Ergonomic Evaluation of Technology Change at Work and Its Effects on Health

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ABSTRACT

Technology changes in a work system at a workplace can have a consequential effect on the health of workers. On the basis of this observation, five studies were carried out using ergonomic methods to evaluate the impact of such effect in relation to four different technology changes. These changes relate to work concept, work tools, work environments, and production system. The purpose was to identify MSDs risk factors caused by the technology changes in order to be able to outline possible preventive measures.

Study I: the aim of this study was to assess the working conditions and the attitude of 12 experienced dentists who are users of the Proprioceptive derivation (Pd) concept in Thailand. Data was collected using questionnaires. The results showed that the Pd concept can reduce the stress level of dentists by making it easier to handle patients with physical limitations, but the continuous sitting posture appears a potential risk for developing back pain. Most dentists who used Pd found it useful.

Study II: the aim of this study was to investigate the differences in dentist’s working posture when adopting the Pd concept and the Conventional concept. Both observation and RULA assessment methods were used. The result showed differences in the dentists’ sitting posture, clock-related working position, and RULA score. It implied that the Pd concept helps the dentists to discover new ways to position themselves, and working comfortably and effectively, which made it possible for the dentists to adopt better working posture and have lower RULA score.

Study III: the aim of this study was to introduce and evaluate a redesigned cleaning tool for cleaning a train wagon. The cleaners’ physiological responses, trunk posture and subjective assessment were measured. The results showed that floor cleaning in the train wagons is associated with moderately high cardiovascular load and high frequency of stressful working postures. The redesigned cleaning tool allowed cleaners to maintain more upright posture while cleaning, which reduce biomechanical and physiological loads on them.

Study IV: the aim of this study was to identify cleaning problems and evaluate the effect of low-cost improvement on the cleaners’ working posture. Data was collected using participatory ergonomic technique and the OWAS method. The results showed that the participatory ergonomics technique is a good means for identifying cleaning problem and the outlining of possible improvement. The low-cost improvement eliminated awkward working postures in the cleaners such as sitting on one and/or two bent knees, as well as working with arms raise above the shoulder.

Study V: the aim of this study was to evaluate the ergonomic and production system effectiveness in a redesigned production system (from parallel flow dock-based, to serial flow line-based assembly). Data was collected by informal interviews, questionnaires, and video recording. The results showed that the line-based system displayed much tighter link between operators and the technical system resulting in the introduction of system balance and downtime losses. There were also reductions in cycle times (upto 6% of previous), decision
latitude, influence and control over work, perceived work load, and perception of available pauses. Layout and technology changes helped improve co-worker interaction and support, and reduce instances, but not magnitude, of peak spinal loading.

In conclusion, technology changes can have both positive and negative effects on the humans’ health. Ergonomic methods can be used to evaluate these effects. Self-reported questionnaire can give the information on working condition, and attitude of the people working under the change in technology. RULA and OWAS were very useful for identifying and analyzing the postural risk factor. Direct measurement such as physiological responses was useful to identify work load on human body. Participatory ergonomic is also a very useful method for identifying problem, and possible solutions for improving the working conditions. Further, the results from ergonomic evaluation can provide useful information which is needed for future intervention or work-system design in each industry for preventing MSDs at the work place.

**Key words:** Ergonomics, technology change, MSDs risk factor, dentists, cleaners, workers, Proprioceptive derivation, production system
LIST OF PUBLICATIONS

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1. INTRODUCTION

Ergonomics (or human factors) is a scientific discipline concerned with the understanding of interactions among humans and other elements of a system. According to the International Ergonomics Association (IEA, 2000), ergonomics is a discipline that applies theory, principles, and methods in the design of work in order to optimize human well-being and overall system performance. In other words, ergonomics is a science concerned with the ‘compatibility’ between people and their work system. It puts people first, taking account of their capabilities and limitations. It aims to make sure that tasks, equipment, information and the environment fits each worker (HSE, 2003). Ergonomics involves making workers comfortable and safe among other things, while they work through the design of equipment and processes that integrate with the body to allow low-stress activity for extended periods. In order to assess the fit between a person and his/her work, ergonomists have to consider many factors. These include the following:

- The job being done and the demands on the worker.
- The equipment used (its size, shape, and how appropriate it is for the task).
- The information used (how it is presented, accessed, and changed).
- The physical environment (temperature, humidity, lighting, noise, vibration).
- The social environment (such as teamwork and supportive management).

1.1 Incompatibility in a work system

A system, from the perspective of Checkland (1981), is a set of elements connected together which form a whole. As he explains, this set of elements possess properties of the whole rather than of that its component parts. In this respect, activity within a system is viewed to be a result of the influence of one element on another. According to Checkland, this influence is called feedback and can be positive or negative in nature. Based on this perspective, Smith and Sainfort (1989) have observed that every workplace has a work system that can be characterised by its technology, organisation, environment, tasks, and the people necessary to perform these tasks (figure 1). Within this context, they suggest that the connections between these components may be in or out of balance. According to Smith and Sainfort, when any of the connections are broken or out of balance, performance or quality suffers and/or more injuries occur. Thus by ensuring that these connections are balanced, the health of any workplace can be improved.

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1 i.e. the characteristics of the feedback can be either positive or negative.
A simple system can be depicted as a user using a tool, within a workplace and in a given environment. As Bridger (2003) explains, the incompatibility, unfit, or out of balance in the work system can occur for a variety of reasons as exemplified below:

- Inappropriate task design (e.g. new device introduce unexpected changes in the way tasks are carried out and incompatible with user knowledge, habits, or incapability with other tasks).
- Inappropriate tool design (e.g. tools require high cost of energy to operate).
- Inappropriate work environment design (e.g. the environment is uncomfortable and inappropriate to perform task, such as very low room temperature in office).

1.2 Common consequential impact of incompatibility in the work system

The common consequential impact of such incompatibility in the work system (as concerns the relation between the human and his/her workplace) is the emergence of musculoskeletal disorders (MSDs). Whereas, Work-related musculoskeletal disorders (WMSDs) is a musculoskeletal disorder caused (or aggravated) by either the work environment or performance of the work (Armstrong et al., 1993; Hales, 1996). Musculoskeletal disorders (MSDs) is viewed as a significant problem throughout the world, and also as one of the major occupational disease of the early twenty-first century. Specifically, it is considered to be a major occupational health problem (i.e. musculoskeletal disorders) in many industrialised countries.

These musculoskeletal disorders can have considerable socio-economic effect on both workers and organisations, in terms of increased costs to workers, organisations and the society in general. As clarified by SWEA (2001) as well as Buckle and Devereux (2002), these costs represent both direct costs (compensation, medical care, etc.) and indirect costs such as long sickness-related absences, reduced productivity and quality (Alexander and Albin 1999). Yet, despite the scale of economic impact, the consequences of WMSDs now

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2 For example, Hagberg et al., 1995; Bernard et al., 1997; WHO, 1999.
includes adverse effect on physical and psychological well being of affected people as well (Bernard et al., 1997; Hoogendoorn et al., 2000; van den Heuvel et al., 2005).

1.3 Why is it important to do this research?

It is important to do this research, because some MSDs risk factors may be reduced in the ergonomic intervention with relatively little cost, others risk factor can be inherent to the design of tools/task/environment itself. Change in technology and/or design of tools, task, and work stations are considered as common ergonomic interventions for musculoskeletal health. Thus, a change in one factor can affect the others and ultimately the system output. For example, a change in technology can have an impact on the human operator, the environment, and the social, political and economic system (Shahnavaz, 2000). In addition, the impact of an intervention will depend on the extent to which risk factor, described in the epidemiological evidences (e.g. Bernards 1997), are eliminated from the workplace. If the risk factor are not reduced substantially the little impact on ever increasing MSDs can be expected. For prevention of MSDs, a proper analysis of work tasks and associated exposure to work related factors is necessary (Dul et al., 1989; 1994).

1.4 Rationale behind the research

Ergonomic methods can be used as tools to identify and evaluate the impact of technology on health at the workplace. Health means a dynamic state of complete physical, mental, spiritual and social wellbeing and not merely the absence of disease or infirmity (WHO, 1998). Health can be defined as the absence of illness, functionally as the ability to cope with everyday activities, or positively, as fitness and well-being (Wikipedia, 2005). In this thesis, both definitions were adopted, but focus on musculoskeletal health of the workers and the risk factors related to the musculoskeletal disorders. Therefore, my focus is on using ergonomic methods to identify, and evaluate the effects of four different technological interventions on the heath of people (i.e., muscular discomfort, work posture, and stress at work) from three different professions (dentistry, cleaning, and manufacturing). The interventions which involve the adoption of new technology/changes to work techniques, tools, and work environments are as follows: - change in working concept; change in working tool; change in workstation/environment; change in production system.

1.5 Aim of study

1.5.1. General aim

The purpose of this thesis is to apply the ergonomic methods to evaluate/identify the work conditions, and MSDs risk factors where the change at work existed. Five studies have been incorporated into this thesis. Study I and II, evaluates the effect of the Pd concept in Thai dentistry. Study III, and IV, the effects of changes in work conditions among cleaning personnel through cleaning tools and work environment were evaluated. Study V, an attempt to integrate ergonomic method to identify MSDs risk factors after the change in production system design was explored.
1.5.2. **Specific aims of each study**

The specific aims are as follows:

- The aim of study I was to evaluate the working conditions and the attitude among experienced dentists when working according to the Proprioceptive derivation (Pd) concept.
- The aim of study II was to evaluate working posture among dentists when working according to the Pd vs Conventional concept.
- The aim of study III was to evaluate the effects of the redesigned cleaning tool on Physiological, postural loads and subjective perception in cleaners when working in passenger train wagon.
- The aim of study IV was to apply participatory ergonomic method for identification of the cleaning problems and to evaluate the effect of the low-cost improvement on the cleaner’s working posture.
- The aim of study V was to investigate the MSDs risk factors in relation to the change in production system design.
2. THEORETICAL FRAMEWORK

2.1 Musculoskeletal disorders (MSDs)

The term musculoskeletal disorders (MSDs) stands for a group of pathological conditions that impair the normal function of soft tissue of the musculoskeletal system which involve the nerves, tendons, muscles, and supporting structures such as intervertebral discs (NIOSH, 2000). The disorders of the musculoskeletal system represent a main cause for absence from occupational work and lead to considerable costs for the public health system (WHO, 2003). Common examples of MSDs are: low back pain, neck pain, and upper limbs disorders. The severity of these disorders may vary between occasional aches or pain to exactly diagnosed specific diseases. Occurrence of pain may be interpreted as the result of a reversible acute overloading or may be a pre-symptom for the beginning of a serious disease.

2.1.1. Multi-factorial Origin of MSDs

It is generally agreed that musculoskeletal disorders are characterized as multifactorial occupational problem (van der Beek and Frings-Dressen, 1998). Many epidemiological studies have linked the musculoskeletal disorders development to various factors (Bernard et al., 1997; Hoogendoorn et al., 1999; Bongers et al., 2002; Simoneau et al., 2003). However, findings from several scientific studies have classified these factors into physical (Winkel and Mathiassen, 1994), psychosocial/organizational (Bongers et al., 1993, 2002; Devereux, et al., 2004), and individual (Armstrong et al., 1993) occupational ‘risk factors’ for the development of work-related musculoskeletal disorders (WMSDs).

2.1.2. Relationship between MSDs and Risk Factor

The National Research Council has outlined a broad conceptual framework indicating that various work and other factors may play roles in the development of musculoskeletal disorders (figure 2). This conceptual framework serves as a useful tool to reflect the relationship between various factors (i.e. work procedures, equipment and environment; organisational factors; physical and psychological factors of individuals, non-work-related activities, organisational factors, and social factors) and the development of musculoskeletal disorders.

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3 A risk factor is a condition present in the workplace that is associated with the onset of health problem (Simoneau et al., 2003).
2.2 Ergonomic methods for identifying MSDs risk factors

Several ergonomic techniques have been applied to gather information about “man-at-work” and MSDs risk factors. Among the widely used ones in ergonomic evaluation are systematic observation, questionnaires, direct measurement, subjective assessment, video-based method, and participatory ergonomics.

2.2.1. Systematic observation

Observational methods are the more common means of data collection in the industry. Most observation methods developed are posture-based techniques with the addition of other factors such as force and task duration in some methods. Observations methods have been widely used by many researchers to quantify the posture at work. This is reasonable since posture is one of the major factors that influence muscular strength (Cutlip et al., 2000). The adopted body posture during work is a major contributing factor to the health risks of physical workload. Examples of observation methods are as follows: Rapid Upper Limb Assessment (RULA), designed to assess the severity of postural loading and particularly applicable to sedentary jobs (McAtamney and Corlett, 1993); Ovako Working Posture Analysis System (OWAS) used to assess the quantity and quality of work postures (Louhevaaraa, and Suurnäkki 1992); Quick Exposure Check for work-related musculoskeletal risks. (QEC), used to assess the change in exposure for both static and dynamic task (Li and Buckle, 1998; 1999).
2.2.2. Questionnaires

Questionnaires have been used by many researchers. In terms of reporting the incidence of musculoskeletal problems, the Nordic Musculoskeletal questionnaire has been used extensively (Dickinson, 1998). Kuorinka (1983) used the Nordic Musculoskeletal Questionnaire to define the discomfort parts of the body region. This questionnaire have been tested and shown to be a useful screening instrument for the study of work-related musculoskeletal complaints in different occupations (Kuorinka et al., 1987) and has been shown to be acceptable (Ohlsson et al., 1994; Ingelgård, 1996). There was evident that the psychosocial factors, known as MSDs risk factors, can be identified by using questionnaires as well (Karasek, 1979; Karasek and Theorell, 1990).

2.2.3. Direct measurements

A wide range of this kind of method has been developed. An example of this method is the measurement of oxygen consumption, heart rate are also widely measured to identify physiological workload (Louhevaara et al., 1990; Nevala-Puranen and Sorensen, 1997; Aminoff, et al., 1999). Electromyography (EMG) has been used to identify the muscular workload (Åkesson et al., 1999; 2000). Other methods of direct instrumentation are through the application of Electrogoniometer have been used to determine joint angle (Åkesson et al., 1999; Hansson et al., 2001). However, these methods require direct contact and also have the potential to change work methods, and thus, are not feasible for practical use in the industry (Vedder, 1998). Thus these tools have rarely been used as a major data collection medium in the industries due to the difficulties associated with worker mobility, obtrusiveness and cost (Buchholz et al., 1996).

2.2.4. Subjective assessment

The widely used subjective assessment is Rating of Perceived Exertion (RPE). It gives a cross comparison to the physical measure, and allow the investigator to explore how the job perceived by the job holder (Kilbom, 1995). The Borg’s RPE scale is based on the physical sensations a person experiences during physical activity, including increased heart rate, increased respiration or breathing rate, increased sweating, and muscle fatigue. It is a 15-unit scale (rating from 6-20, scaled to represent one-tenth of heart rate under suitable conditions.) The result of this is a data set that allows the researcher to draw comparisons as to the relative strain of the tasks both between and within individuals. Although this is a subjective measure, a person's exertion rating may provide a fairly good estimate of the actual heart rate during physical activity (Borg, 1998). Borg’s RPE was widely used in many researches (Mital et al., 1994; Norman et al., 2003; Mengelkoch and Clark, 2005) to assess job tasks where the nature of the work is mainly physical. The Borg’s CR-10 scale is a 10-level scale developed later, and can be used to estimate the intensity level of jobs. It equates verbal descriptors with position on the scale according to a quantitative meaning. It is a general intensity scale for most perceptual intensity, exposure, emotions, not only perceived exertion and difficulty. It can be used in a similar way as Borg’s RPE scale, but the CR-10 is more complicate in its construction than RPE scale (Borg, 2005).

In spite of using the RPE scale, interview and questionnaire that make use of two kinds (ranking and/or rating) of questions can be used in subjective assessment as well (Van der Beek and Frings-Dresen, 1998).
2.2.5. Video-based method

The video-based method has been developed and used because it has many advantages in data collection of field studies, and makes it possible to obtain large amounts of data for offline observation methods (Dudley, 1968). Furthermore, analyses of video recordings offer possibilities of assessing the exposure in a precise manner in assembly work (Kilbom et al., 1986; Jonsson et al., 1988), and also meet the main criteria of exposure assessment method that was suggested by the European Agency for Safety and Health at Work (Buckle and Devereux, 1999).

Video-based method has been widely used to record and analyse work postures. Examples included the ARBAN, which was used to record and evaluate work postures to identify stressful parts of the work (Kilbom et al., 1986). VIRA is another video-based method for recording and analysing the stress and pattern of movement (Kilbom et al., 1986). Another video-based method is the VIDAR method (Kadefors and Forsman, 1997), where the subjects themselves study the recordings and judge the discomfort of the work. Furthermore, time aspects of exposure, such as frequencies and variation across time, are strongly suspected to be important to the risk of developing musculoskeletal disorders (Winkel and Westgaard, 1992) have pointed that the. Therefore, the video-based method was used to quantify the amount of time the workers utilised in different activities in many researches (Engström and Medbo, 1997; Chaikumarn, 2001; Forsman et al., 2002).

2.2.6. Participatory ergonomics

According to the Noro and Imada (1991), participatory ergonomics is a method in which end-users of ergonomics take an active role in the identification and analysis of ergonomics risk factors, as well as the design and implementation of ergonomics solutions. Amongst the various ergonomic approaches, participatory ergonomics is an increasingly popular approach where general information and less specific solutions are desired.

