5), 397-411.

Karhu, O., Kansi, P., & Kuorinka, I. (1977). Correcting working postures in industry: A practical method for analysis. *Applied Ergonomics, 8*(4), 199-201.

Karsh, B.-T., Moro, F.B., & Smith, M.J. (2001). The efficacy of workplace ergonomic interventions to control musculoskeletal disorders: a critical analysis of the peer-reviewed literature. *Theoretical Issues in Ergonomics Science, 2*(1), 23-96.

Kee, D., & Karwowski, W. (2001). LUBA: an assessment technique for postural loading on the upper body based on joint motion discomfort and maximum holding time. *Applied Ergonomics, 32*(4), 357-366.

Kemmlert, K. (1995). A method assigned for the identification of ergonomic hazards—PLIBEL. *Applied Ergonomics, 26*(3), 199-

211.

Kennedy, C., Amick Iii, B., Dennerlein, J., Brewer, S., Catli, S., Williams, R., . . . Rempel, D. (2010). Systematic review of the role of occupational health and safety interventions in the prevention of upper extremity musculoskeletal symptoms, signs, disorders, injuries, claims and lost time. *Journal of Occupational Rehabilitation, 20*(2), 127-162.

Keyserling, W.M. (1986). Postural analysis of the trunk and shoulders in simulated real time. *Ergonomics, 29*(4), 569-583.

Kilbom, Å. (1988). Intervention programmes for work-related neck and upper limb disorders: strategies and evaluation. *Ergonomics, 31*(5), 735-747.

Kilbom, A., Persson, J., & Jonsson, B. (1986). *Risk factors for work-related disorders of the neck and shoulder—with special emphasis on working postures and movements*. Paper presented at the The Ergonomics of Working Postures: Models, Methods and Cases: The Proceedings of the First International Occupational Ergonomics Symposium, Zadar, Yugoslavia.

Kilroy, N., & Dockrell, S. (2000). Ergonomic intervention: its effect on working posture and musculoskeletal symptoms in female biomedical scientists. *British journal of biomedical science, 57*(3), 199.

Kim, H.m. (2005). *A design of hazard risk assessment matrices for ranking musculoskeletal disorder risks in automobile processing*. (Master), Korea University, Seoul.

Kim, Y.C., & Kim, D.S. (2012). Development of a new method for whole-body working postures: K-OWAS. *Journal of The Ergonomics Society of Korea, 31*(1), 165-170.

Kogi, K. (2006). Participatory methods effective for ergonomic workplace improvement. *Applied Ergonomics, 37*(4), 547-554.

KOSHA. (2005). Study on ergonomic hazards evaluation tools developed in accordance with the working properties. Seoul.

Kozak, A., Schedlbauer, G., Wirth, T., Euler, U., Westermann, C., &

Nienhaus, A. (2015). Association between work-related biomechanical risk factors and the occurrence of carpal tunnel syndrome: an overview of systematic reviews and a meta-analysis of current research. *BMC musculoskeletal disorders, 16*(1).

Kraatz, S., Lang, J., Kraus, T., Münster, E., & Ochsmann, E. (2013). The incremental effect of psychosocial workplace factors on the development of neck and shoulder disorders: a systematic review of longitudinal studies. *International Archives of Occupational and Environmental Health, 86*(4), 375-395.

Kuijpers, T., van der Windt, D.A., van der Heijden, G.J., & Bouter, L.M. (2004). Systematic review of prognostic cohort studies on shoulder disorders. *Pain, 109*(3), 420-431.

Kumar, R., Chaikumarn, M., & Lundberg, J. (2005). Participatory ergonomics and an evaluation of a low-cost improvement effect on cleaners' working posture. *International Journal of Occupational Safety and Ergonomics, 11*(2), 203-210.

Landis, J.R., & Koch, G.G. (1977). The measurement of observer agreement for categorical data. *Biometrics, 33*(1), 159-174.

Leino, P.I., & Hänninen, V. (1995). Psychosocial factors at work in relation to back and limb disorders. *Scandinavian journal of work, environment & health*, 134-142.

Li, G., & Buckle, P. (1999). Current techniques for assessing physical exposure to work-related musculoskeletal risks, with emphasis on posture-based methods. *Ergonomics, 42*(5), 674-695.

