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Adapting ergonomic assessments to Social Life Cycle Assessment

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Abstract

In Social Life Cycle Assessment (SLCA), the health and safety aspect of workers is usually evaluated by considering the numbers of injuries and accidents; however, the work related musculoskeletal disorders (MSDs), which dominate occupational diseases, are often neglected in SLCA since the effects do not occur immediately. Thus, the MSDs lead to increased working absences and compensation costs, and also reduced productivity of workers. To address the gap, applying ergonomic assessment is proposed since it identifies and quantifies the health risks at work based on a set of pre-defined criteria e.g. force, posture, repetition and duration, and provides the numeric results analyzing the physical load and their sources. In the study, the application of ergonomic assessment and its indicators in SLCA is displayed to screen risks and to further improve working place design.

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1. Introduction

Nowadays, sustainability has become an important goal for global governments and industries to pursue. Sustainability considers the environmental, economic and social dimensions as triple bottom line theory. Apart from focusing on the mitigation of environmental impacts, the concerns on social aspects, especially in improving working conditions, have been increased. According to the Guidelines for Social Life Cycle Assessment of Products, SLCA is defined as a methodology that aims at assessing the potential positive and negative social impacts related to human beings affected by products/services throughout the life cycle, such as health and labor rights of workers, etc. Based on the guidelines, 'health and safety' is one of the most widely-considered aspects to evaluate the health condition or potential health risks of workers while working.

However, how to consider the health condition or potential health risks from mid- and long-term, and even a preventive perspective is a challenge in SLCA. The current dominant measurements of the health and safety aspect are e.g. inventorying the numbers of injuries and accidents occurred in working place and identifying the existence of appropriate

protective gear required in all applicable situations. These indicators reflect only the present existence of injuries or death from a result-based perspective. That means the reduction of injuries may not fully represent the improvement of health and safety since it ignores some chronic or accumulative health impacts which can be predicted, such as Musculoskeletal disorders (MSDs).

MSDs denote health problems of the locomotor apparatus, i.e. muscles, tendons, the skeleton, cartilage, the vascular system, ligaments and nerves [1]. The physical characters frequently cited as risk factors for MSDs are rapid work pace and repetitive motion patterns, insufficient recovery time, heavy lifting and forceful manual exertions, non-neutral body postures, mechanical pressure concentrations, and body vibration [5]. Due to its symptoms occur in chronic and accumulated way, MSDs is often neglected and hard to estimate in existing injury measurements of SLCA. It was indicated as a major occupational diseases, bringing about significant loss, for example increased working absences and compensation costs, and also reduced productivity of workers. MSDs including carpal tunnel syndrome represented 59% of all recognized diseases covered by the European Occupational Diseases Statistics in 2005. In 2009, the World Health

Organization (WHO) reported that MSDs accounted for more than 10% of all years lost to disability [2]. These results indicate that considering MSDs issues in health and safety aspect is a key factor to improve workers' well-being.

To address the challenge, engaging ergonomic assessment in SLCA is proposed due to it identifies and quantifies the health risks at work based on a set of pre-defined criteria and provides the numeric results analyzing the physical load and their sources. The results of ergonomic assessments can be treated as a health condition from mid- and long-term, or preventive perspective, supplementary to the current injury measurements in SLCA.

Despite the direct effects on health and safety of workers, the contribution of ergonomics to sustainable development is also acknowledged [3,4]. Radjiyev et al. [4] concluded that ergonomics influence on sustainable development by improving occupational health and work design. In the context, ergonomics contribute to sustainable development with three different ways: achieving positive benefits for workers' well-being, enhancing the performance of organizations, and applying corporate social responsibility policies [3]. However, the studies only outline that ergonomic can significantly support sustainable development. Currently, there are no available suggestions related to adopting ergonomic assessment into sustainability assessment methods.

In this paper, the aims are to underline the existing gap of considering health conditions (such as MSDs) from mid- and long-term perspective in SLCA and other sustainability assessment methods, and hence to propose integrating ergonomic assessment as a tool in SLCA to address the challenge. The state-of-art studies related to ergonomic intervention and health impacts are also reviewed and summarized to show the relevance of ergonomics to MSDs, and to provide an overview about ergonomic interventions and assessments. The results can encourage the industry to apply ergonomics in working place, and provoke researchers to take ergonomic assessment into one of the key topics in the SLCA.

2. Ergonomics assessment

Ergonomics assessment methods are employed to detect and quantify health risks at work. Basically, these tools consist of a set of pre-defined criteria which are examined on the basis of a manual process. The process can either be performed and recorded by a camera or modeled in simulation tools, such as "Jack & Process Simulate Human" from Siemens [6]. The criteria have been ordered into four categories indirectly related to the common causes of MSDs described before: material handling, action forces, working posture and repetitive movements [7]. Material handling criteria consider the forces the worker is exposed to when lifting, carrying, pushing or pulling loads. Action forces are forces emerging through the worker's actions. The working posture criteria consider the pose of the limbs of the worker without forces from material or tool usage. Criteria on repetitions analyze the physical load from monotonous and

repeated movements at work. Finally, an analysis scheme is provided to accumulate the single criteria into a final result.