Participatory ergonomics consists in the workers' active involvement in implementing ergonomic knowledge and procedures in their workplace, supported by their supervisors and managers, in order to improve their working conditions (Nagamachi, 1995). Participatory ergonomics has been claimed to add several advantages to the traditional ergonomic intervention, including the compilation of a powerful, diverse set of skills and knowledge on which to draw (Launis et al., 1996), with the increased likelihood of successful implementation of ergonomic solutions (Imada, 1991). Participatory ergonomics interventions have been associated with a decrease in the incidence of musculoskeletal symptoms (Halpern and Dawson, 1997; Moore and Garg, 1998), a decrease in work absenteeism (Moore and Garg, 1998) and an improved psychosocial work environment (Laitinen et al., 1998).

2.3 Criteria for selecting identification methods

An ergonomics analysis of a job may use tools that vary from simple, observational methods to more complex multi-dimensional techniques, i.e., directed measurement. The measurement of internal exposure increases the precision and sophistication of the analysis, but requires larger resources of time and money. A decision must be made, based on the expected utility of the tools, as to which method is best suited for the task. Winkel and Mathiassen (1994) have
described the differences in the exposure assessment method regarding cost, capacity, generality and exactness as shown in figure 3. In this respect, the selection of assessment method depends on the goals and setting of the study as well as on economics and practical feasibility. Further, a decision must be made, based on the expected utility of the tools, as to which method is best suited for the task.

![Figure 3. Differences between exposure assessment methods: self-report, observation methods and direct measurements (Winkel and Mathiassen, 1994).](image)

### 2.4 Technology change affect health

Technology is the development and application of tools, machines, materials and processes that help to solve human problems. As a human activity, technology predates both science and engineering. It embodies the human knowledge of solving real problems in the design of standard tools, machines, materials or the process (Wikipedia, 2005). This thesis has also adopted the definition of Technology from the National Library of medicine (NLM) which states that “The application of scientific or other organized knowledge--including any tool, technique, product, process, method, organization or system--to practical tasks”. Implementation of technology at the work places has contributed to economic growth and social progress as well as a reduction in many sources of occupational accidents, injuries and stresses. However, traditionally, an implementation of new technology is technology centred, often failing to consider the implications on the personnel involved. The result is a suboptimal work system, not only in terms of productivity but also in terms of the psychological and physical well-being of employees (Nadin et al., 2001). In addition, advanced technology has also introduced new sources of work stress and injuries (Karuppan, 1997). Consideration of ergonomics in the choice and utilization of the transferred technology can help to create a good fit between technology, users and the operating environment (Shahnavaz, 2000).
2.5 Technology change and MSDs in dentistry

Mangharam and McGlothan (1998) conducted a review of the literatures; their review revealed that there is a relationship between working as a dental professional and the incidence of work-related musculoskeletal disorders and psychological stress. Murphy (1997) also reported a correlation between risk factors and the dental practice. These risk factors included constrained and fixed sitting posture, awkward postures (neck/shoulder/wrist postures), exertion of force (extraction of teeth), repetitive motions (scaling), and duration of force. These risks were related to, so called, ergonomic risk factors,--work station design, tool design, work object (patient), work techniques, work organization (case load), and work environment (lighting, noise, and climate).

A great deal of new technology has been integrated into the modern dental office during the last several decades. The concept of change in dental practice by using technology in dentistry has started many years ago. By the early 1960s, the “sit-down” method was introduced to the dentistry instead of “standing” working posture with an assumption that the sit-down method could reduce the prevalence rate of musculoskeletal disorders, especially low back pain, among the dentists (Murphy, 1997). However, the dentists still have muscular discomfort in their body, even though they had change from standing to sit-down dentistry. With an increasing numbers of developing painful musculoskeletal symptoms, it was suggested that changes must be made to the way they practice to allow for a better healthy status (Graham, 2002). Considering that suggestion, the new technologies and changes aimed to give the dentist better comfort and health condition. Therefore, there were more new technologies and work concepts that have been presented to the dentistry after the sit –down dentistry, which included the four-handed dentistry (Finkbeiner, 2001a,b) , and the Proprioceptive derivation (Pd) concept (Belenky, 1998). Thus new technology was expected to offer dentists the opportunity to maintain their peak performance without compromise of their posture, their work procedure, or their patient’s position while providing the dental care (Belenkey, 1998).

The Pd concept

This thesis will focus on a technology called Proprioceptive derivation (Pd) concept in study I and II. The Pd concept has been used in many countries, such as Japan, North America and some countries in Europe. In Thailand, one dental school implemented the Pd concept at the beginning of the foundation of the school. One objective of using the Pd concept is to improve dentists’ health and performance, increase productivity and the quality of dental care [Thammasat University, 2004]. The Pd concept is developed by Dr Daryl R. Beach. At first, this concept is called Performance logic (Beach, 2001; Dougherty, 2003). A primary aim of the Pd concept is to provide the dentists a good posture and optimal control of dental task while minimizing musculoskeletal discomfort. In the Pd concept, dentists are encouraged to determine their most balanced and comfortable working posture, and then integrate that posture into their clinical practice. Once dentist sit in a comfortable posture, the patients' oral cavity is positioned to support the dentists' derived balanced position, and fine adjustments are made during the appointment concerning the Pd concept, they can maintain their balanced positioning, and able to work more accurately, more efficiently, and with less physical and mental demand (Dougherty, 2005). However, the Pd concept has a suggested sitting posture, or an “Ideal posture”. A simple description of the ideal posture according to the Pd concept is that the dentist sitting upright, both hands at the heart level, being able to easily reach necessary equipment and materials, the patient lies down horizontally (figure 4).
This ideal posture and position can be achieved through the self-proprioceptived derivation and a complementary performance process (Colangelo and Belenky, 1990). In addition, the Proprioceptive derivation concept fundamentally includes a system of reasoning that guides dentists to determine their most comfortable working posture and position, and increases their awareness of work environment and preferred working position. This concept provides the dentists a number of strategies; such as five movements, ten-step protocol, which help them to maintain their ideal posture with optimal control while working (Belenky, 1998; Sunell and Maschak, 1996; Rucker and Sunell, 2002). However, this advanced technology in dentistry may have a harmful effect on dentists relative to musculoskeletal disorders. Hence, both the location of equipments and using patterns can affect the working way of the dental professional (Laderas and Felsenfeld, 2002). Thus, ergonomics evaluation is an effective way to obtain information of the impact on dentists’ health which is derived from the Pd concept (Study I and II).
2.6 Technology change and MSDs in cleaning

An increased prevalence of MSDs among cleaners was associated with hand tools and non-ergonomic tools (De Vito et al., 2000). Furthermore, epidemiological and experimental studies supported the view that poor design and excessive use of hand tools can increase the risk of accidents, fatigue and musculoskeletal disorders (Mital and Kilbom, 1992). From an ergonomics point of view; existing tools, task/methods, working environment needed to be redesigned in order to reduce occupational injuries among cleaners. Consequently, the researches on MSDs in cleaners in the recently year focuses on the potential association of these problems with the design and use of cleaning equipment (Wood and Buckel, 2005).

Passenger train wagon cleaning is a unique type of cleaning work characterised by a high concentration of physical activities in time and space that are not fully under the direct control of the service providers and their workers. The confined workspace (due to maximisation of carrying capacities and comfort of passengers) is potential underlying risk factors for the development of musculoskeletal disorders among the cleaners. Space on board is precious, and thus the working space for cleaners to perform their tasks is usually restricted and very limited. From the workplace analysis in the passengers train wagon, it was found that most of the awkward working postures among cleaners were due to the workstation and existing tool. Changing workstation inside the train wagon was not possible due to lack of flexibility in design and require much more money. Therefore, changing the cleaning tool was an obvious choice which can give cost-effective technological intervention for preventing MSDs in this situation. However, there is need to evaluated whether the redesigned cleaning tool could reduce WMSDs risk factors on the cleaners (Study III).

In an office environment, many high-technology equipments were used in office such as computers, scanners, etc. These equipments benefit the office workers to work more efficient and productively, whilst this kind of working environment may have negative effect on the cleaners, especially on their work postures. In view of the fact that the cleaners generally work in the building that are planned for other workers and not typically designed to accommodate the cleaning and thus can cause problem on cleaners (e.g. location of furniture, layout of the workspace, accesses, office equipments, etc.). Change or intervention of the workplace layout (i.e. location of furniture, accessories) could impact the cleaners’ working posture, thus there is a need for an ergonomic evaluation of this change (Study IV).

2.7 Technology change and MSDs in manufacturing industry

In most manufacturing companies there is a choice of using manual labour and automated production system. However, one must then distribute the manufacturing tasks in an optimal way. This task allocation must be productive for the company and, it must create satisfying jobs for the employees (Helander and Willén, 2003). Technologies have been implemented in the manufacturing industry as a response to more global and expansive marketing in order to improve production system, assembly processes, layout and workplaces. Besides, increased demand on shorter delivery times, higher product variety, and quality and decreased manufacturing costs force manufacturers of complex assembled products to improve the flow of assembly orders together with more efficient employment. Martinelli and Carri (1996) assessed the risk of biomechanical overload of the upper limbs in the ceramics industries, the results shown that the progressive automation of the ceramics industry does not seem to have
reduced the risk of biomechanical overload disorders in the upper limbs, at least in relation to those jobs which still feature manual tasks. Coury et al., (2000) compared the repetition of wrist movements and force produced by workers when packing pencils in three different production systems and their findings indicated that partial automation does not necessarily decrease or eliminate wrist movements performed by human operators.

Moreover, the technology changes within the industry forces the workers to work under time constrain. Consequently, the prevalent rationalization procedures in manufacturing industry include to a large extent the manipulation of different aspects of time. Examples of time-related variables are throughput time, work-in-progress, product cycle time, line balancing, buffer capacity and resource utility, which are optimized to improve performance. On the other hand, manipulation of these parameters may impair workers’ health even with unchanged work postures, total amount of repetitive work and manual material handling. The intensification is achieved through more goal-directed work with gradually less manpower, tighter deadlines, etc, which increases the time in value-added work (Aronsson, 1999; Merllié and Paoli 2000). The consequence of this intensification caused workers having less time for informal breaks/micro pauses in the individual jobs, reduced job control. In addition, this present of risk factors derived from intensification of the work seems to be influencing job contents and the rates of work-related musculoskeletal disorders. In addition, it has long been suggested that technology changes tend to increase the incidence of musculoskeletal disorders in particular occupations (Ohara et al., 1976; Bammer, 1987). Furthermore, the production system and the characteristics of the working environment of advanced manufacturing technology may pose stress-related threats to employees and causing WMSDs among them (Karuppan, 1997). However, the negative impact of these potential sources of stress can be buffered or even eliminated with relatively inexpensive technological features and good management policies designed to increase the operator’s job control.

Different types of production system have impact on the workers working condition. Several studies have reported a relationship between production system and increased risk of musculoskeletal disorder (Ólafsdóttir and Rafnsson 1998; Frediksson et al., 2001; Neumann et al., 2002). The change in production system can have effects on the worker when adopting a new production system. Thus, ergonomic evaluation can be used to investigate such ergonomic consequences (study V).

2.8 The research framework

Musculoskeletal disorders (MSDs) is a complex phenomenon. Several risk factors interacting with one another contribute to its development. Because of the multi-factorial nature of MSDs, it has become necessary to look at a broad spectrum of outcome measures to assess the effects of these factors. To establish a healthy work system, it is important to evaluate the working conditions in order to monitor the presence of MSDs risk factors that could derive from any change in the work system. Job or working conditions presenting multiple risk factors will have high probability of causing MSDs, therefore, the presence of risk factor must be evaluated (Simoneau et al., 2003). By taking this into account, I have outlined the character of my research to reflect the specific phenomenon that can arise with respect to the implementation of the four different technological interventions in different professions as shown in figure 5.
As indicated in the figure 5, WMSDs can result from different types of technology changes. Thus in order to understand the consequences of the introduction of new technology in the work system on health, it is important that an ergonomic evaluation is carried out. In this respect Study I evaluated work condition and attitude of dentists on the Pd concept. Study II assessed the impact of the Pd concept on working posture. Study III investigated the effect of physiological load on cleaners when using a redesigned cleaning tool in a train wagon. Study IV involved the evaluation of new work system for cleaners. Study V looked at the health effect of a new production system among workers in a truck engine assembly line.
3. METHODOLOGY

3.1 Study 1: Working conditions and dentists’ attitude towards Proprioceptive derivation.

- **Participant**
  Twelve dentists (4 males and 8 females) participated in the study. They all worked as dentists and university lecturers. They all know and currently use the Pd concept. Their working experience with the Pd concept ranged from 8 to 36 months.

- **Tools**
  The self-administered questionnaires were designed and the questionnaire was translated into Thai language by the researcher with the help of some Thai dentists. Some questions were taken from the existing questionnaire (Chowanadisai *et al.*, 2000). The questionnaire considering the occupational stress among dentists was adapted from Cooper *et al.*, (1978), and was validated by the Thai dentists before distributed to the participants. The content validity of questionnaire was assured by 3 dentists (including experienced dentist who use the Pd concept). The questionnaire has an instruction part to help the participants to understand how to fill in the questionnaire.

The Questionnaire: a self-administered questionnaire which was divided into two parts.

*Part 1:* Covered the following topics: individual characteristics (age, gender, handedness, level of education, and years in profession) and working conditions (working hours, number of patients per day, working posture, working time, working technique, breaks between cases). The dentists were asked about the working time spent on five main dental work tasks: dental examination, teeth cleaning, dental filling therapy, preparation for crowns and bridges, and tooth extraction and working situations causing stress. They were asked to rate stress caused by each working situation on a 6-point rating scale (from 1—*no stress at all* to 6—*very high degree of stress*).

*Part 2:* In this part of the questionnaire the dentists were additionally asked how often they used Pd, their attitude to it, and the reason for their attitude.

- **Study design and procedure**
  This study is a case study using self-administered questionnaires to collect the information on the working situation, and the attitude of the dentists toward the Pd concept. After the questionnaire was improved, the questionnaires were distributed to all participants by personal distribution, during daytime at work. The questionnaires were collected 1 week after the distribution.

- **Data analysis**
  The SPSSS10.0.1 software was used in order to perform descriptive and analytical statistical analysis.
3.2 Study 2: Differences in dentist’s working posture when adopting Proprioceptive derivation vs Conventional concept

- **Participants**
  Two groups of dentists participated in this study. The first group, *Pd group*, consisted of 8 dentists who have been working with Pd concept. The second group, *Conventional group*, consisted of 10 dentists who have been working with conventional concept.

- **Study design & Procedure**
  The observational study was conducted separately for each group by the same observer. Each observation took around 15-30 minutes on each dentist in both groups. The observation was carried out while the dentists were working with a patient. The postures of each dentist were recorded on the data collection sheet for further postural analysis.

- **Data Analysis**
  The sitting postures of each dentist were analyzed according to categorisation of sitting posture for dentists, clock-related sitting position (Rundcrantz *et al.*, 1991). A RULA assessment (McAtamney and Corlett, 1993) was used to gives a quick and systematic assessment of the posture of dentists. The most extreme, unstable or awkward posture from each dentist was selected and scored in a RULA worksheet. The final score and action level were also processed by using the free online RULA software. The mean RULA score of each group was calculated and compared by using a SPSS statistical analysis software. The RULA score and Action level is shown in table 1.

<table>
<thead>
<tr>
<th>Action level</th>
<th>RULA score</th>
<th>Indicates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 or 2</td>
<td>Posture is acceptable if it is not maintained or repeated for long periods</td>
</tr>
<tr>
<td>2</td>
<td>3 or 4</td>
<td>Further investigation is needed and changes may be required.</td>
</tr>
<tr>
<td>3</td>
<td>5 or 6</td>
<td>Investigation and changes are required soon</td>
</tr>
<tr>
<td>4</td>
<td>7 or 8</td>
<td>Investigation and changes are required immediately.</td>
</tr>
</tbody>
</table>

Table 1. RULA score and Action levels (McAtamney and Corlett, 1993).
3.3 Study 3: Physiological, subjective and postural loads in passenger train wagon cleaning using a conventional and redesigned cleaning tool

- **Participants**
  Thirteen healthy professional cleaners (12 females and 1 male) participated in the study. Their professional experience ranged from 1 to 21 years. Twelve of the cleaners were right-handed and one left-handed.

- **Cleaning tools**
  A commercially available long straight handle cleaning tool for floor mopping was used as a conventional cleaning tool. The length of the tool could be adjusted between 105 cm and 190 cm. The redesigned cleaning tool was bent at three points, upper, middle and lower part of the tool in such way that it produced an arc shown in the figure 6.

![Figure 6. (a) Conventional cleaning tool, (b) redesigned cleaning tool.](image)

- **MetaMax II**
  The MetaMax II was used in this study because it is a portable metabolic measurement system, which can be used to measure oxygen consumption (VO$_2$)$^4$, heart rate (HR) of the participant. It was calibrated before used in each experiment. There is evidence that the O$_2$ uptake reported by the MetaMax is precisely measured within subjects (Medbo *et al.*, 2002). Henriksson-Larsén (2002) also found a good reliability and validity of measurement with MetaMax II system.