Li, G., Haslegrave, C.M., & Corlett, E.N. (1995). Factors affecting posture for machine sewing tasks: the need for changes in sewing machine design. *Applied Ergonomics, 26*(1), 35-46.

Lincoln, A.E., Vernick, J.S., Ogaitis, S., Smith, G.S., Mitchell, C.S., & Agnew, J. (2000). Interventions for the primary prevention of work-related carpal tunnel syndrome. *American Journal of Preventive Medicine, 18*(4), 37-50.

Linton, S.J. (2000). A review of psychological risk factors in back and neck pain. *Spine, 25*(9), 1148-1156.

Linton, S.J. (2001). Occupational psychological factors increase the risk for back pain: a systematic review. *Journal of Occupational Rehabilitation, 11*(1), 53-66.

Ljungberg, J.K., & Neely, G. (2007). Stress, subjective experience and cognitive performance during exposure to noise and vibration. *Journal of Environmental Psychology, 27*(1), 44-54.

Locke, E.A. (1969). What is job satisfaction? *Organizational Behavior and Human Performance, 4*(4), 309-336.

Long, M.H., Johnston, V., & Bogossian, F. (2012). Work-related upper quadrant musculoskeletal disorders in midwives, nurses and physicians: a systematic review of risk factors and functional consequences. *Applied Ergonomics, 43*(3), 455-467.

Magnusson, M.L., Pope, M.H., Wilder, D.G., & Areskoug, B. (1996). Are occupational drivers at an increased risk for developing musculoskeletal disorders? *Spine, 21*(6), 710-717.

Mahmud, N., Kenny, D.T., & Rahman, H.A. (2012). The Effect of Workplace Office Ergonomics Intervention on Reducing Neck and Shoulder Complaints and Sickness Absence.

Malchaire, J., Cock, N., & Vergracht, S. (2001). Review of the factors associated with musculoskeletal problems in epidemiological studies. *International Archives of Occupational and Environmental Health, 74*(2), 79-90.

Mayer, J., Kraus, T., & Ochsmann, E. (2012). Longitudinal evidence for the association between work-related physical exposures and neck and/or shoulder complaints: a systematic review. *International Archives of Occupational and Environmental Health, 85*(6), 587-603.

McAtamney, L., & Nigel Corlett, E. (1993). RULA: a survey method for the investigation of work-related upper limb disorders. *Applied Ergonomics, 24*(2), 91-99.

Miedema, M.C., Douwes, M., & Dul, J. (1997). Recommended maximum holding times for prevention of discomfort of static standing postures. *International Journal of Industrial Ergonomics, 19*(1), 9-18.

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D.G. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Annals of internal medicine, 151*(4), 264-269.

Moore, J.S., & Garg, A. (1997). Participatory ergonomics in a red meat packing plant, Part I: Evidence of long-term effectiveness. *American Industrial Hygiene Association Journal, 58*(2), 127-131.

National Research Council and the Institute of Medicine. (2001). *Musculoskeletal disorders and the workplace: Low back and upper extremities. Panel on Musculoskeletal Disorders and the Workplace. Commission on Behavioral and Social Sciences and Education*. Washington, DC: National Academy Press.

Nelson, N.A., & Hughes, R.E. (2009). Quantifying relationships between selected work-related risk factors and back pain: a systematic review of objective biomechanical measures and cost-related health outcomes. *International Journal of Industrial Ergonomics, 39*(1), 202-210.

Norman, R., Wells, R., Neumann, P., Frank, J., Shannon, H., Kerr, M., & Study, T.O.U.B.P. (1998). A comparison of peak vs cumulative physical work exposure risk factors for the reporting of low back pain in the automotive industry. *Clinical Biomechanics, 13*(8), 561-573.

Occupational Health and Safety Council of Ontario. (2008). MSD prevention toolbox more on in-depth risk assessment methods *Musculoskeletal Disorders Prevention Series*: OHSCO.

Paksaichol, A., Janwantanakul, P., Purepong, N., Pensri, P., & Van der Beek, A.J. (2012). Office workers' risk factors for the development of non-specific neck pain: a systematic review of prospective cohort studies. *Occupational and environmental medicine, 69*(9), 610-618.

