Safety and Health at Work 5 (2014) 97–105

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.org

Original Article

Development of a Decision Support System for Analysis and Solutions of Prolonged Standing in the Workplace

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A R T I C L E I N F O

Article history:
Received 30 December 2013
Accepted 15 April 2014
Available online 9 May 2014

Keywords:
decision support system
discomfort
ergonomics
fatigue
prolonged standing

A B S T R A C T

Background: Prolonged standing has been hypothesized as a vital contributor to discomfort and muscle fatigue in the workplace. The objective of this study was to develop a decision support system that could provide systematic analysis and solutions to minimize the discomfort and muscle fatigue associated with prolonged standing.
Methods: The integration of object-oriented programming and a Model Oriented Simultaneous Engineering System were used to design the architecture of the decision support system.
Results: Validation of the decision support system was carried out in two manufacturing companies. The validation process showed that the decision support system produced reliable results.
Conclusion: The decision support system is a reliable advisory tool for providing analysis and solutions to problems related to the discomfort and muscle fatigue associated with prolonged standing. Further testing of the decision support system is suggested before it is used commercially.

1. Introduction

Many industrial workplaces require workers to perform their jobs in a standing position. One of the advantages of standing is that it can provide a large degree of freedom to workers when manipulating materials and tools at their workstation. In addition, a standing position is practical and effective when workers are operating large machines and work pieces, reaching out for materials and tools, and pushing and pulling excessive loads. For instance, a worker who works at a conventional surface grinding machine requires a large degree of freedom to push and pull the machine table when grinding the surface of the work piece. This type of job is almost impossible to perform in a sitting position, so standing is the best option. A standing working position also encourages workers to be more productive and consequently contributes to higher productivity.

However, when workers spend long periods of time standing, they may experience discomfort and muscle fatigue at the end of the working day. In the long term they may experience occupational injuries such as work-related musculoskeletal disorders, chronic venous insufficiency, and carotid atherosclerosis [1]. A worker is considered to be exposed to prolonged standing if he or she spends over 50% of their total working hours during a full work shift in a standing position [2]. Working in a standing position for an extended period of time has been recognized in industry as contributing to a decrease in workers' performance. This decrease may be a result of occupational injuries, a decrease in productivity, and an increase in treatment and medical costs. Prolonged standing can lead to subjective discomfort in workers. When workers perform jobs in a prolonged standing position, static contraction occurs, particularly in their back and legs, resulting in discomfort and muscle fatigue [3]. Employers may also be affected due to the

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http://dx.doi.org/10.1016/j.shaw.2014.04.002

loss of revenue in the form of productivity, workers' compensation, and health treatment costs [4]. For example, a pain in the lower back due to prolonged standing can affect the ability of a worker to perform a job involving flexion or extension postures. This may, in turn, affect the productivity of the worker. In addition, workers who suffer from occupational injuries must be referred to clinical experts for health treatment, which involves substantial amounts of consultancy and treatment costs.

Many ergonomics simulation systems have been introduced to improve the productivity, comfort, and safety of workers in manufacturing workplaces [5,6] and numerous assessment tools have been suggested to assess and analyze the risk factors associated with prolonged standing. For example, the Rapid Entire Body Assessment (REBA) [7] and the Guidelines on Occupational Safety and Health for Standing at Work [8] can be applied to analyze and minimize postural stress due to standing jobs. However, almost all existing methods are only available as pen and paper forms and do not provide a comprehensive assessment of prolonged standing. The methods are time consuming, difficult to retrieve electronically, require manual data processing, and may suffer from human errors when performing calculations. In addition, the existing assessment methods are seen as individual, isolated tools, hence it is difficult to perform multiple assessments concurrently [9]. Innovative best practice and the underlying measurement science for assessing and analyzing the risk factors associated with prolonged standing and documenting the results of the computations do not yet exist. As a consequence, the authorized institutions and industry practitioners who are concerned with occupational safety and health do not have a reliable measurement tool with which to assess and analyze the risk factors associated with jobs involving prolonged standing in the workplace. This includes the proposition of solutions to minimize the level of risk.