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$^4$ **VO$_2$**: The oxygen consumption is determined by calculating the difference between the amount of oxygen inhaled and exhaled.
• **Study design & Procedure**

The design of this study was an experimental design. The maximum oxygen uptake (VO_{2\text{max}})\(^5\) of the cleaners was determined by performing a test on a bicycle ergometer (Tuntri, 850 ECB PRO, Ergometer). Cleaners were asked to cycle at a steady rate (60 revolutions per minute) of 50 watts for two minutes with subsequent increases of 50 watts every two minutes until exhaustion (Price and Campbell, 1997). The cleaners were asked to try to maintain a certain pedal frequency of 60 rpm by using a metronome, which produced a sound signal (Åstrand and Rodahl, 1986).

To minimize the fatigue effects due to the bicycle ergometer test, the cleaning tests were performed after three days (Mackinnon, 1999). The cleaning tool was randomly assigned to each cleaner in performing each test.

They cleaned an area of 52 m\(^2\) where dry sand and papers were used as materials to be cleaned during the 15-minute test. The cleaners were required to maintain a fixed work pace. During the test, oxygen consumption was recorded every 10 seconds and heart rate was recorded every five seconds (Bridger et al., 1997).

After the first test, the cleaners had a rest interval of 15-30 minutes during which the resting heart rate was obtained (Bridger et al., 1997). The Cleaners were asked to rate their perceived exertion to ascertain the magnitude of estimation of work intensity due to change in floor cleaning tool on the Borg’s RPE scale (Borg, 1982) 30 seconds before the end of each test (Borg, 2001).

The same protocol was repeated for the second test, but another tool was used. Both tests were recorded on videotape in profile for posture and biomechanical analysis of the cleaner’s postures during the tests.

• **Data analysis**

All values of measured variables are expressed as means and standard deviation. Postural angles (maximum trunk bending) were assessed using photographs in profile of cleaners reaching under the bed while cleaning with both tools (figure 7). The reference point was lumbosacral (L5/S1) and cervical (C7) joining the centre of gravity line (Hagner, 2001).

A paired t-test was used to determine differences between the oxygen consumption, heart rate and postural variable. A Sign test was used to determine the differences in perceived exertion. Probability values of \(p<0.05\) were accepted as being statistically significant.

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\(^5\) The maximum capacity for oxygen consumption by the body during maximum exertion
Figure 7: Trunk angle, (a) trunk angle while cleaning with conventional cleaning tool, (b) trunk angle while cleaning with redesigned cleaning tool.
3.4 Study 4: Participatory ergonomics and an evaluation of low-cost improvement effect on cleaners’ working posture

- **Subject**
  Twenty-three professional female cleaners from one University in Sweden participated in a Participatory Workshop (PW). Their age range from 24 to 54 years, and average length of work experience was 14 years.

  In the evaluation of the effect of workplace improvement, ten female cleaners, from the PW’s participants, participated in test 1-(before change was made) and test 2- (after change was made).

- **Study design & Procedure**
  - **Participatory ergonomic**
    The PW was carried out step by step as the recommended outlines for the process of participatory ergonomics (Noro, 1991; Kuorinka, 1995; Vink et al., 1995). The theme “Problems while cleaning” of PW was defined by active discussion of all the cleaners. The goal of the PW was to highlight all the problems related to the present work situation or conditions, which the cleaners experienced and wanted to change.

    Each participant described the problem that she had been experienced in short form. The PW leader wrote down, the verbatim from the cleaners on a block of large size of paper with a running number. The rounding continued until all the cleaners could not come up with any problem other than what had already been expressed. It meant that cleaners had emptied themselves of all criticisms. After listing all problems, each participant ranked the three most critical problems from the list and the PW leader ranked the listed problems from the first to the last.

    The computer and electric cables were ranked as first by the cleaners due to the difficulties while mopping the floor. Due to the cables on the floor cleaners has to squat and lift the cables with one hand and mop the floor with another. The possible ergonomics solution, suggested by cleaners for first ranked problem, was to fix the cables above the floor by attaching the cables to the working table in such a way that they do not lay on the floor in a scattered fashion, or hang in the air (figure 8).

![Figure 8. a) Cables on the floor; b) cables above the floor attached to the working table.](image)
Evaluation of the effect of low-cost improvement

Six of 220 office rooms were selected for the test purpose; all six rooms were used by the staff of the University.

Ten female cleaners, from the PW’s participants, participated in test 1 and test 2 and the length of each test was 30 minutes per cleaners. In test 1, they cleaned the room with the cables on the floor using their habitual pace and style. Test 2 was carried out after all cleaners finished test 1. In test 2, the cables were fixed above the floor by attaching to the working table, and the cleaners were asked to perform the cleaning task in the same manner as they had performed in first test. One decilitre of dry sand was used as cleaning dust on the floor in both tests so that cleaners should maintain their normal pace.

The working postures of the cleaners in both tests were recorded on videotape for task analysis and postural analysis using the OWAS (Ovako Working Posture Analysis System) method (Hopsu and Louhevaara 1991). The OWAS is a useful tool for the evaluation of postural load during work and it is easy to apply this method in field investigations with a relative high reliability (Karhu et al., 1977; Louhevaara et al., 1992; de Bruijn et al., 1998) and suitable to catch dynamic hazardous working postures when workers are moving around their workstation. OWAS has also shown convergent validity when compared to other posture recording techniques for instance Rapid Entire Body Assessment (REBA) (McAtamney and Hignett 1997).

Data analysis

The cleaners’ postures were analyzed from the recorded videotapes by means of the “Winowas” computer software (WinOWAS, 2003). The random time interval for coding the cleaning posture was 10 seconds. The cleaner’s postures were analyzed according to different work phases (corresponded with the task analysis) for both test, and the proportionate share of postures for different work phase was calculated in percentages and assigned an action category code. The OWAS action code is defined as follows in table 2.

Table 2. The OWAS action code

<table>
<thead>
<tr>
<th>Action category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Change not required</td>
</tr>
<tr>
<td>2</td>
<td>Change required in the near future</td>
</tr>
<tr>
<td>3</td>
<td>Change required as soon as possible</td>
</tr>
<tr>
<td>4</td>
<td>Change required immediately</td>
</tr>
</tbody>
</table>
3.5 Study 5: Ergonomics and productivity consequences in adopting a line-based production system

- **Study design and procedure**
  A longitudinal case study, and comparison the result from pre- and post-production system change was performed. This study integrated qualitative and quantitative methods. A Follow-up measures, were made 6 months after the change. The detailed quantified posture and task information is not yet available in this study; however, preliminary data from qualitative study, postural load analysis, questionnaire, and system performance data were presented.

- **Material**
  - Informal interviews and document analysis were conducted to understand both process and outcomes in the system redesign project. Production and economic data were obtained from company information systems and interviews.
  - Questionnaires (n=81 pairs) were used to assess operators’ perceptions of pain and discomfort using a modified Nordic questionnaire (Kuorinka et al., 1987) status, workload (RPE-10), and psychosocial factors (Karasek, 1979; Karasek and Theorell, 1990).
  - Video recordings were made synchronously with data logging and analysed with respect to the time used for work activities including direct (value adding) and indirect work. Posture data was obtained for each activity category. In order to understand operators’ movement between work areas a position logging system (originally from orienteering) was implemented.
  - Biomechanical models by WATBAK software were used to assess individual loading (Neumann et al., 1999).

- **Data analysis**
  Pair comparison was used to analyse the data from questionnaires (n=81 pairs). Data from video recording were used to compare the cycle time and biomechanical load, and cycle time (n=8 pairs).
### 3.6 Summary of key methodology

Summary of key methodology feature of the 5 studies is showed in table 3.

<table>
<thead>
<tr>
<th>Study feature</th>
<th>Study I</th>
<th>Study II</th>
<th>Study III</th>
<th>Study IV</th>
<th>Study V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study type</td>
<td>Field study</td>
<td>Field study</td>
<td>Experiment</td>
<td>Participatory &amp; field study</td>
<td>Field study</td>
</tr>
<tr>
<td>Study design</td>
<td>Case study</td>
<td>Case study</td>
<td>Experimental</td>
<td>Intervention/ case study</td>
<td>Case study</td>
</tr>
<tr>
<td>Study focus on</td>
<td>workers</td>
<td>workers</td>
<td>workers</td>
<td>workers</td>
<td>workers</td>
</tr>
<tr>
<td>Participants</td>
<td>Dentists</td>
<td>Dentist</td>
<td>Cleaners</td>
<td>Cleaners</td>
<td>Industrial workers</td>
</tr>
<tr>
<td>Industry</td>
<td>Dentistry</td>
<td>Dentistry</td>
<td>Cleaning</td>
<td>Cleaning</td>
<td>Manufacturing</td>
</tr>
<tr>
<td>Study location</td>
<td>Thailand</td>
<td>Thailand</td>
<td>Sweden</td>
<td>Sweden</td>
<td>Sweden</td>
</tr>
<tr>
<td>Technology Change focus</td>
<td>Work concept</td>
<td>Work concept</td>
<td>Work tool</td>
<td>Work environment</td>
<td>Work system</td>
</tr>
<tr>
<td>Ergonomic method used</td>
<td>Questionnaires</td>
<td>Direct observations, RULA assessment</td>
<td>Physiological response, trunk posture, subjective assessment</td>
<td>Participatory ergonomics, video-based analysis, OWAS</td>
<td>Video-based analysis, questionnaire, Direct measurement goniometry Preliminary evaluation (comparison between OLD and NEW system)</td>
</tr>
<tr>
<td>Key ergonomics approach</td>
<td>Evaluation</td>
<td>Investigation, evaluation, Comparison between Pd concept &amp;conventional</td>
<td>Evaluation</td>
<td>Problem identification, Intervention and evaluation</td>
<td>Spinal load, body discomfort, Psychosocial factor</td>
</tr>
<tr>
<td>Key result</td>
<td>Work situation, Attitude, stress level, Working posture, RULA score and action level</td>
<td>Physiological, subjective, postural load assessment</td>
<td>Working posture, and OWAS category</td>
<td>Spinal load, body discomfort, Psychosocial factor</td>
<td></td>
</tr>
<tr>
<td>Level of technological intervention</td>
<td>organisation</td>
<td>organisation</td>
<td>individual</td>
<td>individual</td>
<td>organisation</td>
</tr>
</tbody>
</table>
4. RESULTS

4.1 Study I: Working Conditions and Dentists’ Attitude Towards Proprioceptive Derivation.

Part 1: working condition

- **Working posture**
  All dentists used a sitting posture as their working posture.

- **Working Techniques**
  All dentists used the 4-handed technique (they always had dental assistants when they gave dental care to patients).

- **Working time spent on each dental work task**
  The dentists reported how much time, on the average, they spent on each task. The result is presented in table 4.

Table 4. Time Spent on Each Dental Task

<table>
<thead>
<tr>
<th>Dental Task</th>
<th>Duration (min) M ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dental examination</td>
<td>9.0 ± 7.7</td>
<td>3–30</td>
</tr>
<tr>
<td>Teeth cleaning</td>
<td>24.1 ± 5.9</td>
<td>15–30</td>
</tr>
<tr>
<td>Dental filling therapy</td>
<td>24.6 ± 5.2</td>
<td>20–30</td>
</tr>
<tr>
<td>Crown and bridge therapy</td>
<td>42.0 ± 21.0</td>
<td>20–60</td>
</tr>
<tr>
<td>Tooth extraction</td>
<td>16.0 ± 6.1</td>
<td>10–30</td>
</tr>
</tbody>
</table>

- **Breaks between patients**
  Only five dentists (41.7%) reported that they had breaks between patients. The average duration of brake was 5 min.

- **Physical demands and feeling of exhaustion after work**
  Most of the dentists felt that dental work was physically demanding, and they also felt exhausted at the end of their working day.

- **Overtime work**
  The dentists were asked if they worked overtime. The results showed that most of them did not. Only one out of the 12 dentists worked overtime, Monday to Friday, 12 times during the past month.

- **Working situations that cause stress**
  “Patients disliked the treatment provided” was rated as the most stressful working situation among all dentists (Table 5).
Table 5. Working Situations That Cause Stress and Average Scores ($M \pm SD$) of Dentists’ Stress.

<table>
<thead>
<tr>
<th>Working Situation</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients with physical limitations</td>
<td>2.75 ± 0.62</td>
</tr>
<tr>
<td>Patients do not cooperate</td>
<td>3.17 ± 0.83</td>
</tr>
<tr>
<td>Patients dislike the treatment they are given</td>
<td>3.50 ± 1.24</td>
</tr>
<tr>
<td>Pain and anxiety in patients</td>
<td>2.75 ± 1.06</td>
</tr>
<tr>
<td>Cancelled or late appointments</td>
<td>1.91 ± 1.08</td>
</tr>
<tr>
<td>Difficult communication and interaction with staff</td>
<td>2.08 ± 1.31</td>
</tr>
<tr>
<td>Routine and dull work</td>
<td>1.75 ± 0.75</td>
</tr>
<tr>
<td>Patients do not accept treatment</td>
<td>2.25 ± 1.36</td>
</tr>
<tr>
<td>Difficult cases</td>
<td>3.33 ± 0.89</td>
</tr>
<tr>
<td>Keeping to schedule</td>
<td>3.33 ± 1.23</td>
</tr>
</tbody>
</table>

Notes. Scores: 1—no stress at all, 2—very low degree of stress; 3—low degree of stress; 4—moderate degree of stress; 5—high degree of stress; 6—very high degree of stress.

Part 2: Dentists’ Attitude towards the Pd concept

- **How often did they use the Pd concept?**

Five dentists used the Pd concept sometime and seven dentists used it always. In this study, *use* means that the dentist was used about (a) hardware, i.e., proprioceptive derived-tools and equipment, and (b) software, i.e., the working procedure, the senses, feelings, and the relationship between him or her and the environment (derived from using Pd) while providing dental care.

- **Did they like or dislike the Pd concept?**

Ten dentists liked Pd, and seven of them always used it. Only two dentists disliked Pd and both of them used it sometime.

- **Why did they like or dislike the Pd concept?**

Figure 9 shows the assigned reasons on why the dentists like the Pd concept.

![Figure 9. The reasons why the dentists liked the Pd concept (n=12).](image-url)
4.2 Study II: Dentist working posture and muscular discomfort in adopting different work concept

Working posture
All dentists chose to sitting as their main working posture. None of the dentist alternated their posture between sitting and standing. Further, dentists in Pd group used dental chairs with lumbar support which was designed according to the Pd concept. Dentists in conventional group used normal office chairs with backrest.

Categories of sitting posture
The sitting posture of dentist can be categories into 4 categories (Rundrantz et al., 1991). The results were shown in table 6.

<table>
<thead>
<tr>
<th>Sitting Posture Category</th>
<th>Description</th>
<th>Pd (n=8)</th>
<th>Conventional (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The whole back bent and the seat straight</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>Straight low and upper back, the neck bent, the seat straight</td>
<td>7</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>The whole back bent, the seat tilted forward</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Straight low and upper back, the neck bent, the seat tilted forward</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>

The clock-related working positions
The most frequent clock-related working positions were assessed. The result was show in table 7.
Table 7. The main clock-related working positions of dentists working with the Pd and the Conventional concepts.

<table>
<thead>
<tr>
<th>Position</th>
<th>Pd (n=8)</th>
<th>Conventional (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 o’clock</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>11 o’clock</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>10 o’clock</td>
<td>1</td>
<td>8</td>
</tr>
</tbody>
</table>

RULA score and Action Level

There was a significant difference in average RULA score between two groups of dentists (p<0.05). The average RULA score of dentist in Pd group was 3.5, which fall into Action level 2: indicates that further investigation is needed and changes may be required. The average RULA score of dentists in Conventional group was 5.6, which was fall into Action level 3: indicates that investigation and changes are required soon.
4.3 Study III: Physiological, subjective and postural loads in passenger train wagon cleaning using a conventional and redesigned cleaning tool.

Physiological and subjective assessment
Table 8 shows the physiological variable measured on the cleaners: average oxygen consumption, average heart rate in beats per minute, perceived exertion on Borg’ RPE scale, and percent maximum oxygen uptake on the cleaners.

Table 8. Variables measured on the cleaners while cleaning with the conventional and the redesigned cleaning tools (n = 13).

<table>
<thead>
<tr>
<th>Variables</th>
<th>Conventional cleaning tool</th>
<th>Redesigned cleaning tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Oxygen consumption (l/min)</td>
<td>0.94</td>
<td>0.18</td>
</tr>
<tr>
<td>Oxygen consumption (ml/m/kg)</td>
<td>15.25</td>
<td>2.38</td>
</tr>
<tr>
<td>Average heart rate (BPM)</td>
<td>105</td>
<td>12.59</td>
</tr>
<tr>
<td>Perceived exertion (Borg scale, CR-20)</td>
<td>13</td>
<td>1.77</td>
</tr>
<tr>
<td>Maximum oxygen uptake capacity in %</td>
<td>36</td>
<td>6.26</td>
</tr>
</tbody>
</table>

* Significant difference between conventional and redesigned cleaning tool (p < 0.05).

Postural analysis
There was a significant difference (p=0.05) in angle of the trunk bending. The mean angles of trunk bending, while the cleaners using the conventional cleaning tool was 87°, and when using the redesigned cleaning tool was 50°.

Participatory ergonomics

The computer and electric cables were ranked as first by the cleaners due to the difficulties while mopping the floor. Due to the cables on the floor the cleaners has to squat and lift the cables with one hand and mop the floor with the other. One possible ergonomics solution, suggested by cleaners for first ranked problem, was to fix the cables above the floor by attaching the cables to the working table in such a way that they do not lay on the floor in a scattered fashion, or hang in the air.