Park, K.S. (2006). *Human factors engineering* (2 ed.). Seoul, South Korea: Youngchi.

Paul, J.A., & Frings-Dresen, M.H. (1994). Standing working posture compared in pregnant and non-pregnant conditions. *Ergonomics, 37*(9), 1563-1575.

Persson, J., & Kilbom, A. (1983). VIRA: En enkel videofilmteknik for registrering och analys a arbetsstallningar ochrorelser. *Undersokningsrapport. Solna: National Board of Ocuppational Safety and Health*.

Pieper, D., Antoine, S.-L., Mathes, T., Neugebauer, E.A., & Eikermann, M. (2014). Systematic review finds overlapping reviews were not mentioned in every other overview. *Journal of clinical epidemiology, 67*(4), 368-375.

Piligian, G., Herbert, R., Hearns, M., Dropkin, J., Landsbergis, P., & Cherniack, M. (2000). Evaluation and management of chronic work-related musculoskeletal disorders of the distal upper extremity. *American Journal of Industrial Medicine, 37*(1), 75-93.

Pillastrini, P., Mugnai, R., Bertozzi, L., Costi, S., Curti, S., Guccione, A., . . . Violante, F.S. (2010). Effectiveness of an ergonomic intervention on work-related posture and low back pain in video display terminal operators: A 3 year cross-over trial. *Applied Ergonomics, 41*(3), 436-443.

Rivilis, I., Van Eerd, D., Cullen, K., Cole, D.C., Irvin, E., Tyson, J., & Mahood, Q. (2008). Effectiveness of participatory ergonomic interventions on health outcomes: A systematic review. *Applied Ergonomics, 39*(3), 342-358.

Rubenowitz, S. (1997). Survey and intervention of ergonomic problems at the workplace. *International Journal of Industrial Ergonomics, 19*(4), 271-275.

Ryan, G.A. (1989). The prevalence of musculo-skeletal symptoms in supermarket workers. *Ergonomics, 32*(4), 359-371.

Sanders, M.S., & McCormick, E.J. (1987). *Human factors in engineering and design*. New York, United States: McGraw-Hill book company.

Seghers, J., Jochem, A., & Spaepen, A. (2003). Posture, muscle activity and muscle fatigue in prolonged VDT work at different screen height settings. *Ergonomics, 46*(7), 714-730.

Shevade, S.K., Keerthi, S.S., Bhattacharyya, C., & Murthy, K.R.K. (2000). Improvements to the SMO algorithm for SVM regression.

Neural Networks, IEEE Transactions on, 11(5), 1188-1193.

Silverstein, B., & Clark, R. (2004). Interventions to reduce work-related musculoskeletal disorders. *Journal of Electromyography and Kinesiology, 14*(1), 135-152.

Smith, M.J. (1997). Psychosocial aspects of working with video display terminals (VDTs) and employee physical and mental health. *Ergonomics, 40*(10), 1002-1015.

Snook, S.H. (1988). Comparison of different approaches for the prevention of low back pain. *Applied Industrial Hygiene, 3*(3), 73-78.

Song, J., Lee, C., Lee, W., Bahn, S., Jung, C., & Yun, M.H. (2016). Development of a job rotation scheduling algorithm for minimizing accumulated work load per body parts. *Work, 53*(3), 511-521.

Straker, L., Burgess-Limerick, R., Pollock, C., Murray, K., Netto, K., Coleman, J., & Skoss, R. (2008). The impact of computer display height and desk design on 3D posture during information technology work by young adults. *Journal of Electromyography and Kinesiology, 18*(2), 336-349.

Straker, L., Pollock, C., Burgess-Limerick, R., Skoss, R., & Coleman, J. (2008). The impact of computer display height and desk design on muscle activity during information technology work by young adults. *Journal of Electromyography and Kinesiology, 18*(4), 606-617.

Swedish National Board of Occupational Health. (1998). Ergonomics for the prevention of musculoskeletal disorders. AFS 1998. Stockholm, Swden: SNBOH.