To counter these limitations, this study aimed to develop a decision support system to assess, analyze, and propose solutions for minimizing the discomfort and muscle fatigue associated with prolonged standing in industrial workplaces. Six risk factors related to prolonged standing (working posture, muscle activity, duration of standing, holding time, whole-body vibration, and indoor air quality) [10] were considered as the basis to develop knowledge for the decision support system. These risk factors are related to humans, machines, and the environment in the workplace. All the risk factors were analyzed individually to determine their risk levels. The risk levels of each risk factor were then assigned with multipliers to represent their severity for discomfort and fatigue. A strain index was developed through multiplicative interactions between the assigned multipliers. The decision support system developed in this way proposes alternative solutions to minimizing the risk levels corresponding to the strain index. In the decision support system developed, an Ergonomic Workstation model and a Decision Support System for Prolonged Standing (DSSfPS) model were designed to function as data capturing and analysis models, respectively.

2. Materials and methods

2.1. Stage 1: knowledge acquisition

The first stage in developing the decision support system was knowledge acquisition. In a decision support system, knowledge can be considered as the "brain" to process the input data and information supplied to the system. The knowledge can be obtained by extracting, structuring, and organizing knowledge from one or more sources [11]. In this study, knowledge acquisition was performed to determine the risk factors that contribute significantly to the discomfort and muscle fatigue associated with jobs involving prolonged standing. The ergonomics evaluation tools used to analyze the risk factors were also obtained at this stage. This was carried out by obtaining information from reliable sources such as published literature, onsite observations in industry, interviews with management staff and production workers, guidelines and standards from authorized organizations, and expert opinion.

Reviews of published papers were carried out using hard-copy publications, such as magazines, journals, and guidelines, as well as online databases. The main purpose of the literature review was to determine the risk factors that contribute significantly to the discomfort and muscle fatigue associated with jobs involving prolonged standing. Literature reviews are also useful in identifying ergonomics evaluation tools and control measures that can be applied to assess, analyze, and minimize discomfort and muscle fatigue. The identified risk factors, methods, and control measures were compiled for consideration in the decision support system.

A series of onsite observations was conducted in three metal-stamping companies in Malaysia. The main purpose of the onsite observations was to identify the risk factors that are present in standing workstations. A video camcorder was used to record these risk factors. The video camcorder was set close to the workstation to record posture, movements, and job cycles while the workers were performing their jobs. The process of video recording took about 30 minutes to ensure that all the risk factors, working practices, and job processes in the workstation were recorded completely. The advantage of video recording is that the recorded information is easy to replay, stop, or pause so that the postures, movements, and job cycles in the workstation can be monitored. In addition, the risk factors captured by video recording can be considered as knowledge for the decision support system.

In addition to the onsite observations, interview sessions with management staff and production workers were carried out to acquire the personal background and job activities of the workers, the discomfort and fatigue experienced by the workers while performing their jobs in a prolonged standing position, any history of pain and treatment taken, and suggestions to improve the standing workstations. The Prolonged Standing Questionnaire [12] was applied during the interview sessions. Through the interview sessions, we were able to acquire useful information that could not be obtained during the onsite observations, such as the solutions applied by the management staff and production workers to minimize the discomfort and muscle fatigue associated with prolonged standing.

Authorized organizations such as the International Organization for Standardization and Department of Safety and Health of Malaysia are good sources from which to acquire information on prolonged standing in workplaces. These institutions have published regulations and guidelines on standing in the workplace. The Guidelines on Occupational Safety and Health for Standing at Work [8], the Code of Practice on Indoor Air Quality [13], and standards of comfort levels due to acceleration values of whole-body vibration [14] were referred to in order to establish the knowledge base of the decision support system.

Experts, including ergonomic practitioners, medical doctors, physiotherapists, safety and health engineers, and academics, were significant contributors in developing the knowledge of the decision support system. Their opinions and advice were gathered through discussions in seminars and conferences. One of the outcomes from the discussion was the selection of ergonomics evaluation tools to be applied in the decision support system.

All the risk factors related to the discomfort and muscle fatigue associated with prolonged standing which were compiled from these sources were categorized into three domains, namely: human, machine, and environment. Each risk factor from these domains was equipped with ergonomics evaluation tools to analyze