Postural Analysis

The total number of OWAS observation for each test was 1370 for the 10 participated cleaners. The proportionate share of postures of different body parts were analyzed and categorized into different action categories. After analyzing the posture of test 1, it was found that only mopping and dusting proportions fell into category 3 and 4. In test 2, floor mopping task does not fall into the categories 3 and 4 (table 9).

Table 9. OWAS Category for Mopping Task Before and After Fixed Cables

<table>
<thead>
<tr>
<th>Cleaning Task</th>
<th>% of Working Time</th>
<th>OWAS Category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cables on Floor</td>
<td>Cables Above Floor</td>
</tr>
<tr>
<td>Mopping</td>
<td>38 40</td>
<td>35 60</td>
</tr>
<tr>
<td></td>
<td>4 -</td>
<td>24 -</td>
</tr>
<tr>
<td></td>
<td>73 75</td>
<td>2 2</td>
</tr>
<tr>
<td>Dusting</td>
<td>25 23</td>
<td>25 -</td>
</tr>
<tr>
<td></td>
<td>73 75</td>
<td>2 2</td>
</tr>
</tbody>
</table>

The amount of working posture for floor mopping was decreased from 36% to 33% of the total working time after fixing the cables above the floor (figure 10).
The differences were found in the proportion of the back, arms and legs posture between test 1 and test 2 during floor mopping task (Table 10).

Table 10. The OWAS Proportion of Back, Arms and Legs Posture in Floor Mopping Task in Test 1 and Test 2.

<table>
<thead>
<tr>
<th>Posture</th>
<th>Test 1 (Cables on Floor, %)</th>
<th>Test 2 (Cables Above Floor, %)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BACK</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straight</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>Bent</td>
<td>32</td>
<td>37</td>
</tr>
<tr>
<td>Twisted</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Bent and Twisted</td>
<td>29</td>
<td>23</td>
</tr>
<tr>
<td><strong>ARMS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both below shoulder</td>
<td>74</td>
<td>100</td>
</tr>
<tr>
<td>One above shoulder</td>
<td>26</td>
<td>—</td>
</tr>
<tr>
<td>Both above shoulder</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><strong>LEGS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standing on two legs</td>
<td>36</td>
<td>51</td>
</tr>
<tr>
<td>Standing on one leg</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>Sitting on two bent knees</td>
<td>6</td>
<td>—</td>
</tr>
<tr>
<td>Sitting on one bent knee</td>
<td>17</td>
<td>—</td>
</tr>
<tr>
<td>Kneeling</td>
<td>6</td>
<td>—</td>
</tr>
<tr>
<td>Walking</td>
<td>30</td>
<td>39</td>
</tr>
</tbody>
</table>
It was found that by fixing the cables above the floor did affect the posture of cleaners only in floor mopping task and the cleaners did not squat while cleaning under the table (Figure 11).

Figure 11. Change of working posture during floor mopping task; a) with cables on the floor; b) cables above the floor.
4.5 Study V: Ergonomics and productivity consequences in adopting a line-based production system.

Postural loading
- The system-wide peak spinal loading was about the same in both systems with 470N shear loading and L4/L5 compression over 2600N.

Questionnaires
- Pair-wise comparisons of operators experienced in both dock and line systems (n=54) indicate significant (p<0.05) reductions in ‘decision latitude’, ‘influence and control of work’, and ‘physical exertion’ scales and increases in ‘social support’ and ‘relationships with fellow workers’ scales in the NEW system compared to OLD system.
- While a trend (p<0.11) of reduced general ‘physical discomfort’ was observed, the ‘Nordic’ symptom instrument indicated increases in shoulder pain (3-month history).
- Most operators also reported reduced work variation, and reduced stimulation in the NEW system.
- The operators reported lower back loading on the Borg RPE scale (P<0.01) on the new system.
- These results are consistent with a shorter cycle, pace-controlled system with in which operators are close enough to talk to each other.

System performance
- There was a 6% reduction in production cycle times from the NEW system.
5. DISCUSSION

The introduction of new technology in a work system can have both positive and negative impact on how work is designed, organized, and managed. This can be viewed from the perspective of the synergy that can exist between the new technology and its users (workforce). Negative consequences of technology have been a major concern to ergonomists. Health problems, human error and social consequences have been addressed (Ohara et al., 1976; Bammer, 1987; Mital and Kilbom, 1992; Smith and Carayon, 1995; Karuppan, 1997; Merlić and Paoli 2000, Shahnavaz, 2000; Velachi and Velachi, 2003). Despite the existence of problems associated with such changes, there are positive effects present too. The positive effects of technology change are mostly seen in many workplaces where ergonomic interventions were implemented. The following effects have been found: reduction of workers’ musculoskeletal pain and discomfort, reduction of work load, reduction of working time, better working posture, increased productivity, improved working condition (Kogi et al., 2003 Robertson and O’Neill, 2003; Street et al., 2003).

5.1 Technology change – positive or negative for the people involved?

5.1.1 Positive effects of technology change

In Study I, my analysis shows that the Proprioceptive derivation (Pd) concept made it possible for the dentists to spend less time on Dental examination and Crown and bridge therapy tasks. When comparing this finding to that of Finsen et al., (1998), the dentists using Pd concept spend less amount of time only in Dental examination task. The cycle time that the dentist performs can be influenced by many factors. Though these factors were not clearly obvious to me from this study, Fujita et al., (1997) has reported that skilled dentist have an advance ability to have shorter cycle time. Also, by using the Pd concept, the dentists reported low stress score in Solving problems in patients with physical limitations which is in contrast to the high score reported by Cooper et al., (1978). Possible explanation of the low stress score, in my opinion, can be ascribed to the advantage of using the Pd concept equipment. In this respect, the dental bed allows easier accessibility to patients with physical limitations, such as disabilities and the elderly. The special headrest helps the dentist to position the patient’s head and also keeps the patient’s mouth in a predictable position, irrespective of the patient’s height. The study also found that the majority of the dentists who used the Pd concept liked it, and viewed it as useful for their dental work. The reasons they assigned for this view is that it minimised physical stress in the muscles, especially in shoulder and back region, enhanced the accuracy of treatment, provided better communication with patients and assistants, minimised treatment time, and minimised finger-hand contact with the light and chair.

In Study II, data on quality of sitting posture, and RULA postural analysis on dentists adopting the Pd concept and conventional concept was analysed. The results showed that most of the dentist working with Pd concept retain better sitting posture and have lower RULA score than dentists who use the conventional concept. The implication of these results is that the Pd concept helps the dentists to discover new ways of positioning themselves. It also allows the dentists to work comfortably and effectively by ensuring that they adopt a better working posture, which exposes them to lower risks of upper limbs disorders.
Nevertheless, the Pd technology may not be a main cause for the observation made earlier (i.e. its positive effect on the dentists’ working postures) since many factors can influence the determination of posture and position of dentists (e.g. type of treatment, patient’s position) as observed by Pollack (1996).

The redesigned cleaning tool was introduced for cleaning passenger train wagons (Study III). Analysis of the cleaners’ oxygen consumption (VO₂) showed that they used 31% of their VO₂ max while using the redesigned cleaning tool. This means that by using the redesigned cleaning tool, the cleaners can work 8-hours shift within an acceptable working load as recommended by International Labour Organisation (ILO) (Vanwonterghem, 1986). There was a significant reduction in heart rate during cleaning with redesigned tool as compared to conventional tool, which may be due to postural factors. The possible reason could be that in the adoption of upright cleaning posture, the large group of muscles of upper part of the body is not engaged as in the bending posture (Bridger et al., 1997). In addition, the trunk-bending angles of cleaners were decreased when they used the redesigned cleaning tool. Furthermore, using the Borg’s RPE scale, cleaning with the conventional cleaning tool was assessed by the workers to be somewhat hard (scale value 13) as compared to the redesigned cleaning tool which they assesses to be light (scale value 11). The overall RPE selection is based on the integration of cardiovascular, metabolic and localized sensations arising from the contracting skeletal muscles. Thus the possible reason of differences in RPE could be that the large group of muscles of upper part of the body is not engaged in more upright cleaning posture (Bridger et al., 1997).

In Study IV, the low-cost workplace change was implemented by means of fixing electrical cables above the floor and the effect this change was evaluated. The results revealed that none of the cleaners’ working postures fell into OWAS category 3 and 4. This indicates that the workplace change helped the cleaners to adopt a more safe working posture for mopping task. This finding is consistent with that of Street et al., (2003), which recommend that a participatory ergonomics programme may have a rapid effect on improving work posture in short duration and minimally disruptive to the normal workplace routine. Similarly, Kogi et al., 2003 found a reduction in work related musculoskeletal disorders and discomfort among employees after applying low-cost improvement to small enterprises. Therefore, it is clearly shown that this low-cost change benefits the cleaners to have a better working posture for floor mopping compared to an unchanged workplace condition.

In study V, video analysis of the working time showed a reduction in the cycle times of the workers by up to 6% of the previous production system. Questionnaire analysis showed a reduction in the workers’ perceived work load. Biomechanical analysis also showed a reduction of spinal load of the workers. Additionally, the Layout and technology changes in the NEW line system helped the workers to improve co-worker interaction and support as compared to the OLD dock system.
5.1.2. Negative effects of technology change

The result from Study I show that most of the dentists had breaks of around 5 min between patients. This is because they perceived dental work as a physically demanding job and felt exhausted at the end of the day. Continuous sitting in the same posture with no break can cause muscular discomfort. This seems to affect their perception of dental work as a demanding job causing exhaustion after work. Concerning responses on situations that cause stress, the notion that ‘patients disliked the given treatment’ was the most stressful situation among the dentists. This finding is consistent with that of Gorter et al., (1999) who reported that dentists had the highest mean scores of work stress related to patient contacts and work contents items. Furthermore, time management issue, such as cancelled or late appointment and coping with difficult patients also caused stress. As Wilson et al., (1998) has noted, time management including running behind schedule, coping with difficult or uncooperative patients, and working constraints were major job stressors among general dental practitioners. In addition, it was suggested that job stress may illicit responses that increase muscle co-activation and thus increase loading of the musculoskeletal system. Job stress may also reduce the ability to unwind, that is, it may hamper the ability to reduce the physiological activation to resting levels during breaks and after work and thus adversely influence recovery period (Lundberg, 2002).

An appraisal on the attitude of the dentists toward the Pd concept showed that only few of them did not like it. The assigned reason for this is that it did not cover all types of dental tasks/treatments. Specifically, one dentist did not want to use this concept due to its complexity and difficulty. These results might imply that dentist did not find it easy to adopt the Pd concept. As van Beer et al., (1998) has pointed out, the dentist may need more practice in order to get the right proprioceptive information. In addition, lack of adequate skills to use the technology leads to poor motivation, stress and diminished performance (Carayon and Smith, 2000). It was evidenced that attitudes towards expectation of mastery of technology together with usability were the most prominent sources of negative consequences of technology changes as well (Endestad, 2001). On the other hand when new technology is applied appropriately it can enhance job content and skill utilisation, leading to increased motivation and performance with decreased stress.

Based on Postural analysis in study II, it was found that all dentists working with the Pd concept chose to work in a sitting posture throughout the working period. Furthermore, the overall RULA score of the dentist who used the Pd concept are lower than that of dentists using the conventional concept. Although, the RULA score was low among the dentists who use the Pd concept, they still need to reduce MSDs risk that can result from static muscular work. Hence, sitting continuously was suggested to be a risk for back pain in dentists (Ratzon et al., 2000). Decreased micro-pauses in muscle activity may lead to muscle fatigue, even in case of low loads due to continuous firing of low threshold motor units, which are not only triggered by low level physical loading, but also by mental loading (Westgaard, 1999; Sjøgaard et al., 2000). Altering their working postures or having micropause during work may serve as a strategy to decrease or vary the muscular load (Hagberg and Hagber 1989; Hagber and Wegman 1987).
The redesigned cleaning tool (as appraised in Study III) has shown some advantages in its usage by the cleaners. Results showed a reduction in the cleaners’ physiological work load as well as their rating of perceived exertion (RPE). It also showed an enhancement in the ability of the cleaners to adopt a more upright posture in their cleaning task inside the passenger train wagons. However, further biomechanical analysis of load on the cleaners’ spine and upper extremities when using this redesigned tool need to be carried out. Such additional investigation can show if the redesigned tool has any negative biomechanical effect on human body.

In Study IV, the technology change was related to the low-cost improvement at the workplace as suggested by cleaners via a participatory ergonomics session. It was observed that as a result of this change, there was a reduction in the OWAS action category for floor mopping task (from category 3 and 4 to category 2). However, it was observed that the mopping task will still require future changes, as suggested in the description of OWAS action category by Mattila and Vilkki (1999).

In Study V, it was observed that workers experienced a decrease in decision latitude, influence and control over work after changing over from an OLD production system to a NEW one. This finding implies that the change in technology may have a negative effect on the psychosocial conditions of workers. As has been argued by Carayon and Lim (1998), psychosocial work factors fall into task elements such as; job demands (e.g., perceived quantitative workload, work pressure, cognitive demands), job content (e.g., challenge, repetitiveness), machine-pacing and job control. Thus the combination of high job demands and low decision latitude is the most stressful, according to the Job Strain model (Karasek, 1979), and which can lead to various health problems.

5.2 How to minimise the negative effect from technology change?

Once the presence of WMSDs problem has been detected, the next step is to take action. The further intervention to minimise the negative effect of technology must take into account the five main components of the work system: - the individual, task, organisation, the technology, and environment. Healthy work system is depending on a better balance between these components. By balancing the various elements of the work system, it will provide positive aspects to counter the negative ones. For instance, the negative influences of inadequate skill to use new technology can be offset by increased worker training (for Study I). The adverse influences of low job content can be balanced by an organizational supervisory structure that promotes employee involvement and control over the tasks (for study V). Jobs with many negative elements are jobs that produce the most adverse impact on the employee, whereas jobs that have better balance are less stressful and may actually produce positive outcomes, such as high quality of working life and enhanced quality of performance (Carayon and Lim 1994; Eklund, 1997).
5.3 Organisational factor helps to minimise the negative effect

Among work-related factors (such as work station design), ergonomic problems are not the only causes of MSDs. Organisational factors may also play a role. It is therefore evidence that if workers are involved in the process of technology change, it can help to reduce the subsequent negative effect that can evolve during implementation as was highlighted in study IV. In this regard, work organization can be viewed as an “objective” characteristic of the work environment (as noted by Hagberg et al., 1995) and which is depending upon many factors, such as management style, type of product or service, characteristics of the workforce, level and type of technology, and market conditions.

In the same vein, work organisation and psychosocial work factors can influence work-related musculoskeletal disorders in two ways (Smith and Carayon 1996). Firstly, work organisation defines the nature of work activities, the exposure to loads, the number and duration of actions, and other ergonomic considerations such as the environment and tool design. These factors interact as a system, producing an overall load to the musculoskeletal system of the worker (as observed in all studies). Secondly, work organisation may contribute to physiologic, psychological, and behavioural stress reactions to work factors, as observed in Study I and V. This therefore indicates that stress can lead to an increased physiologic susceptibility to work-related musculoskeletal disorders (Lundberg, 2002).

Other organizational considerations, such as work schedule and brakes, as was observed in Study I and II, can also have negative mental and physical health consequences on workers. This is supported by the findings of Smith and Carayon (1995) that the way in which workers are introduced to new technology or some other change, and the organizational support they receive—such as training and time to acclimate—are related to stress and performance. It is also generally assumed that participation and empowerment are positive characteristics of a work organization that can foster quality of working life, and reduce stress and health problems (Speer and Hughey, 1996; Wilson and Haines, 1997), as can be seen from study IV. Therefore, this is in line with the new theories of work organization and design which emphasized the need for more workforce involvement during the implementation of new technology, and for better workplace design to enhance human-machine interfaces as argued by Smith and Carayon (1995).
6. CONCLUSION

Though, the meaning of health is different for different individuals. As the objective of ergonomics is to improve both performance and health and safety, ergonomist could play his/her role in health promotion under this context by applying ergonomic knowledge which is aimed to ensure that technology is appropriately designed, properly installed and safely operated; to provide information of the health impacts of existing adopted technologies and modifying the work condition to remove hazards and to offer the preventive and remedial measures.

This thesis demonstrates that technology change could affect one's health. Technology changes can induce both positive and negative effects on the humans’ health in the work system. Ergonomic methods can be used to evaluate these effects. Self-reported questionnaires can give information on working condition, and attitude of the people working during the change in technology. RULA and OWAS were very useful for identifying and analyzing the postural risk factor. Direct measurement such as physiological responses was useful to identify work load on human body. Participatory ergonomic is also a very useful method for identifying problem, and possible solutions for improving the working conditions. Furthermore, it is therefore evidence that if workers are involved in the process of technology change, it can help to reduce the subsequence negative effect that can evolve during implementation of technology into the work system. Additionally, the results from ergonomic evaluation can provide useful information which is needed for future intervention or work-system design in each industry for preventing MSDs at the work place.
7. RECOMMENDATION

- The introduction of technology should not be confined only to the technology itself, there is a concern to provide information on the effects of the technology on the safety and health, and the working lives, of those involved.

- Ergonomists could play their role in health promotion under the technology change context by applying ergonomic knowledge which is aimed to ensure that technology is appropriately designed, properly installed and safely operated; to provide the means of analysing the safety and health aspects of existing imported technologies and modifying the work condition to remove hazards and to offer guidance for setting up the preventive and remedial measures.