Szeto, G.P.Y., Straker, L., & Raine, S. (2002). A field comparison of neck and shoulder postures in symptomatic and asymptomatic office workers. *Applied Ergonomics, 33*(1), 75-84.

van der Beek, A.J., van Gaalen, L.C., & Frings-Dresen, M.H. (1992). Working postures and activities of lorry drivers: a reliability study of on-site observation and recording on a pocket computer. *Applied Ergonomics, 23*(5), 331-336.

van der Windt, D.A., Thomas, E., Pope, D.P., de Winter, A.F., Macfarlane, G.J., Bouter, L.M., & Silman, A.J. (2000). Occupational risk factors for shoulder pain: a systematic review. *Occupational and environmental medicine, 57*(7), 433-442.

Van Rijn, R.M., Huisstede, B.M., Koes, B.W., & Burdorf, A. (2010). Associations between work-related factors and specific disorders of the shoulder—a systematic review of the literature. *Scandinavian journal of work, environment & health*, 189-201.

Van Wely, P. (1970). Design and disease. *Applied Ergonomics, 1*(5), 262-269.

Vapnik, V. (2013). *The nature of statistical learning theory*: Springer Science & Business Media.

Vergara, M., & Page, A. (2002). Relationship between comfort and back posture and mobility in sitting-posture. *Applied Ergonomics, 33*(1), 1-8.

Vieira, E.R., Schneider, P., Guidera, C., Gadotti, I.C., & Brunt, D. (2015). Work-related musculoskeletal disorders among physical therapists: A systematic review. *Journal of back and musculoskeletal rehabilitation*(Preprint), 1-12.

Walker-Bone, K., & Cooper, C. (2005). Hard work never hurt anyone: or did it? A review of occupational associations with soft tissue musculoskeletal disorders of the neck and upper limb. *Annals of the rheumatic diseases, 64*(10), 1391-1396.

Wall, M.d., RIEL, M.V., AGHJNA, J., Burdorf, A., & Snuders, C. (1992). Improving the sitting posture of CAD/CAM workers by increasing VDU monitor working height. *Ergonomics, 35*(4), 427-436.

Wang, S.-C. (2003). Artificial neural network *Interdisciplinary Computing in Java Programming* (Vol. 743, pp. 81-100). New York, United States: Springer US.

Waters, T.R., Putz-Anderson, V., Garg, A., & Fine, L.J. (1993). Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics, 36*(7), 749-776.

Weiss, H.M. (2002). Deconstructing job satisfaction: Separating

evaluations, beliefs and affective experiences. *Human Resource Management Review, 12*(2), 173-194.

Westgaard, R.H., & Winkel, J. (1997). Ergonomic intervention research for improved musculoskeletal health: A critical review. *International Journal of Industrial Ergonomics, 20*(6), 463-500.

Wickens, C.D., Gordon, S.E., & Liu, Y. (1998). *An introduction to human factors engineering*. New York, United States: Longman.

Wickström, G., Laine, M., Pentti, J., Hyytiäinen, K., & Salminen, J. (1996). A video-based method for evaluation of low-back load in long-cycle jobs. *Ergonomics, 39*(6), 826-841.

Winkel, J., & Mathiassen, S.E. (1994). Assessment of physical work load in epidemiologic studies: concepts, issues and operational considerations. *Ergonomics, 37*(6), 979-988.

Woods, V. (2005). Work-related musculoskeletal health and social support. *Occupational medicine, 55*(3), 177-189.

Xu, Y.-W., Cheng, A.S., & Li-Tsang, C.W. (2013). Prevalence and risk factors of work-related musculoskeletal disorders in the catering industry: A systematic review. *Work, 44*(2), 107-116.

Yeow, P.H.P., & Nath Sen, R. (2003). Quality, productivity, occupational health and safety and cost effectiveness of ergonomic improvements in the test workstations of an electronic factory. *International Journal of Industrial Ergonomics, 32*(3), 147-163.

You, D., Smith, A.H., & Rempel, D. (2014). Meta-analysis: association between wrist posture and carpal tunnel syndrome among workers. *Safety and health at work, 5*(1), 27-31.