- A recognition of the ergonomics consequences inherited from technology change or intervention should be emphasised, in order to minimize or avoid the negative effect derived from technology change in the work system, and to support human performance and thus to promote system efficiency. The theory of Job design can be used in order to maintain balance of the work system. For example, if it is difficult to change the repetitive nature of the particular job, this problem could perhaps be offset by improving work postures, reducing the effort required, and getting workers more involved in determining the content of their job.
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Paper I

Proprioceptive derivation (Pd), a new method of organising a dentist workstation as well as a working procedure, was introduced to Thailand. The aim of this study was to assess the working conditions and the attitude to Pd among experienced users. Questionnaires were distributed among 12 dentists. The results showed that all dentists chose to work in a sitting posture and mostly worked without breaks between patients. They spent less time on dental examination and crown and bridge therapy tasks. Solving problems in patients with physical limitations resulted in a low stress level. Seven dentists (58.3%) always used Pd and liked it. Five dentists (41.7%) sometimes used Pd, with 3 of them liking it. Only 2 dentists, who sometimes used Pd, did not like it because it could not cover all dental tasks and treatment, and it was difficult and complex.

In this concept, proprioception means "a sense or perception, usually at a subconscious level, of the movements and position of the body and especially its limbs, independent of vision; this sense is gained primarily from input from sensory

1. INTRODUCTION

Dental work includes a wide range of physical hazards. Musculoskeletal disorders are one obvious hazard. They may be caused by exposure to high precision work with long-lasting static loads in the cervical and shoulder regions [1]. Moreover, dentistry is an occupation with high psychological demands and with other ergonomics risk factors, which require effective ergonomics interventions to solve those problems [1, 2]. According to Pollack [3] the key aim of ergonomics for dentists is to allow them to achieve optimum access, visibility, comfort and control in clinical work.

The concept of ergonomics was introduced into dentistry in order to improve the dental profession’s working conditions; the work concepts included sit-down and four-handed dentistry [4]. An American dentist, Dr. Daryl Beach, developed a new concept for dental practice. It focuses on the positions, movements, contacts and comfort that dentists can sense with their bodies [5]. This concept is widely known as proprioceptive derivation (Pd). However, when the concept was first introduced, it was also identified as system or performance logic. In the Pd concept the adjustable conventional dental equipment and the work process are causative factors behind the high prevalence of musculoskeletal discomfort in dentists. Therefore, instead of a tilted dental chair and an adjustable lamp, Pd introduces equipment with minimum adjustability. The patient lies horizontally during treatment, and the dentist consistently works in a full upright alert seated posture. The dentist’s upright posture is considered to provide the best control of the fine stabilized finger movements required when operating in the mouth. By stabilizing the position of the mouth, the dentist and the assistant are able to easily reach necessary equipment and materials, they can work more accurately, more efficiently, and with less physical and mental wear and tear on both the patient and the dentist [6].

In this concept, proprioception means “a sense or perception, usually at a subconscious level, of the movements and position of the body and especially its limbs, independent of vision; this sense is gained primarily from input from sensory

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nerve terminals in muscles and tendons (muscle spindles) and the fibrous capsule of joints combined with input from the vestibular apparatus\textsuperscript{\textregistered} [7]. In other words, the concept of Pd allows the dentist to use proprioceptive self-awareness to determine the most efficient, stress-free process of performing dental procedures [8, 9].

When dentists learn Pd, starting with the training period, the dentist is neither told nor shown how to sit, how to position the patient, or how to maintain the relations in the dental process (such as height of the supportive system, position of the dental instrument tray). Instead, dentists individually remember these setting via their proprioception. The determination of the dentist’s posture, patient positioning, and the dental process are based on the five movements along with the ten-step protocol derived through the skilled practice of Pd [8].

1.1. Five Movements

During dental treatment based on Pd, dentists focus on five movements related to dentist

![Figure 1. Five movements in Proprioceptive Derivation [8] (p. 292).](image-url)
performance, posture and patient’s position (Figure 1):

1. Dentist movement around the patient’s head in a clockwise or counter-clockwise direction;
2. Patient head movement by rotation to the left or right;
3. Patient head tilt upward or downward;
4. Patient mandible movement: minimising or maximising the mouth opening of patient;
5. Elevation of the patient’s support by moving the supportive system upward or downward [8] (p. 291).

1.2. Ten-Step Protocol

Dentists are additionally given a ten-step protocol guide to optimal perception and control of dentist performance:

1. Establish appropriate inter-maxillary opening;
2. Grasp instrument or item to be used with thumb and index finger;
3. Place instrument or item to place to task site;
4. Stabilize instrument or item with middle finger on task site or as proximal as possible;
5. Check posture to determine whether steps 1–4 have compromised (to cause impairment) posture. If not, then process directly to step 6. If posture is compromised, correct it by rotating patient’s head right or left and by dentist’s movement clockwise or counter-clockwise;
6. Check vector of force application (axis of instrument or item) to assure alignment with mid-sagittal plane. If adjustment is necessary, correct it by rotating patient’s head or dentist’s movement;
7. Plan to move instrument or item from distant point to near point on task site;
8. Establish eye-to-task sight line with direct or indirect view as appropriate;
9. Stimulate performance to ensure optimal performance;

Pd is also combined with a training program called SATV (Skill, Acquisition, Training and Verification), which helps dentists in gaining self-derived experience. The SATV system is divided into skill acquisition, skill transfer, and skill verification phases [6].

In the skill acquisition phase, dentists use models for training. Body positions and setting requirements that are compatible with the highest imaginable level of clinical performance are recorded. These conditions are considered to minimize physical stress during dental treatment. The derivations are then used to adjust the SATV clinical setting to the dentist’s unique body dimensions for optimal delivery of care.

The skill transfer phase emphasizes that the acquired basic skills may be applied to clinical procedures such as oral examination, extraction, anaesthesia, tooth cavity restoration, root canal treatment and preparation for crowns and bridges.

Skill verification—by means of multimedia such as a camera, digital video recordings or data forms, and standardized simulated pathologies—of skill acquisition and transfer is used throughout the system.

Terui, Iwao, and Taniguchi [10] reported that, by using SATV, the concept of Pd can give dentists many benefits:

1. It establishes and maintains optimum finger control for precision work;
2. It minimises distraction from the care receiver (patient);
3. It helps to keep the dentist’s spine healthy;
4. It maintains consistent accuracy, and minimizes treatment time by eliminate unnecessary acts;
5. It establishes a basis of infection control by minimizing the number of finger-instrument contacts (p. 244).
Pd has been used in many countries, such as Japan, North America and some countries in Europe. In Thailand, one dental school implemented Pd at the beginning of its foundation. The aim of using Pd is to improve dentists’ health and performance, increase productivity and the quality of dental care [5].

Even though Pd has been used in many countries for many years, it is still considered as a new concept in Thai dentistry. There are few studies on how it could improve work performance or reduce musculoskeletal symptoms as Pd is claimed to do. For that reason, it is important to investigate working conditions and the dentists’ attitude towards Pd, which were the aims of this study. The results—information necessary to make decisions before introducing any changes in dental clinics in relation to this concept—could benefit other dentists and dental schools. Further, the results could contribute to ergonomists’ concern regarding dentists’ workstation organization and the working process as well.

2. PARTICIPANTS AND METHODS

Twelve dentists (4 males and 8 females) participated in the study. They all worked as dentists and university lecturers. They all knew and used Pd. Their working experience of Pd ranged from 8 to 36 months. A two-part self-administered questionnaire was distributed to all participants.

Part 1 concerned individual characteristics (age, gender, handedness, level of education and years in profession) and working conditions (working hours, number of patients per day, working posture, working time, working technique and breaks between cases). They were asked about the working time spent on five main dental work tasks: dental examination, teeth cleaning, dental filling therapy, preparation for crowns and bridges, and tooth extraction and working situations causing stress. The dentists were asked to rate stress caused by each working situation on a 6-point rating scale (from 1—no stress at all to 6—very high degree of stress).

In part 2 of the questionnaire the dentists were additionally asked how often they used Pd, what their attitude to Pd was and why.

3. RESULTS

Table 1 shows the participants’ characteristics.

3.1. Working Posture

For all 12 dentists sitting was the only working posture in the clinic.

3.2. Working Techniques

All 12 dentists used the 4-handed technique: they always had dental assistants when they gave dental care to patients.
3.3. Working Time Spent on Each Dental Work Task

The dentists reported how much time, on average, they spent on each task. The result is presented in Table 2.

3.4. Breaks Between Patients

Only five dentists (41.7%) reported that they had breaks between patients. Their average duration was 5 min.

3.5. Physical Demand and Feeling Exhausted After Work

The dentists were asked if dental work was physically demanding. They were also asked to rate how exhausted they felt at the end of their working day. The results are shown in Table 3.

3.6. Overtime Work

The dentists were asked if they worked overtime. The results showed that most of them did not. Only one out of the 12 dentists worked overtime, Monday to Friday, 12 times during the past month.

3.7. Working Situations That Cause Stress

Patients who disliked the treatment provided was the most stressful working situation among all dentists (Table 4).

3.8. Part 2: Dentists’ Attitude Towards Pd

The dentists had used Pd for 8–36 months. The average time was 19.67 ± 11.3 months (M ± SD).

3.8.1. How Often Did the Dentists Use Pd?

Five dentists sometime used Pd and seven dentists always used it. In this study, use means that the dentist was concerned about (a) hardware, i.e., proprioceptive-derived tools and equipment, and (b) software, i.e., the working procedure, senses, feelings, and the relationship between him or her and the environment (derived from using Pd) while providing dental care.
3.8.2. Did the Dentists Like or Dislike Pd?
Ten dentists liked Pd, with seven of them always using it. Only two dentists disliked Pd: both of them sometime used it.

3.8.3. Why Did Dentists Like or Dislike Pd?
The dentists who always used Pd said they liked it because it helped to reduce physical stress on the muscles, especially in the shoulder and back regions, enhance accuracy of the treatment procedure, enhance communication with patients and assistants, reduce treatment time, and increase high-quality control of infection (by minimizing finger-hand contact with the lamp and table). Three out of the five dentists who sometimes used Pd also mentioned that it helped to enhance the accuracy of the treatment procedure, and was good for infection control. Only two dentists did not like Pd, one dentist wrote that Pd on its own could not been applied to all types of dental practice. The other did not like or did not want to use it due to its complexity and difficulty (Figure 2).

4. DISCUSSION
This study showed that the majority of the dentists who used Pd liked it and reported improved work performance and reduced musculoskeletal load. However, few dentists participated in the study mainly because there is only one dental school in Thailand which uses Pd and this school has a limited number of staff members. In order to increase the number of participants in a future study, dental students who also use this concept should be included. Hence, it should be stressed that the results of this study are based on a small number of dentists using Pd; consequently it may not be appropriate to generalize those results to all users or to other participant groups. On the other hand, this study could have some benefit as one contribution regarding Pd, as not many studies or much information has been available on this subject. Dentists' working posture is a topic that many researchers have paid attention to because it is considered as a risk factor for musculoskeletal symptoms [11, 12, 13, 14]. The results from this study showed that 100% of the dentists chose to work in a sitting posture. No one alternated their posture between sitting and standing, which might explain why some disliked Pd. Runderantz, Johnsson, and Moritz [11] reported that 95% of dentists worked in a sitting posture when working conventionally. Further, Finsen, Christensen, and Bakke [13] found that the majority (82%) of dentists sat while working. Sitting continuously is considered a risk factor for low back pain because dentists who work in a sitting posture all the time had more severe back pain than those who alternated between sitting and standing [15]. An observation study of dentists using Pd would give more information on how they sit [16].

Figure 2. Reasons why dentists like Proprioceptive Derivation (n = 12)
Interruptions or micropauses are presumed essential in decreasing or varying musculoskeletal load [17, 18]. However, only five dentists (41.7%) had breaks of around 5 min between patients. Also, most dentists perceived dental work as physically demanding and felt exhausted at the end of the day. Ilmarinen, Suurnakki, Nygård, and Landau [19] reported that among 88 professions, the highest stress factor level was found in dentists, kitchen supervisors and physicians. Continuous sitting and no breaks are probably related to sitting in the same posture, and it is thus related to muscular discomfort, affecting the dentists’ perception of dental work as a demanding job causing exhaustion after work.

Table 5 compares Pd users to dentists studied by Finsen, Christensen and Bakke [13]. There were differences in the average time spent on dental work tasks. Pd users in this study spent less time on dental examination and crown and bridge therapy tasks. However, they spent more time on teeth cleaning and dental filling therapy tasks. These differences could be related to many factors such as dentists’ skills, type of treatment and patients. Dentists who worked conventionally [13] spent less time on each dental work task compared to dentists in this study, which is contrary to expectations.

Fujita, Kawamoto, Kohmi, Onchi, Inoue, and Fujii [20] reported that skilled dentists have an advanced ability to have shorter cycle times when performing dental care under Pd. An observation study with a video-based analysis [21] would help to clarify why dentists who used Pd in this study spent more time on each task. Also a paper-based task analysis [22] or actual time measurements on patient visits [23] could give more interesting information on the variability of working time in dental work tasks.

According to the responses, patients who disliked the given treatment was the most stressful situation for the dentists in this study. Gorter, Albrecht, Hoogstraten and Eijkman [24] reported similarly: dentists had the highest mean scores of work stress related to patient contacts and work contents items. Further from the present study, time management such as cancelled or late appointments and coping with difficult patients also caused stress. Similarly, Wilson, Coward, Capewell, Laidler, Rigby, and Shaw [25] found time management including running behind schedule, coping with difficult or uncooperative patients, and working constraints set by the National Health Service (NHS) as major job stressors among general dental practitioners. Furthermore, occupational stress in dental work also came from trying to sustain and build a practice, lack of career perspectives and having to cope with difficult patients [26, 27]. It seems that Pd does not help dentists in solving their problem with difficult patients and running behind schedule.

Interestingly, the stress score in solving problems in patients with physical limitations was lower among dentists in this study, compared to Cooper, Mallinger, and Kahn’s study [26]. Pd, which includes a dental bed, provides easier accessibility to patients with limitations, such as the disabled and the elderly, which might be an advantage. Further, the special headrest might help the dentist to position the patient’s head and to keep the patient’s mouth in a predictable position regardless of the patient’s height, and thus reduce stress in dentists.
In this study, attitude meant a feeling or an opinion about Pd or a behaviour caused by that concept. The results showed that the main reason for using Pd was that it minimized physical stress in the muscles, especially in shoulder and back regions, enhanced the accuracy of treatment, provided better communication with patients and assistants, minimized treatment time, and minimized finger-hand contact with the light and chair. Interestingly, dentists who always or sometimes used the concept liked it because of two reasons: enhanced accuracy of treatment and high-quality control of infection. These results are in agreement with what is reported deriving from the skill program, the SATV system. They claim that Pd equipment is required together with SATV. However, further studies need to be done to evaluate if SATV is sufficient for achieving high work quality and if SATV can be combined with conventional dental equipment or not.

Two dentists did not like Pd. One stated that, on its own, it did not cover all types of dental tasks and treatments. Additionally, one dentist did not want to use this concept due to its complexity and difficulty. These results might imply that Pd is not easy to learn because the two dentists were experienced in working conventionally prior to using Pd. Van Beer, Sittig, and Denier van der Gon found that “the precision of proprioceptive localization of the hand in humans is based on three different sources of information: proprioceptive information about the left hand, proprioceptive information about the right hand, and visual information” (p. 367). Therefore, dentists may need more practice in order to get the right proprioceptive information before they can consciously perform dental care under Pd without difficulty. Consequently, further studies on the effect of the training period on dentists’ performance may provide additional information to supplement that of the current study.

Hendrick divided ergonomics technology and its application into four groups: (a) hardware ergonomics or human-machine interface technology, (b) environmental ergonomics or human-environment technology, (c) cognitive ergonomics or human-software technology, (d) macroergonomics or human-organization technology. It is also possible to discuss Pd and its ergonomics application in all aspects. In hardware ergonomics, it concerns dentist performance capabilities as applied to the design of the dental workstation (e.g., the dental bed). In its environmental ergonomics aspect, it concerns dentist capabilities and limitations caused by the stress imposed by environmental modalities (e.g., lighting, vibration). It can be seen that the dental workstation environment, according to this concept, tries to minimize the environmental stress on dentists’ performance, enhance comfort for dentists and patients and enhance productivity. Pd shows its concern in the software ergonomics aspect as well, as to how dentists conceptualize and process information from proprioception to their practice by having a guideline on movements; the five movements, the ten-step protocol, and the SATV as a training system. Lastly, it also concerns macroergonomics as the results show that it benefits dentists by enhancing better communication between dentist and assistant, dentist and patient, and dentist and dentist. In conclusion, it seems that this concept has shown its importance in work design and its contribution in many aspects of ergonomics.

5. CONCLUSIONS

Pd seems to reduce the level of stress, but the continuous sitting posture is a risk for back pain in dentists, from the ergonomics point of view. Pd, with a dental bed, can provide easy accessibility to patients with physical limitations and it results in a lower stress level among dentists. Most dentists who used Pd found it useful. However, further studies are needed regarding sitting postures, whether SATV program can be combined with conventional dental equipment, the training period needed to
reach high work performance, and also the attitudes among the patients regarding the concept.

REFERENCES


Paper II

Differences in Dentist’s Working Posture

When Adopting Proprioceptive Derivation VS Conventional Concept

Short form of title: Differences in dentist’s posture: Pd & conventional

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ABSTRACT

New technologies and changes in dental care aimed to give the dentist better comfort and better health condition, among them Proprioceptive derivation (Pd) concept was introduce in Thailand. The aim of this study was to investigate the differences in dentist’s working posture when adopting different work concepts: - Pd and Conventional concept. The result show differences in dentists’ sitting posture, clock-related working position, and RULA score. It implied that Pd concept helps the dentists to discover new ways to position themselves, and working comfortably and effectively, which made it possible for the dentists to adopt better working posture and have lower RULA score. In conclusion, Pd concept has an effect on the working posture of dentists.