Appendix A. Micropostural classification

Table A.1 The micropostural classification

Body Part	Status	References									
		1	2	3	4	5	6	7	8	9	10
	Extension										
	Neutral		0-20		0-15						0-30
	Mild										31-60
	Severe		> 20		> 15				> 0	> 0	> 60
Neck	**Flexion**										
	Neutral	0-20	0-20		0-15		0-20		0-10		0-20
	Mild	> 20	21-45		16-45	> 20	> 20		11-20	0-20	21-45
	Severe		> 45		> 45				> 20	> 20	> 45
	Twist/lateral bending										

Table A.1 The micropostural classification

Body Part	Status	References									
		1	2	3	4	5	6	7	8	9	10
	Neutral				0-15				> 0 twist		0-30
	Mild										31-45
	Severe		> 20		> 15	> 45			> 0 lateral bending		> 45
Back	**Extension (standing)**										
	Mild		0-20		0-15					0-20	
	Severe		> 20		> 15					> 20	
	Flexion (standing + sitting)										
	Neutral		0-20		0-15			0-15		Upright	
	Mild (standing)		21-45		16-45	20-60		15-45	0-20	0-20	
	Mild (sitting)		> 20						20-60	20-60	
	Severe (standing)		> 45		> 45	> 60		45-75	> 60	>60	

Table A.1 The micropostural classification

Body Part	Status	References									
		1	2	3	4	5	6	7	8	9	10
	Severe (standing)							> 75			
	Twist/lateral bent										
	Neutral (standing + sitting)				0-15			> 0	> 0 twist; > 0 lateral bending		
	Severe (standing + sitting)		20		> 15	> 45					
	Lying on back/side										
	Sit 'neutral'		+ back supported		Sitting				+leg supported		
	Sit 'severe'		- back supported						-leg supported		
Shoulder to frontal plane	**Extension**										
	Mild								0-20	0-20	
	Severe			> 25	>15		> 0		> 20	> 20	

Table A.1 The micropostural classification

Body Part	Status	References									
		1	2	3	4	5	6	7	8	9	10
	Flexion										
	Neutral		0-45 flexion/ abduction	25 extension-20 flexion	15 extension-15 flexion/ abduction	Hand below shoulder height	Rest, hanging/ supported or -elevation 0-30 or +elevation	0-60 flexion/ abduction both	0-20 or arm supported	0-20	
	1 Mild			20-60	15-45 flexion/ abduction		30-60	> 60 flexion/ abduction one	20-45 or +elevation	20-45	
	2 Mild		45-90 flexion/ abduction	60-100	45-90	Flexion/ abduction	60-90	> 60 flexion/ abduction both	45-90	45-90	
	1 Severe		> 90 flexion/ abduction	100-140	> 90 flexion/ abduction	Hand above shoulder height or without hand tool			> 90	>90	

Table A.1 The micropostural classification

Body Part	Status	References									
		1	2	3	4	5	6	7	8	9	10
	2 Severe			140-180		Hand above shoulder height or with a hand tool					
Shoulder to sagittal plane	**Adduction**										
	Neutral				0-15		Hanging/ supported or -elevation		Arm supported		
	Severe			> 10	> 15		+elevation				
	Abduction										
	Neutral		0-45 flexion/ abduction	10 adduction-45 abduction	15 extension-15 flexion/ abduction	Hand below shoulder height	0-30	0-60 flexion/ abduction both			

Table A.1 The micropostural classification

Body Part	Status	References									
		1	2	3	4	5	6	7	8	9	10
	1 Mild				15-45 flexion/ abduction		30-60	> 60 flexion/ abduction one	> 0 or +elevation		
	2 Mild		45-90 flexion/ abduction	45-90	45-90 flexion/ abduction		60-90	> 60 flexion/ abduction both			
	1 Severe		> 90 flexion/ abduction	90-145	> 90 flexion/ abduction	Hand above shoulder height or without hand tool	> 90				
	2 Severe					Hand above shoulder height or with a hand tool		Pump			
	Rotation external										

Table A.1 The micropostural classification

Body Part	Status	References									
		1	2	3	4	5	6	7	8	9	10
	Severe			> 5					> 0		
	Rotation internal										
	Neutral			5 external rotation-25 internal rotation							
	Mild			25-65					> 0		
	Severe			> 65							
	Flexion										
	Neutral			80-125	60-120				60-100	60-100	
Elbow	Mild			45-80; 125-150	0-60; > 120				0-60; > 100	0-60; > 100	
	Severe			0-45; 150-180							
	Supination										