Key words: Proprioceptive derivation, Posture, RULA, dentist
1. INTRODUCTION

Musculoskeletal disorders (MSDs) are common among dental care workers as indicated in many studies [1, 2, 3, 4, 5]. Over a third of Finnish dentists have experienced at least one diagnosed musculoskeletal disease, which is above the average in the whole population [6]. A study in Sweden showed that both female and male dentists have higher prevalence of musculoskeletal symptoms during the past 12 months at neck and shoulder region [4]. In Thailand, one of the most common occupational health problems (78%) among Thai dentists was musculoskeletal pain [7]. It has been suggested that work-related musculoskeletal disorders are associated with a number of ergonomic-related risk factors, such as, vibration, repetitive movements, high static muscle and joint load, and lack of pauses, forceful exertions, non-neutral body postures, [8,9]. The most concerned risk factor for MSDs is working posture [10]. Many difficult working postures, including rotation and flexion of cervical spine, flexion of elbow and repetitive forceful hand grip, are inherited in dental work [11], since the nature of dental work consists of precision tasks, involving a high degree of visual and manipulative elements, sometimes in combination with exertion of force [12]. Poor working postures generate high static loads (increased muscle tension) which creating musculoskeletal discomfort or fatigue in the neck, shoulders, and upper back, and also work-related injury among professionals [13, 14, 15, 16, 17].

The Proprioceptive derivation (Pd) concept

Not only do the work-related musculoskeletal disorders cause suffering to the dental professionals and their family, but it also adds to the overall cost to society through lost productivity and increased use of medical and welfare services. The cost to society has been estimated at 2%-14% of the gross national product in different studies in different countries [18, 19]. Therefore, the attention and awareness of musculoskeletal disorders in the dental profession has increased noticeably in recent years. A great deal of ergonomics and new
technology has been integrated into the modern dental office during the last several decades. The concept of changes in dental practice by using technology in dentistry started many years ago. Considering that the new technologies and changes aimed to give the dentist better comfort and better health condition, many new technologies have been presented to the dentistry after a sit–down dentistry, including the four-handed dentistry [20] and the Proprioceptive derivation [21, 22].

The Proprioceptive derivation (Pd) concept is developed by Dr. Dr. Daryl R. Beach. At first, this concept is called *Performance logic* [22, 23, 24]. A primary aim of the Pd concept is to provide the dentists a good posture and optimal control of dental task while minimizing musculoskeletal discomfort. In Pd concept, dentists are encouraged to determine their most balanced and comfortable working posture, and then integrate that posture into their clinical practice. However, the Pd concept has a suggested sitting posture, or an “Ideal Posture”, which is simply described that the dentist sit upright, both hands at the heart level, being able to easily reach necessary equipment and materials, the patient lies down horizontally, and the dentist are encourage to maintain the optimum posture with maximum balance and comfort (figure 1). Once dentist sit in a comfortable posture, the patients' oral cavity is positioned to support the dentists' derived balanced position, and fine adjustments are made during the appointment to allow the dentist to maintain balanced positioning, and able to work more accurately, more efficiently, and with less physical and mental demand [25].

[Figure 1.about here]

This ideal posture and position can be achieved through the self-proprioceptived derivation and a complementary performance process [26]. In addition, the Proprioceptive derivation
concept fundamentally includes a system of reasoning that guides dentists to determine their most comfortable working posture and position, and increases their awareness of work environment and preferred working position. This concept provides the dentists a number of strategies; such as *five movements, ten-step protocol*, which help them to maintain their ideal posture with optimal control while working [21, 22, 27, 28].

None of study had done regarding the differences in working posture when dentists adopting different work concepts in Thailand. Therefore, the aim of this study was to investigate the differences in dentist’s working posture when adopting different dental work concepts, namely, Proprioceptive derivation and Conventional concept.

2. PARTICIPANTS AND METHODS

2.1 Participants

Two groups of dentists participated in this study. The first group, *Pd group*, was 8 dentists who have been working with Pd concept. The second group, *Conventional group*, was 10 dentists who have been working with conventional concept.

2.2 Methods

The observations study was conducted separately for each group by the same observer. Each observation took around 15-30 minutes on each dentist in both groups. The observation was carried out while the dentists were working with patient. The postures of each dentist were coded on the data collection sheet according to the categorisation of sitting posture for dentists, clock-related sitting position [29]. A RULA assessment [30] was used to gives a
quick and systematic assessment of the posture of dentists. The most extreme, unstable or awkward posture from each dentist was selected and scored in a RULA worksheet. The final score (RULA grand score) and action level were also processed by using the free online RULA software [31]. The RULA grand score and the action category were presented in table 1. The mean RULA score of each group was calculated and compared by using SPSS statistical analysis software.

[Table 1. about here]

3. RESULTS

3.1 Characteristic of the dentists

Characteristic of the dentists in this study were shown in table 2.

[Table 2. about here]

3.2 Postural analysis

3.2.1 Working posture

All dentists choose to sitting as their main working posture. None of dentist alternated their posture between sitting and standing. Further, dentists in Pd group used dental chairs with lumbar support which was designed according to the Pd concept. Dentists in conventional group used normal office chairs with backrest.

3.2.2 Categories of sitting posture

The sitting posture of dentist can be categories into 4 postures [29]. The results shown that most frequently sitting posture among dentists working according to the Pd concept was posture 2 (90%) and posture 1 (10%). Comparing to the dentists working conventionally, they adopted posture 1 (50%) and posture 3 (40%) while working.
3.2.3 The clock-related working positions

The most frequent clock-related working positions were assessed. Dentists in Pd group sit at position 12 o’clock (87.5%) and position 10 o’clock (12.5%). Whilst, the dentist working conventionally were working in a sitting posture as well but most of them were working at position 10 o’clock (80%) while few of them were working at position 9 o’clock (10%), and 11 o’clock (10%).

3.3 RULA score and Action Level

There was significant different in average RULA score between two groups of dentists (p<0.05). The average RULA score of dentist in Pd group was 3.5, which fall into Action level 2: indicates that further investigation is needed and changes may be required. The average RULA score of dentists in Conventional group was 5.6, which was fall into Action level 3: indicates that investigation and changes are required soon.

4. DISCUSSION

Working posture of dentist is one of the topics to which many researchers have paid most attention [2, 29, 33]. All dentists from both groups chose to work in a sitting posture 100% of the time. This finding is similar to a study by Runderantz et al. [33], which found that 95% of dentists working in sitting posture. As well as a study conducted by Finsen et al. [2] found that 82% of dentists mainly sit while working when giving treatment to patient. Currently,
Marklin and Cherney [34] reported that dentists were seated 78 percent of the time. However, it was found that dentists who work in the sitting posture have more severe low back pain than do those who alternate between sitting and standing [35]. Therefore, it is important to recommend dentists in both groups to alternate their postures in order to prevent musculoskeletal disorders.

Sitting posture of dentist was categorized into four sitting postures [29]. Based on these categories, the result showed that 7 of dentists working with Pd concept mainly sitting in posture 2: Straight low and upper back, the neck bent, the seat straight. Only one dentist in this group had adopted sitting posture 1: The whole back bent and the seat straight. Whilst the dentist working with conventional concept had adopted posture 1 and posture 3: The whole back bent, the seat tilted forward, most of the time. Obviously, Pd concept provided horizontal seat for the dentists based on its philosophy and the ideal working posture a shown in Figure 1. [21, 22]. On the other hand, dentists working with conventional concept had the possibility to tilt their seats. A study by Bandix [36] had reported that the 5 degrees forward inclination and the horizontal seats gave better comfort than backward inclined seat. However, it is not definitely clear either the horizontal seat or forwardly inclined is better. Another noticeable difference in sitting posture is that the dentists working with Pd concept adopting more upright sitting. This resulted implied that the Pd concept gives the dentists better sitting posture than that in dentists working with conventional concept.

In this study, the dentists working with conventional concept mostly (80%) worked at position 10 o’clock, whilst few of them were working at position 9 (10%) and 11 (10%) o’clock (Table 3). Few study have been included the clock-related position in their studies. However, this result corresponds well with an investigation done in Denmark by Finsen et al.[2], which
found that almost half of dentists used the position 10 o’clock as their most common position, while the second most and third most common were at 11 and 9 o’clock respectively. Runderantz et al. [33] also found in her study that the most frequently adopted position was position 9 o’clock when giving a treatment to patient. In contrast, all dentists working with the Pd concept mainly worked at position 12 o’clock most of the time. The possible reason for what most of dentists in Pd group chose to work at this position is related to the movement guideline provided by the concept [21]. Nevertheless, a further investigation on this issue is possibly gives more explanation. In addition, Pollack [37], reported that many factors influencing the determination of posture and position of dentists, e.g. type of dental treatment, patient’s position, etc. (Figure 3).

[Figure 3. about here]

The result of postural analysis by using RULA, showed that there was a significant different in RULA grand score between two groups of dentists. Most of dentists working with the Pd concept had lower RULA grand score, even though one of them had RULA grand score equal to 6 as what the dentist in conventional group had. Moreover, significantly different in posture combination was reflecting in different in grand RULA score between two group. Figure 4 shows the example of posture combination which gives grand RULA score = 3 and 6 from in this study. It is clearly seen that awkward postures of neck, trunk, and upper limbs were contributing to high RULA score.

[Figure 4. about here]

However, it was recommended that this action levels can be used as an aid in efficient and effective control of any risks identified, and the actions lead to a further detailed investigation [32].
In this study, a Rapid Upper Limb Assessment (RULA) was selected to use as a quick and systematic objective assessment of the posture, forces and activities undertaken by the dentists. Because RULA is a tool that assesses biomechanical and postural loading on the whole body with particular attention to the neck, trunk and upper limbs and also a survey method developed for use in ergonomic investigations of workplaces where work related upper limb disorders are reported [30]. Furthermore, RULA assessment requires little time to complete and the scoring generates an action level which indicated the level of intervention required to reduce the risks of injury due to physical loading on the dentist [32].

The reliability of the postural analysis is crucial. Both tool and observation are playing an important role. Additionally, the Reliability of RULA has been conducted on VDU users and sewing machine operators [37]. The dental work can be considered as sedentary work as VDU user and sewing machine operator, because the dentist sitting most of the time while giving patient the treatment. The experience of the observer is also play an important role in postural analysis. However, the observer in this study had long experience of using RULA method and also had a rehearsal of the RULA procedure and technique before conducting the each observation. In addition, Dismukes [38] had done a study on the accuracy of using RULA on people with untrained in ergonomics, it was concluded that they can provide accurate, rapid initial assessments of jobs that may result in upper limb disorders.

There were constraints in conducting this study, which affected the study design. Firstly, there was a differences in working hours and as a result of being the youngest dental school in Thailand, the dentists who were working with the Pd concept had less number of years of profession practice when compare with the dentists from Conventional group. Due to the shortage of lecturers in that new dental school, the dentists had to do more lecturing and spent shorter time in clinic. The numbers of participants in this study was limited due to the fact that
CONCLUSION

The results implied that the Pd concept helps the dentists to discover new ways to position themselves, and working comfortably and effectively, which made it possible for the dentists to adopt a more neutral, less awkward working posture and have low level of RULA score. However, the dentists who are working with the Pd concept still have awkward posture such as twisted, abducted upper arm, side bended trunk. Besides type of working concept, there are many factors that can affected the working posture of dentist as discussed such as a nature of dental work itself.

REFERENCES


Table 1. The RULA grand score can be categorised into four Action Levels of RULA grand score [32].

<table>
<thead>
<tr>
<th>Action level</th>
<th>RULA score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 or 2</td>
<td>Indicates that posture is acceptable if it is not maintained or repeated for long periods.</td>
</tr>
<tr>
<td>2</td>
<td>3 or 4</td>
<td>Indicates that further investigation is needed and changes may be required.</td>
</tr>
<tr>
<td>3</td>
<td>5 or 6</td>
<td>Indicates that investigation and changes are required soon</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>Indicates that investigation and changes are required immediately</td>
</tr>
</tbody>
</table>
Table 2. Characteristic of two groups of dentists in the study.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Working concept</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Proprioceptive derivative (Pd)</td>
<td>Conventional (n =10)</td>
</tr>
<tr>
<td></td>
<td>(n =8)</td>
<td></td>
</tr>
<tr>
<td>Age (Mean ± SD)</td>
<td>32.38 ± 7.76</td>
<td>44.60 ± 5.70</td>
</tr>
<tr>
<td>Gender:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Female</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>Handiness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Both</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Years of profession (Mean ± SD)</td>
<td>6.19 ± 6.29</td>
<td>18.83 ± 5.22</td>
</tr>
<tr>
<td>Working hours in clinic/week (Mean ± SD)</td>
<td>24.00 ± 8.73</td>
<td>39.9 ± 6.40</td>
</tr>
</tbody>
</table>
Table 3. Category of sitting posture and number of the dentists in each category.

<table>
<thead>
<tr>
<th>Sitting Posture Category</th>
<th>Pd (n=8)</th>
<th>Conventional (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The whole back bent and the seat straight</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>2. Straight low and upper back, the neck bent, the seat straight</td>
<td>7</td>
<td>-</td>
</tr>
<tr>
<td>3. The whole back bent, the seat tilted forward</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>4. Straight low and upper back, the neck bent, the seat tilted forward</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 4. The main clock-related working positions of dentists working with Pd and Conventional concepts.

<table>
<thead>
<tr>
<th>Position</th>
<th>Pd (n=8)</th>
<th>Conventional (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 o’clock</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>11 o’clock</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>10 o’clock</td>
<td>1</td>
<td>8</td>
</tr>
</tbody>
</table>
Figure 1. Dentist and patient posture according to the Pd concept [21, p.288].
Figure 2. RULA score among the dentists in each group.

Notes. RULA- Rapid Upper Limb Assessment
Figure 3. Factor influencing the working posture of dentist (Modified from [34]).
Figure 4. Differences in posture combination for RULA score 3 and 6 from this study.

Notes. 1) RULA- Rapid Upper Limb Assessment  2) RULA score = 3 from one of dentists in Pd group, and RULA score = 6 from one of dentists in conventional group.

*In Press*
Physiological, subjective and postural loads in passenger train wagon cleaning using a conventional and redesigned cleaning tool

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Abstract

Methods: In this study, cleaning process was studied and analyzed with special reference to cleaning tools. A group of 13 professional cleaners participated in this study. While they performed their normal tasks, their oxygen consumption, heart rate, rating of perceived exertion and postural data were obtained. The perceived exertion during cleaning task using the “redesigned cleaning tool” was less than that of the “conventional cleaning tool”. The oxygen consumption when cleaning with the redesigned tool (mean 0.84 l/m, SD ±0.17) was significantly less (p<0.05) compared to the conventional cleaning tool (mean 0.94 l/m, SD ±0.18). Heart rate was also found significantly lower using redesigned cleaning tool (mean 101 bpm, SD ±11.10) compared to that of conventional cleaning tool (mean 105 bpm, SD ±12.59) (p<0.05). Using redesigned cleaning tool the trunk postural load was also found significantly less than that of conventional cleaning tool (p<0.05). It is concluded that redesigned cleaning tool allowed cleaners to maintain more upright posture when cleaning, which reduced biomechanical load.

Relevance for Industry: There is need to develop ergonomic criteria or recommendation to enable manufacturers of cleaning equipment to specify and evaluate usability qualities when formulating user requirements for new cleaning tools.

Keywords: Ergonomics; Redesigned cleaning tool; Oxygen consumption; Heart rate; Perceived exertion

1. Introduction

It has been repeatedly stated that the stress experienced on exposure to repetitive work can give rise to low job-satisfaction, poor job
Many factors of work and environmental conditions affecting professional cleaners increase the risk of occupational diseases (i.e., musculoskeletal disorders). Among them are inappropriate and poor working postures, lack of task variation, poor ergonomics design of the work places, cleaning tools and the task including work organization. In professional cleaning most of the work is done by using long-handled equipment (25–35% of the work hours) (Hopu et al., 1994). Cleaning floors with a wet mop is one of the most time-consuming and physically demanding tasks among professional cleaners. During wet mopping a long-handled mop is moved across the floor in the shape of figure of eight while walking backwards slowly. In Finland, wet mopping is not common, as it has been determined to have a heavy physical demand on workers from measurement of heart rate, the evaluation of work postures and perceived load (Krüger et al., 1997). The cleaners have also rated it as a strenuous task. Therefore, most interventions have focused on this task and during the few last decades many new tools and techniques have been introduced (Søgaard et al., 1995). A research study done by Hagner and Hagberg (1989), among 11 professional female floor cleaners showed that the “figure-of-eight” method is more strenuous than the “push” method requiring high oxygen consumption.

In professional cleaning static postural load is frequent, and particularly, poor work postures are common for the back and arms. Some of the studies for different types of cleaning (Louhevaara (1997), Hopu (1997) and Hopu et al. (1994)) have found an average of 36–56% of working hours spent bent forward and/or with a twisted back, about 24–43% of working hours with one arm or both arms above shoulder level, and cleaners also spend 3–14% of their working hours in a squatting posture.