Table A.1 The micropostural classification

Body Part	Status	References									
		1	2	3	4	5	6	7	8	9	10
	Neutral			35 supination-30 pronation	15 supination-15 pronation				> 0 supination/ pronation		
	Severe			> 35	> 15				At/near end		
	Pronation										
	Severe			> 30	> 15				At/near end		
	Extension										
	Mild			16-45	16-45				0-15	0-15	
Hand	Severe			> 45	> 45				> 15	> 15	
	Flexion										
	Neutral			0-15	0-15				0	0	

Table A.1 The micropostural classification

Body Part	Status	References									
		1	2	3	4	5	6	7	8	9	10
	Mild			16-45	16-45				0-15	0-15	
	Severe			> 45	> 45				> 15	> 15	
	Ulnar deviation										
	Neutral			0-25	0						
	Severe			25-50	> 0				> 0		
	Radial deviation										
	Severe			0-20	> 0				> 0		
	Neutral				Standing; sitting;						

Table A.1 The micropostural classification

Body Part	Status	References									
		1	2	3	4	5	6	7	8	9	10
Lower extremity	Mild				Kneeling; moderate squat: 91-180°;				If the legs and feet are well supported when seated with weight evenly balanced; if standing with the body weight evenly distributed over both feet, with room for changes of position	Bilateral weight; walking or sitting	

Table A.1 The micropostural classification

Body Part	Status	References									
		1	2	3	4	5	6	7	8	9	10
	Severe				Severe squat: < 90°				If the legs and feet are not supported or the weight is unevenly balanced.	Unilateral weight bearing; feather weight bearing or unstable posture	

Note. 1=Kilbom et al. (1986); 2=Keyserling (1986); 3=Armstrong et al. (1982); 4=Genaidy et al. (1993); 5=Fransson-Hall et al. (1991); 6=Persson and Kilbom (1983); 7=van der Beek et al. (1992); 8=McAtamney and Nigel Corlett (1993); 9=Hignett and McAtamney (2000); 10=Kee and Karwowski (2001).

Appendix B. Literature reviews of the contributing factors for working posture

Table B.1 Literature reviews of the contributing factors for working posture

Body part	Contributing factors	Concepts included	Remarks	Reference
Shoulder, trunk, elbow, wrist	Physical exposure factors	Adjustability of workstation, Type of keyboard, Time of day, Sex	Keyboard operation	(Green et al., 1991)
Head lateral/sagittal, Trunk lateral/ sagittal Head-trunk lateral/ sagittal		Height of the monitor, angle of the screen	VDT operators, Sitting	(Wall et al., 1992)
Upper extremity, upper torso	Psychosocial factors	Job Content Instrument (psychological work load; decision latitude; job insecurity; job dissatisfaction), Work Interpersonal Relationships Inventory (WIRI) (supervisor support and conflict; co-worker support and conflict)	VDT operators, Sitting	(Faucett & Rempel, 1994)
	Pregnancy	Pregnant vs. non-pregnant	Standing	(Paul & Frings-Dresen, 1994)
Trunk, head, upper arm	Machine design parameters	Sewing machine design, slope of sewing table, arm support, pedal distance, pedal height	Sewing tasks, Sitting	(Li et al., 1995)

Table B.1 Literature reviews of the contributing factors for working posture

Body part	Contributing factors	Concepts included	Remarks	Reference
Head(neck), trunk, cervical spine		Computer monitor height	Computer use, Sitting	(Burgess-Limerick et al., 1998; Burgess-Limerick et al., 1999)
Upper body, seated posture		Keyboard tray geometry, wrist rests	Computer use, Sitting	(Hedge et al., 1999)
Upper limb	Ergonomic interventions	Extension of benches; removal of the underside of work benches; provision of adjustable chairs; provision of foot stools; provision of wrist rests and document holders; adjustment of computer-screen height	Female biomedical scientists	(Kilroy & Dockrell, 2000)
Upper body		Table height, desk slope and pedal position	Sewing machine operation, Sitting	(Delleman & Dul, 2002)
Neck, shoulder		Symptomatic/asymptomatic	Office workers	(Szeto et al., 2002)
Back	Comfort		Sitting	(Vergara & Page, 2002)
Neck, shoulder		Screen height	VDT work	(Seghers et al., 2003)
Upper extremity		Upper extremity support	Keyboard use	(Cook et al., 2004)

Table B.1 Literature reviews of the contributing factors for working posture

Body part	Contributing factors	Concepts included	Remarks	Reference
Neck, low back		Furniture, computer use	School students	(Grimes & Legg, 2004)
Back, arms, legs		Low-cost ergonomic improvement	Cleaners, OWAS	(Kumar et al., 2005)
Trunk forward, flexion motion	Personal factors	Obesity	Standing task	(Gilleard & Smith, 2007)
Head, neck, upper limb		Computer display height, desk design (forearm support)	Information technology work by young adults	(Straker, Burgess-Limerick, et al., 2008; Straker, Pollock, et al., 2008)
Upper arm, trunk		Working heights, weights of milking units	Female Milking Parlor Operative	(Jakob et al., 2012; Jakob et al., 2009)
Arm elevation, neck flexion, trunk flexion	Personal factors	Gender		(Hooftman et al., 2009)
Head, neck, upper extremity		Notebook lap (on or not)	Computer user	(Asundi et al., 2010)

Abstract (in Korean)

자세는 특정 순간의 신체 관절 위치의 조합으로 결정되고, 사람은 매 순간 자연스럽게 좋거나 나쁜 자세를 취하며 살아간다. 좋은 자세는 건강한 삶을 위한 필요 조건으로, 좋은 자세의 중요성은 이제는 누구에게나 당연한 진리가 되었다. 좋은 자세는 건강과 여러 이점을 보장해주지만, 반대로 나쁜 자세는 여러 질환을 유발한다. 특히 나쁜 자세는 여러 질환 중에서도, 근골격계 질환을 유발한다고 알려져 있다.

근골격계 질환은 근골격계 시스템에 발생하는 고통이나 통증을 의미하는데, 누적성 질환의 성격이 크다. 산업화와 함께 분업이 정착되고 반복성 작업이 근로자들의 주작업이 되면서 근골격계 질환의 발병률 또한 갈수록 증가하고 있다. 작업과 관련되어 발생하는 근골격계 질환은 특히 작업 관련성 근골격계 질환이라 한다.

작업 관련성 근골격계 질환을 예방하고 대응하기 위해 수많은 연구들이 이루어져 왔는데, 이러한 시도들 중, 근골격계 질환의 위험 요인을 파악하기 위한 노력들 또한 중요한 주제로 아주 최근까지도 계속 진행되어 오고 있다. 연구 결과 가장 영향력 있는 요인들로는 부적절한 작업 자세, 과도한 힘, 반복성임이 분명하게 밝혀졌다. 이 중 부적절한 작업 자세는 여러 연구들에서도 가장 많이 인용되는 요인이기도 하다.

그렇지만, 이러한 작업 자세에 영향을 주는 요인을 규명하는 연구들은 작업 관련성 근골격계 질환의 위험 요인 관련 연구들과는 달리 아직까지 많이 이루어지지 않았다. 작업 자세와 관련된 연구들은 주로 특정 조건 하에서 특정

과업을 취할 때 자세가 어떻게 변화하고 영향을 받는지 등과 같은 연구들이 전통적으로 이루어졌고, 작업장 내 여러 요소들이 실제로 작업 자세에 어떻게 영향을 주는지에 대한 연구는 아직 진행되지 않았다.

본 논문은 이러한 연구 동기에서 출발하여 '작업 자세에 영향을 주는 요인들은 무엇이 있으며, 그들의 영향력 수준은 어떠한가'의 연구 과제를 해결하는 것을 목적으로 한다. 해당 과제를 해결하기 위해 모든 요인을 고려할 수는 없으므로, 영향력을 줄 것으로 예상되는 후보군 선정이 우선되어야 한다. 후보군 선정을 위해 작업 자세 영향 요인을 직접 연구한 연구들을 우선적으로 참고하였다. 그렇지만, 이와 관련된 연구들은 전술했듯이 많지가 않기 때문에, 작업 자세가 가장 주요한 원인으로 꼽히는 작업 관련성 근골격계 질환의 영향 요인 관련 연구를 참고하였다.