A literature review indicates that there has been no study published on professional cleaners in passenger train wagons related to the floor-cleaning tool. Cleaning of passengers train wagons is different compared to other cleaning jobs. Performing cleaning activities in passenger train wagons is very difficult to do, as passenger train wagons have limited room. To clean and see under the lower berth requires strenuous activities. As a result, cleaners have to adopt awkward working postures (Fig. 1).

Some excellent studies have been done on the physical aspects of professional cleaning by Hopu et al. (1994) and Hagner and Hagberg (1989) and Søgaard et al. (1996). They indicated that the most important risk factors involved in the physical work of professional cleaning are namely, static muscular work, especially in terms of bent and/or twisted posture of the back and repetitive movements of the arms and hands with a high output of force. From an ergonomics point of view existing tools, task/methods, working environment needed to be better designed in order to reduce occupational injuries among cleaners. From the workplace analysis in the passengers train wagon, it was found that most of the awkward working postures among cleaners were due to the workstation and existing tool. Changing workstation inside the train wagon was not possible due to lack of...
flexibility in design. Changing the tool was an obvious and cost effective ergonomics strategy. Consequently, the cleaning tool was redesigned and compared against the conventional tool for postural, physiological and subjective load on cleaners. The specific objectives of the study were to determine the following:

1. Whether oxygen consumption and heart rate could be reduced when using redesigned cleaning tool in comparison to the conventional cleaning tool.
2. Whether redesigned cleaning tool reduced the trunk angle compared to the conventional cleaning tool.
3. Whether the cleaners perceived less exertion while using the redesigned cleaning tool in comparison to the conventional cleaning tool.

2. Method

2.1. Subjects

Thirteen healthy professional cleaners (12 females and 1 male) participated in the study. Their professional experience ranged from 1 to 21 years (Table 1). Twelve of the cleaners were right-handed and one left-handed. One week prior to the study, cleaners practiced with both cleaning tools.

2.2. Cleaning tools

A commercially available long straight handle-cleaning tool for floor mopping was used as a conventional cleaning tool. The length of the tool could be adjusted between 105 and 190 cm. The redesigned cleaning tool was bent at three points, upper, middle and lower part of the tool in such a way that it produced an arc shown in Fig. 2.

The redesigned cleaning tool allowed neutral wrist posture while mopping the floor as compared to the conventional cleaning tool where flexion and extension of the wrist was needed while mopping the floor (Fig. 3). The arrow in the figure shows the movement of the wrist/hand using each tool.

Table 1

<table>
<thead>
<tr>
<th>Subject characteristics</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>38</td>
<td>12.9</td>
<td>55</td>
<td>20</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>163</td>
<td>9.6</td>
<td>180</td>
<td>150</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>63.2</td>
<td>11.7</td>
<td>90</td>
<td>50</td>
</tr>
<tr>
<td>Employment (yrs)</td>
<td>5.6</td>
<td>6.95</td>
<td>21</td>
<td>1</td>
</tr>
<tr>
<td>Maximum oxygen uptake (l/min)</td>
<td>2.60</td>
<td>0.29</td>
<td>3.16</td>
<td>2.04</td>
</tr>
<tr>
<td>Maximum oxygen uptake (ml/kg/min)</td>
<td>42</td>
<td>6.06</td>
<td>54.55</td>
<td>27.89</td>
</tr>
<tr>
<td>Resting heart rate (bpm)</td>
<td>72</td>
<td>10</td>
<td>90</td>
<td>56</td>
</tr>
</tbody>
</table>
2.3. Procedure

The maximum oxygen uptake of the cleaners was determined by performing a test on a bicycle ergometer (Tuntri, 850 ECB PRO, Ergometer). Cleaners were asked to cycle at a steady rate (60 revolutions per minute) of 50 W for 2 min with subsequent increases of 50 W every 2 min until exhaustion (Price and Campbell, 1997). The cleaners were asked to try to maintain a certain pedal frequency of 60 rpm by using a metronome, which produced a sound signal (Åstrand and Rodahl, 1986). The measured values in liters per minute (l/m) as well as milliliter per minute per kilogram (ml/m/kg) of gross body weight were obtained by using a MetaMax II. The MetaMax II is a multifunctional metabolic measurement system, which can be used as a portable system to measure under real conditions or as a stationary system in a laboratory. It measured oxygen consumption, carbon dioxide output, ventilation, heart rate, ambient temperature and pressure. The devices were calibrated before each use.

To minimize the effects due to the fatigue from the bicycle ergometer test, the cleaning tests were performed after three days (Mackinnon, 1999).

Cleaners were randomly assigned the tool to use in each test. Cleaners had a rest of 10–15 min before starting the initial test. They cleaned an area of 52 m² where dry sand and papers were used as materials to be cleaned during the 15-min test. The cleaners were required to maintain a fixed work pace. During the test, oxygen consumption was recorded every 10 s and heart rate was recorded every 5 s (Bridger et al., 1997).

After the first test, the cleaners had a rest interval of 15–30 min during which the resting heart rate was obtained (Bridger et al., 1997). The
protocol was repeated for the second test, but the alternative tool was used at the same pace. Cleaners were asked to rate their perceived exertion while performing the test. The Borg’s scale was used for rating. Just 30 s before the end of each test, cleaners rated their perceived exertion on the Borg scale (Borg, 1982, 2001). Each cleaner received a standardized verbal and written explanation of how to use the Borg scale prior to the test.

The tests were recorded on videotape in profile for posture and biomechanical analysis of the cleaner’s postures during the tests. Postural angles (maximum trunk bending) were assessed using photographs in profile of cleaners reaching under the bed while cleaning with both tools (Fig. 4). The reference point was lumbosacral (L5/S1) and cervical (C 7) joining the center of gravity line (Hagner, 2001).

2.4. Analysis

All values of measured variables are expressed as means and standard deviation. A paired t-test was used to determine differences between the oxygen consumption, heart rate and postural variable. A Sign test was used to determine the differences in perceived exertion. Probability values of $p<0.05$ were accepted as being statistically significant.

3. Results

Table 2 shows the results of the analysis of average oxygen consumption in l/m and ml/m/kg of body weight average heart rate in beats per minute (bpm), perceived exertion and percent maximum oxygen uptake required to do the job.

![Fig. 4. Trunk angle: (a) using conventional tool; (b) using redesigned cleaning tool.](image-url)
using two cleaning tools. Average oxygen consumption and heart rate were found to be significantly different for the conventional cleaning tool compared to redesigned cleaning tool \( (p < 0.05) \).

The mean value for oxygen consumption (VO₂) was 0.94 l/min with the conventional cleaning tool and 0.84 l/min with the redesigned cleaning tool. The heart rate (HR) mean value was 105 bpm with the conventional cleaning tool and 101 bpm with the redesigned cleaning tool (Table 2).

The cleaners used 36% of their maximal oxygen (VO₂ max) uptake capacity while cleaning with the conventional cleaning tool. The corresponding percentage for the redesigned cleaning tool was 31% \( (p < 0.002) \). The mean perceived exertion while cleaning with the conventional cleaning tool was 13 on the 20-point Borg's scale and for cleaning with the redesigned cleaning tool was only 11 \( (p < 0.001) \). From using the \( t \)-test for postural analysis a significant difference was found for the angle of the trunk between conventional and redesigned tool use \( (p < 0.05) \). The mean angle of trunk bending while using the conventional cleaning tool was 87° and with the redesigned cleaning tool was 50° \( (p < 0.001) \) (Fig. 5).

### 4. Discussion

Work requiring the oxygen uptake from 0.50 to 1.01 l/min is considered as moderate (Astrand and Rodahl, 1986). In the present study, the oxygen consumption (l/m) had a higher mean value (0.94 l/m) while cleaning with the conventional cleaning tool, which was statistically significantly different compared to redesigned cleaning tool (0.84 l/m). Nonetheless, cleaning with both tools can still be considered as moderate work (Astrand and Rodahl, 1986) and not heavy as previously suspected. The International Labor Organization (ILO) suggested 33% of the maximal oxygen consumption (VO₂ max) as an acceptable load during 8-h of working day (Vanwonerghem, 1986). From this study, the cleaners used 36% of their VO₂ max while using the conventional cleaning tool and 31% while using the redesigned cleaning tool, which is statistically significant. This means that by using redesigned cleaning tool the cleaners can work 8-h shift within
an acceptable working load as recommended by ILO.

There was significant reduction in heart rate during cleaning with redesigned tool as compared to conventional tool, which may be due to postural factors. The possible reason could be that in upright cleaning posture, the large group of muscles of upper part of the body is not engaged as in the bending posture (Bridger et al., 1997).

Heart rate increases linearly with oxygen consumption in response to increasing workload (McArdle et al., 1991). Some studies found a linear relationship between heart rate and oxygen consumption during non-steady state activities however tests were limited to progressive incremental exercise (Bernard et al., 1997). Findings from this study also showed the significant relation between heart rate and oxygen consumption.

No correlation was found in this study between heart rate and oxygen consumption and perceived exertion. In one study Datta et al. (1983), found high positive correlation between heart rate and perceived exertion. However, Mital et al. (1993) investigated workload and fatigue in highly trained cleaners and found a difference between ratings of perceived exertion and objective measures with the cleaners underestimating the actual workload. In this study it might be possible that cleaners underestimated the actual workload with perceived exertion. However, comparative values show an advantage for the redesigned tool. Borg (1982) himself stated that the close relationship between perceived exertion and heart rate was not intended to be taken literally since the latter is only one indicator of exercise strain.

The cleaners rated the conventional cleaning tool more strenuous than the redesigned cleaning tool while cleaning the wagon’s floor. Cleaning with conventional cleaning tool was assessed to the scale value 13 (somewhat hard) compared to redesigned cleaning tool to the scale value 11 (light) according to the Borg RPE scale. Most likely very frequent and excessive bending of the torso of the cleaners created greater biomechanical loads on the back compared to the redesigned cleaning tool, and muscles had to work with higher forces against center of the gravity while bending. This could be the possible reason that cleaners perceived higher exertion in using conventional tool compared to redesigned cleaning tool (Kumar, 2001).

The study reveals that the cleaners bent less when they used the redesigned cleaning tool. The conventional cleaning tool required frequent and excessive bending in order to clean the lower berth of the wagon compared to redesigned cleaning tool.

This study focused only on the floor cleaning task, even though the floor cleaning task does not represents the entire cleaning task required for the passenger train wagon, but it was one of the major tasks. Though, the upper limb stress was not systematically studied in the present study, however, it was observed in video recordings and also reported from the cleaners that excessive extension and flexion of the wrist/hand required with conventional cleaning tool were completely eliminated while using redesigned cleaning tool.

5. Conclusions

It can be concluded that floor cleaning in the train wagons is associated with moderately high cardiovascular load and high frequency of stressful working postures. The introduction of the redesigned cleaning tool allowed cleaners to maintain more upright posture while cleaning, which reduce biomechanical and physiological loads on them.

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PARTICIPATORY ERGONOMICS AND AN EVALUATION OF A LOW-COST IMPROVEMENT EFFECT ON CLEANERS’ WORKING POSTURE

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Montakarn Chaikumarn
Jan Lundberg

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Cleaning is a highly physically demanding job with a high frequency of awkward postures and working environments as contributing risk factors. Participatory ergonomics is a method in which end-users take an active role in identifying risk factors and solutions. The aim of this study was to apply the participatory ergonomics method to identify cleaning problems and to evaluate the effect of a low-cost improvement on cleaners’ working postures in an office environment. The results show that the cleaning problem was identified, and the low-cost ergonomics solution suggested by the cleaners was implemented. Thus an improved working environment reduced the number of awkward cleaning postures and the Ovako Working Posture Analysis System (OWAS) action category for floor mopping decreased. It can be concluded that working in an improved environment can lead to better working postures which, in turn, leads to the cleaners’ better health and better cleaning results.

participatory ergonomics  cleaning  OWAS  postural analysis  low-cost improvement

1. INTRODUCTION

Cleaning is considered a high physically demanding job, resulting in high cardiovascular load [1, 2], high frequency of awkward postures [3, 4] and, as such, it is rated as a highly strenuous job [1, 2]. In several studies the relationships between a poorly designed workplace, poor working posture and diseases of the musculoskeletal system have been demonstrated [5, 6, 7].

According to Noro and Imada [8] participatory ergonomics is a method in which its end-users take an active role in the identification and analysis of risk factors, as well as in the design and implementation of ergonomics solutions. Participatory ergonomics interventions have been associated with a decrease in the incidence of musculoskeletal symptoms [9, 10], a decrease in work absenteeism [10] and an improved psychosocial work environment [11].

Amongst the various ergonomics approaches, participatory ergonomics is a popular one. In participatory ergonomics workers are involved in implementing ergonomics knowledge and principles in their workplace, supported by their supervisors and managers, in order to improve their working conditions [12]. Several studies have shown the success of problem identification and solution through participatory ergonomics intervention [10, 13, 14].

The aim of this study was to use the participatory ergonomics method to evaluate cleaning problems and to evaluate the effect of a low-cost improvement...
on cleaners’ working postures in an office environment.

2. METHOD

Twenty-three motivated professional female cleaners from one university in Sweden took part in a participatory workshop (PW). Their age ranged from 24 to 54 years and the average length of their work experience was 14 years. The PW was carried out according to the following steps:

- Step 1: Definition of the framework/theme of the PW,
- Step 2: Establishment of the goal,
- Step 3: Identification of the problem,
- Step 4: Development of a possible ergonomics solution,
- Step 5: Implementation of the solution,
- Step 6: Evaluation.

The PW method is based on recommended outlines for the process of participatory ergonomics [15, 16, 17].

The theme of the PW, “Problems while cleaning”, was defined in an active discussion of all the cleaners. The conditions were flexible and informal with access to refreshments and materials for visualizing the output of the PW. The cleaners sat in a U-shaped seat arrangement. The cleaners’ supervisor also participated as a neutral person to guide the PW. Researchers facilitated the PW, which took about 3 hrs.

The goal of the PW was to highlight all the problems related to the present work situation or conditions, which were experienced by the cleaners and which they wanted to change. Each participant briefly described a problem she had experienced. The PW leader wrote it down verbatim on a large sheet of paper with a running number. This continued until no cleaner could come up with any problem other than what had already been expressed. This meant that the cleaners had expressed all their criticisms.

After listing all the problems, each participant ranked the three most critical problems from the list and the PW leader ranked the listed problems from the first to the last. The first ranked problem was selected for developing a possible ergonomics and economical solution.

The computer and electric cables were ranked first by the cleaners because they made mopping the floor difficult. Due to the cables on the floor, the cleaners had to squat, lift the cables with one hand, and mop the floor with the other. A possible ergonomics solution to the problem, suggested by the cleaners, was to fix the cables above the floor by attaching them to the working table in such a way that they did not lie on the floor in a scattered fashion, or hang in the air (Figure 1).

Two hundred and twenty offices in one of the university buildings were observed closely, and it was found that 65% of those rooms had cables sprawled on the floor. Out of the 220 office rooms, six were selected for the purposes of the test; all of them were used by university staff.

(a)

(b)

Figure 1. (a) Cables on the floor, (b) cables above the floor, attached to the working table.

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Ten female cleaners, who had taken part in the PW, participated in Tests 1 and 2, each of which lasted 30 min per cleaner. In Test 1, they cleaned a room with the cables on the floor using their usual pace and style. Test 2 was carried out after all cleaners finished Test 1. In Test 2, the cables were fixed above the floor (they were attached to the working tables) and the cleaners were asked to perform the cleaning task in the same manner as in the first test. One deciliter of dry sand was used as cleaning dust on the floor in both tests so that cleaners maintained their normal pace. Both tests were recorded on videotape for task analysis and postural analysis of cleaners with the Ovako Working Posture Analysis System (OWAS) method [18].

In the OWAS method there are about 252 posture combinations: work postures for the back, arms, legs, and for carrying load, all of which are assigned action codes [19, 20]. The four action codes are defined as follows:

- Action category 1: change not required,
- Action category 2: change required in the near future,
- Action category 3: change required as soon as possible,
- Action category 4: change required immediately.

After the second test, the videotapes were analyzed with the WinOWAS computer software [21] for analyzing working postures according to the OWAS method. The random time interval for coding a cleaning posture was 10 s.

3. RESULTS

3.1. Task Analysis

Task analysis was done by analyzing the videotapes recorded while the cleaners cleaned a selected room for the purposes of the tests. The task started with pushing the cleaning cart into the office door, and ended with closing the door (Figure 2).

As a result of task analysis, nine main activities of the cleaning job were identified. Floor mopping and wet dusting were the major ones (Figure 3).

![Figure 2. Cleaning activities from task analysis.](image-url)
Figure 3. The proportion of cleaning activities: (a) with cables on the floor, (b) with cables above the floor.

3.2. Postural Analysis

The obtained data was analyzed according to the different work phases (corresponding with task analysis) for both tests, and the proportionate share of postures for different work phases was calculated in percentages.

The total number of OWAS observations for each test was 1,370 for the 10 participating cleaners. The proportionate share of postures of different body parts was analyzed and categorized into different action categories. After analyzing the postures in Test 1, it was found that only mopping and dusting proportions fell into categories 3 and 4. In Test 2, the floor mopping task did not fall into categories 3 or 4 (Table 1).

The number of working postures for floor mopping decreased from 36 to 33% of the total working time after the cables were fixed above the floor. The differences were found in the proportion of the back, arms, and legs postures between Tests 1 and 2 during the floor mopping task (Table 2).

It was found that fixing the cables above the floor affected the cleaners’ posture in the floor mopping task only: the cleaners did not squat while cleaning under the tables (Figure 4).

**TABLE 1. OWAS Category for the Mopping Task Before and After Fixing Cables**

<table>
<thead>
<tr>
<th>Cleaning Task</th>
<th>Cables on Floor</th>
<th>Cables Above Floor</th>
<th>OWAS Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mopping</td>
<td>38</td>
<td>40</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>60</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>—</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>—</td>
<td>4</td>
</tr>
<tr>
<td>Dusting</td>
<td>25</td>
<td>23</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>75</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

TABLE 2. The OWAS Proportion of Back, Arms, and Legs Posture in the Floor Mopping Task in Tests 1 and 2

<table>
<thead>
<tr>
<th>Posture</th>
<th>Test 1 (Cables on Floor, %)</th>
<th>Test 2 (Cables Above Floor, %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Straight</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td>Bent</td>
<td>32</td>
<td>37</td>
</tr>
<tr>
<td>Twisted</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Bent and twisted</td>
<td>29</td>
<td>23</td>
</tr>
<tr>
<td>Arms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both below shoulder</td>
<td>74</td>
<td>100</td>
</tr>
<tr>
<td>One above shoulder</td>
<td>26</td>
<td>—</td>
</tr>
<tr>
<td>Both above shoulder</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Legs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standing on two legs</td>
<td>36</td>
<td>51</td>
</tr>
<tr>
<td>Standing on one leg</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>Sitting on two bent knees</td>
<td>6</td>
<td>—</td>
</tr>
<tr>
<td>Sitting on one bent knee</td>
<td>17</td>
<td>—</td>
</tr>
<tr>
<td>Kneeling</td>
<td>6</td>
<td>—</td>
</tr>
<tr>
<td>Walking</td>
<td>30</td>
<td>39</td>
</tr>
</tbody>
</table>

Notes. OWAS—Ovako Working Posture Analysis

Figure 4. Change of working posture during the floor mopping task: (a) with cables on the floor, (b) with cables above the floor.

3.3. Quality of Floor Cleaning

It was observed that in Test 1, sand was still left under the table where there were cables on the floor. In Test 2, no sand was left on the floor after the cables had been fixed above it.

4. DISCUSSION

In this study, the participatory ergonomics method was successful in identifying ergonomics problems at the workplace and possible ergonomics solutions. The reason why workers’ participation is important in problem solving is that workers know their work and workplace better than others, and they act as problem solvers [15, 22]. Further, participatory ergonomics enhances the development of a two-way information flow between a supervisor/researcher and the workers (Figure 5), which facilitates ergonomic activities for problem identification and ergonomics solutions [23].

The low-cost change was implemented in the office environment as suggested by the cleaners
and an evaluation of the effects of the change on the cleaning postures was carried out. Task analysis was done in order to classify the activities/tasks of the cleaning job, which was done in OWAS in the form of work phases, such as pushing the cart, opening/locking the door, etc. (Figure 2).

Some minutes of observation were ruled out from the video analysis because of other activities which were not related to the cleaning job, such as talking on the phone, waiting for the occupant to leave the room, etc. Therefore, the average cleaning time was shorter than the required 30 min. Although the recommended time interval for an OWAS analysis is 30 s, the researchers chose to use 10-s intervals in order to obtain more observations.

After implementing the low-cost improvement, none of the cleaning activities fell into categories 3 or 4. Further, in Test 1, we found that the cleaners’ arms posture was 74% for both arms below the shoulders, and 26% for one arm above the shoulder as compared to 100% for both arms below the shoulders in Test 2 during the floor mopping task. It was also found that the cleaners’ legs posture for standing on two bent knees, standing on one bent knee, and kneeling were completely eliminated after the low-cost improvement.

The reason is that after fixing the cables above the floor, none of the cleaners squatted or sat on bent knees while cleaning the floor under the table in Test 2. This was in contrast with Test 1, in which the cleaners had to bend their knees in order to hold the cables in one hand, and to mop the floor with the other hand (Figure 4).

We also found that after fixing the cables above the floor, the cleaners bent their back more than in Test 1. The reason is that while standing and cleaning the floor, the cleaners had to bend their backs in order to see under the table.

Although the quality of floor cleaning was not measured in this study, it was clear that the floor was completely cleaned when the cables were fixed above the floor. The possible explanation is that fixing the cables above the floor gave the cleaners a complete clear space to clean under the table. In contrast, cables on the floor forced the cleaners to squat and hold the cables with one hand, which limited them in cleaning the whole area properly.

It has been clearly shown that thanks to this low-cost improvement the cleaners have a better working posture for floor mopping compared to unimproved working conditions. One research study [24] made a low-cost improvement for small enterprises in the Phillipines and many low-cost improvements were shown to reduce work-related musculoskeletal disorders and discomfort. After fixing the cables above the floor, no working postures fell into categories 3 or 4. This finding indicates that an improvement in working conditions helps cleaners to maintain a safe working posture during the mopping task. In their study, Hopsu and Louhevaara [18] used the OWAS method to measure postural load in cleaners’ work during an intervention study: this intervention study included educational training and ergonomic job redesign, and the results showed a decrease from 39 to 25% in the number of postures in categories 2 through 4.

The OWAS action category for the floor mopping task decreased and fell from categories 3 and 4 to category 2. However, the mopping task still requires changes in the near future.

5. CONCLUSIONS

From this study it can be concluded that participatory ergonomics is an appropriate ergonomics tool for identifying and solving ergonomics problems. A low-cost improvement improved the cleaners’ working postures by eliminating the awkward ones such as sitting
on one and two bent knees, and holding an arm above the shoulder. This study also indicates that
the quality of floor cleaning improved after cables were fixed above the floor. The results from this
study can be used as a general means for improving cleaners’ working postures.

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ERGONOMICS AND PRODUCTIVITY CONSEQUENCES IN ADOPTING A LINE-BASED PRODUCTION SYSTEM

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Ergonomic and production system effectiveness are evaluated in a case of a production system redesign: from parallel flow dock-based, to serial flow line-based assembly. The line-based system displayed much tighter coupling of operators to the technical system and introduced system, balance and downtime losses. We observed reductions in: cycle times to 6% of previous, decision latitude, influence and control over work, perceived work load, and perception of available pauses. Layout and technology changes helped improve co-worker interaction and support, and reduce instances, but not magnitude, of peak spinal loading. It is concluded that serial flows can negatively affect psychosocial conditions and, if losses are high, reduce physical workload. An 'Action Group' has been formed in the company to adopt an evidence-based approach to the development of systems that are sustainable from both productivity and ergonomics perspectives.

INTRODUCTION

In this paper we use a case study in the redesign of motor assembly system, from a long-cycle dock system to a line-based system (Figure 1), to examine the relationship between system design, technical performance and work related musculoskeletal disorder (MSD) risk. Recent surveys indicate societal trends of increased work intensity – a MSD risk factor. This case’s scenario appears to be a trend in Sweden of returning to line based production models after decades of more sociotechnically-based approaches. However evidence suggests that parallel flow systems can be more productive with better ergonomic potential than conventional line systems (Medbo 1999).

Integrating human factors into manufacturing system design remains an under-utilised mechanism for ergonomics intervention (Westgaard & Winkel 1997). While we focus on MSD risk factors, we adopt a systems perspective (Neumann 2001) including also performance and productivity variables of traditional interest to factory design teams. Joint optimisation of all of these factors may allow ergonomic problems to be solved in a profitable way (Winkel & Westgaard 1996). This study is part of a line of research that aims to understand the basis by which a production model is chosen and the consequences of this choice in the realized system.

METHODS

A longitudinal case study with most measures implemented

Figure 1: OLD system dock workstation (left) & NEW line system (right)
pre and post system re-design was performed. We integrate qualitative and quantitative methods. Informal interviews and document analysis were conducted to understand both process and outcomes in the system redesign project. Production and economic data were obtained from company information systems and interviews. Questionnaires (n=81 pairs) were used to assess operators’ perceptions of pain status, workload, stress, energy and psychosocial conditions. Portable data loggers were used to measure postures of wrists, arms, head, and back while working under normal conditions (n=8 pairs). Video recordings were made synchronously with data logging and analysed with respect to the time used for work activities including direct (value adding) and indirect work. Posture data were obtained for each activity category. In order to understand operators’ movement between work areas a position logging system (originally from orienteering) was implemented. Biomechanical models were used to assess individual loading and production simulation models were used to understand system behaviour and working patterns.

Follow-up measures, planned jointly with the company, were made 6 months after the change. While detailed quantified posture and task information is not yet available, qualitative, modelling, questionnaire, and preliminary system performance data will be reviewed. System performance data will be re-examined 12 months after baseline to control for seasonal and run-in effects.

PRELIMINARY FINDINGS

OLD system. The OLD production system, designed with 18 ‘dock’ stations, was studied having 12 Docks and a small ‘learning line’ in parallel for newer Operators. Operators worked alone at each dock to assemble each motor. Operators were required to finish 5 engines per day that increased to 5.5 shortly before measurement. Operators could stop working once this quota was reached. The system was designed, based on standard times, to allow 6.2 motors to be completed per shift per dock but this target was not enforced and not all operators were believed to be capable of this pace. Hand-steered motorized carts allowed transport and lift-tilt position adjustment of motors. Parts were supplied to the dock using a 5-shelf ‘kit’ stocked with variant specific components by stock ‘pickers’.

NEW system. The NEW line system used a serial flow of 18 stations and reduced station cycle time to 6% of the ‘dock’ cycle time. Automated Guided Vehicles (AGVs) provided motor transport and eliminated short walks between assembly cycles. Parts were supplied directly to the line in large crates. Operators retrieved parts directly from the crates occasionally adopting awkward postures. The AGV contained a computer monitor providing part numbers for the particular variant to the operator. The product itself was largely unchanged between OLD and NEW systems requiring about the same component mounting work. There were however many product variants requiring different components that, for lower volume variants, were positioned further away from the operators’ workstation resulting in load carrying.

Motivation for the re-design. Reasons for the change, examined through company documents and interviews, included overcoming current capacity limitations and was summarized in the project directive: “A line will mean it is easier to come to clear the expected 70,000 rate, that we decrease learning time, simplify material supply, make it easier to make other changes (because we skip changing 18 places), have a more social workplace with fewer work injuries and, above all reach a reduced product price”. In apparent contradiction the corporation’s own standard on work organisation stated: “serial flows with short cycle times generate waiting times that are not experienced as pauses but as disturbances in the work rhythm. This also generates accelerated work with poor ergonomics as a consequence.” These waiting times were observed in the new system, with utilization times in the NEW system as low as 67% as seen in simulation modelling (Figure 2). Balance losses were not modelled but are also a relevant factor. These results were predicted by the corporate standard: “leaving the concept of the traditional line means that the system losses are reduced since the time dependence between fitters/operators is reduced” and “parallel flows reduce the need of buffers and reduce balance losses.”

The Work Organization. The 5 motor quotas in the OLD system limited production to 81% of planned capacity (89% at 5.5 quota) and reduced the impact of other

![Figure 2: Sensitivity of NEW line and OLD dock systems' operator utilization rates to variability in operators' cycle time (10% & 20% coefficient of variation) and to machine downtime (5% downtime) based on flow simulation models.](image)
losses seen in Figure 2. The OLD system appeared to invite faster work paces to accumulate rest time for operators who could reach the quota. The NEW system had a team structure in which operators rotated every break within the 4-6 stations of the team’s area. Operators stayed on-line for the full shift. Waiting patterns in the NEW system, which may not be fully restful, was determined by system loss patterns. Neither system collected information on operators’ work pace or work pattern related loading.

System performance. Planned comparisons of system performance are presented in Table 1. Data is not presented for the NEW system as the effects due to design strategy were confounded by ongoing run-in activity and simultaneous increases in customer demands that placed unrepresentative pressures on the NEW system. Qualitatively we can report increasing output with similar staffing levels, despite the line system’s losses. Labour was saved in ‘kit picking’ but added with line-‘runners’ who move along the line as needed. Investment in the AGV system increased capital costs. Extra resources were required to maintain quality levels during the run-in period. More detailed assessment of performance indicators, especially economic factors connected to MSDs, is currently underway.

Biomechanical loading. Affordability of lift-assists was seen as an ergonomic advantage of the NEW system and three were installed. These could not reach more distant component variants however, which then required manual handling and some carrying. Although all stations no longer handled heavy parts, the system-wide peak spinal loading was about the same in both systems with 470N shear loading and L4/L5 compression over 2600N. Nevertheless operators reported lower back loading on the Borg RPE-10 scale (P<0.01) on the new system. More detailed profiling of postures and load accumulation, now underway, must also account for system functioning and loss patterns. Duration of exposure to powered hand tools, for example, could be expected to rise as direct labour efficiency is increased in the new system. The company collects no systematic data with regards to operators’ exposure to biomechanical load.

Questionnaires. Pair-wise comparisons of operators experienced in both dock and line systems (n=54) indicate significant (p<0.05) reductions in ‘decision latitude’, ‘influence and control of work’, and ‘physical exertion’ scales and increases in ‘social support’ and ‘relationships with fellow workers’ scales in the NEW system compared to OLD. While a trend (p=0.11) of reduced general ‘physical discomfort’ was observed, the ‘Nordic’ symptom instrument indicated increases in shoulder pain (3-month history). In this sub-sample of operators, 71% reported fewer pauses in the new system (6% said more) - consistent with the quoted corporate standard. Most operators also reported reduced work variation (68% vs. 19%), and reduced stimulation (63% vs. 16%) in the NEW system. These results are consistent with a shorter cycle, pace-controlled system with in which operators are close enough to talk to each other.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>OLD</th>
<th>NEW</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRODUCTION- Volumes (normal to Old)</td>
<td>100</td>
<td>n/a</td>
</tr>
<tr>
<td>Standard Cycle Time (normal to Old)</td>
<td>100</td>
<td>6</td>
</tr>
<tr>
<td>Throughput time (normal to OLD)</td>
<td>100</td>
<td>n/a</td>
</tr>
<tr>
<td>STAFFING – Total Operators (% OLD )</td>
<td>100</td>
<td>102</td>
</tr>
<tr>
<td>Middle section (% OLD Total)</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Picking (% OLD Total)</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Docks/Line (% OLD Total)</td>
<td>34</td>
<td>46</td>
</tr>
<tr>
<td>USA Motor line (% OLD Total)</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Other (% Old Total)</td>
<td>37</td>
<td>30</td>
</tr>
<tr>
<td>ECONOMICS – Total Costs (norm/motor)</td>
<td>100</td>
<td>n/a</td>
</tr>
<tr>
<td>Direct Labour Costs (%OLD Total)</td>
<td>50</td>
<td>n/a</td>
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<tr>
<td>Indirect Costs (%OLD Total (%OT))</td>
<td>50</td>
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</tr>
<tr>
<td>Ind. Costs – Labor (%OT)</td>
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<td>Ind. Costs – Capital (%OT)</td>
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</tr>
<tr>
<td>Ind. Costs – Maintenance (%OT)</td>
<td>1</td>
<td>n/a</td>
</tr>
<tr>
<td>Ind. Costs – Other (%OT)</td>
<td>3</td>
<td>n/a</td>
</tr>
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</table>

DISCUSSION

This is a case study and therefore represents a particular instance and time-point of these two production strategies. Table 2 presents an overview of specific system design elements and their apparent consequences for system effectiveness and ergonomics. These results are consistent with previous case studies (eg Neumann 2001) and generally show internal consistency across qualitative and quantitative domains. Of the many measurement issues affecting this study the interpretation and stability of company data systems posed a particular challenge. The dynamic nature of the production system itself, where coefficient of variations in monthly production indicators ranged from 10-25% or more during this run-in period pose interpretational challenges. To overcome this variability we applied a broad range of measures to triangulate on the ergonomic and

productivity consequences of production system design choices (Table 2). This analysis sets the stage to identify system elements that could be strengthened or modified to improve both ergonomics and effectiveness simultaneously.

Assembling motors is largely a job of getting components and bolting them on. An important aspect for MSD risk will be how concentrated these activities become for operators. If efficiency gains are sought by maximising operators’ nut-running time, for example, then MSD risk will increase. If, on the other hand, current losses could be filled with productive work that does not increase critical biomechanical exposures then both good ergonomics and good productivity could be achieved. This is the challenge for the company’s ‘Action Group’, recently established at this site. This multi-stakeholder group is to make ‘evidence based’ improvements to 1) current systems, 2) future system designs, and 3) the product by which both human factors and other productivity goals can be met in a sustainable production system. We will operate in an action research mode offering tools and using information feedback, including the analysis presented here, while monitoring both process and outcome factors during the development project. The objective is to see if productivity can be improved in a sustainable way by working smarter - not just harder.

CONCLUSIONS & RECOMMENDATIONS

While physical load amplitudes were controlled by workstation layout factors, system-flow & work organisation strategies controlled individuals’ exposure time patterns. Adoption of the line system bypassed work organisational barriers in the OLD dock system (the quota) that limited productivity and rewarded operators who rushed with longer rest periods. Instead system and other losses in the NEW line system created many small waiting periods during the day and resulted in reductions in productivity, work autonomy, and decision latitude. The current case shows both systems to be sub-optimal when ergonomics and productivity are considered jointly. Companies should adopt tools and processes to generate and evaluate evidence of both human and technical factors in designing production systems. We suggest that hybrid systems with parallel elements and team-based work may provide new opportunities for innovation. Follow-up monitoring is necessary to track system stabilisation and aid the ongoing joint optimisation of ergonomics and productivity in this manufacturing system.

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