본 논문의 첫 연구는 현재까지 발표된 체계적 문헌 연구 (systematic review)들의 결과를 종합하는 개요 연구 (overview study)이다. 본 개요 연구를 통해 작업 관련성 근골격계 질환의 위험 요인들을 수집 및 표준화를 수행하였고, 각 위험 요인들과 신체 부위 별 관계를 파악하였다. 본 연구 결과를 활용하여 작업 자세 영향력 요인의 후보군을 도출하였다. 해당 후보군은 크게 개인 요인, 사회심리적 요인, 물리적 위험 요인으로 구분된다.

도출된 후보군을 기반으로 실제 현장 조사를 통해 데이터를 수집하였다. 현장 조사는 7 년에 걸쳐 자동차 조립 공장을 대상으로 진행되었다. 수집된 데이터는 앞선 세 가지 요인과 작업 자세를 포함한다. 조사된 작업 자세 정보와 기타 데이터들에 대한 통계적 분석을 통해 각 요인들의 영향력을 파악할 수 있었다.

기존의 인간공학적 평가 기법들은 작업 평가 시, 작업의 위험 수준과 조치 수준 개념을 제시하고 있다. 그렇지만, 기존 기법들에서 제시하는 이들 값들은 변별력이 크지 않고, 개발 근거가 빈약하다. 또한 기존 기법들은 개발된 목적이 한정적이기 때문에, 다양한 특성의 작업들에 일괄적으로 적용될 수 없다는 문제점을 지니고 있다. 이러한 기존 기법들의 한계점 및 문제점을 보완할 수 있는 개선된 기법이 요구되어, 본 논문에서는 새로운 기법을 제시하는 것을 목적으로 하였다. 이를 위해 작업 만족도와 작업 스트레스 등을 반응 변수로 하여 통계적 기법과 기계 학습 기법을 적용하였다. 이를 통해, 작업 만족도 및 작업 스트레스 정량화 모델이 개발되었다.

자동차 조립 공장을 조사하면서 작업 자세 측정 이외에도, 작업장 내의 인간공학적 문제점을 발견하고 이를 해결하기 위한 시도를 진행해왔다. 인간공학적인 문제를 해결하는 것은 작업 자세와 근골격계 측면에서도 매우 중요하다. 이에 본 논문에서는 사례 연구로써, 자동차 조립 공장 내의 인간공학적 문제를 파악하고 이들 문제점의 근본적인 원인을 파악해보았다. 그리고 이들 문제점을 해결하기 위한 개선안을 제시하였다. 제시된 개선안 중 실제 작업 현장에 적용이 된 개선안들은 추적 조사를 통하여 효과성을 검증해보았다. 효과성 검증 과정에서는 개선 전후 작업 자세의 비교와 인간공학적 평가 기법 평가 결과의 비교가 이루어졌다.

작업 현장의 근골격계 질환을 효과적으로 관리하기 위해서는, 수많은 관련 정보들을 효율적으로 관리할 수 있어야 한다. 정보의 효율적인 관리는 정보의 입력과 출력의 용이성으로 결정되는데, 이러한 측면에서는 데이터베이스 시스템이 가장 적합한 시스템이라 할 수 있다. 이에 본 연구에서는 작업 현장의 근골격계 질환을 관리하기 위한 데이터베이스 시스템을 개발하였다.

해당 데이터베이스 시스템은 접근성을 제고하기 위하여 웹 기반으로 개발하였다. 또한 데이터베이스 시스템과 더불어, 신뢰성 있고 손쉬운 작업 자세 분석을 위해 작업 자세 분석 소프트웨어를 개발하였다. 해당 연구를 통해 개발된 두 시스템은 학계의 연구자들과 현장의 실무자들 모두를 도울 수 있을 것이라 기대된다.

주요어: working posture, musculoskeletal disorders, risk factors, video observation, follow-up study

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