Ergonomics assessment methods differ in the level of detail they provide and are designed for different target groups. Coarse screening methods, such as MSI Risk Factor Identification [8–10] can provide a rough overview for identifying potential risks of workplaces. Their biggest advantage is their simplicity, such that even non-experts can use them after short training. These methods suit for a pre-selection of work places and processes for further investigation [7]. Screening methods, such as RULA [11] and REBA [12] contain a more complex set of criteria and allow a more detailed analysis. Hence, measurements to improve working conditions can be better derived from the outputs. Screening methods often provide numerical values for the risk, which allows a more nuanced comparison between different workplace designs. Detailed screening methods or expert screening methods provide additional information to screening methods. The transition between these two groups is merely continuous, such that a clear distinction is often not possible. Similar to screening methods, expert methods provide point scales for a sophisticated comparison. Examples are EAWS [13], NIOSH [14] and OCRA [15]. Due to their complexity they are often only properly usable by experts. Finally, methods based on physical measuring can be used to determine ergonomic variables based on biomechanical variables. An example is CUELA [16], which measures the tilt angle of the back using a set of acceleration sensors and gyroscopes. Measuring methods do not directly suit a high-level assessment, but can provide data for advanced biomechanical analyses. Their disadvantage compared to the methods mentioned before is that they require high investments in expensive sensory equipment.

Looking at the set of criteria and the scores assigned for different kinds of physical load, one might ask whether they are able to reliably predict risks based on complex biomechanical processes. Therefore, there have been various studies to investigate the validity of results of ergonomics assessment trying to find correlations between scores and injury rates or musculoskeletal complaints. Examples are Window [17], Coyle [18], and Pascual and Naqvi [19].

Having derived scores from assessment methods, they can be applied for different fields. The applications can be divided into two groups. Firstly, ergonomics assessment has become a vital part in factory process planning tools, such as Tecnomatix, where workplace and process designs can be simulated and evaluated. A human biomechanical model performs the actions a regular worker would do providing data for the assessment methods. Therefore, risks can be revealed before the physical workplace has been set up. Secondly, ergonomics assessment results represent the basis for measurements for existing workplaces and processes. The next section will give an overview over different ergonomic interventions performed in different fields and their impacts.

3. Ergonomic intervention and health impacts

In the section, the relationship between ergonomic intervention and health impacts is investigated by carrying out literature review. In this paper, the literature was collected from international peer-reviewed journals. The searching keywords were ergonomic intervention, health, musculoskeletal disorder and workplace. In total 15 journal articles were chosen due to their high correspondence with the keywords. Among the selected articles, three are review papers, and the others are empirical studies of the contribution of ergonomic intervention to MSDs.

The three review papers examined the effectiveness of workplace ergonomic interventions to control MSDs [20–22]. Karsh et al. [20] reviewed 101 studies prior to 1999, and found out that 84% of the studies showing the positive results of ergonomic interventions. Among these 101 reviewed studies, 21.4% of the studies involved ergonomic and/or lifting training as the only or primary intervention, and 48% engaged multiple intervention components [20]. Following Karsh et al [20], Silverstein and Clark [21] inspected the studies of ergonomic interventions between 1999-2003. The results supported that demonstrating combinations of intervention measures appear to have the greatest effect in reducing MSDs. In addition, the paper also suggested that ergonomic interventions can be coupled with other epidemiological and laboratory studies to increase the precision in estimates of exposure-load relationships [21]. Furthermore, the effectiveness of participatory ergonomic (PE) interventions was specifically investigated by Rivlis et al. [22]. PE is defined as ‘the involvement of people in planning and controlling a significant amount of their own work activities, with sufficient knowledge and power to influence both processes and outcomes in order to achieve desirable goals’ [22,23]. In PE interventions, an ergonomics team consisting of employees or their representatives, managers, ergonomists, health and safety personnel, and research experts will undergo training by experts to obtain ergonomic principles. With the fundamental knowledge of ergonomic concepts and methods, the group can newly develop solutions and adjustments to improve their workplace [22]. Half of its collected studies in the article provided partial to moderate evidence that PE interventions have positive impacts on MSDs, reducing injuries and workers’ compensation claims, and a reduction in lost days from work or sickness absence [22]. Though all the three review papers conclude that ergonomic interventions lead to positive influence to worker’s health and safety; however, the intensity of the effect demands more precise definition.

Apart from the chosen review papers, 12 empirical studies [24–35] were investigated to identify the effects on workers’ health contributed by ergonomic intervention in practical case studies. The overview of the selected empirical studies is provided (see Table 1). As shown in Table 1, the applications covered service and manufacturing sectors in developed (US, Finland, Canada and Sweden) and developing countries (Malaysia, Iran, Brazil, and Hong Kong district of China).

The results of empirical studies generally stated the positive contribution of ergonomic interventions to workers’ health.

The summary of these studies is described in the following:

- **Areas of application:** The areas are involved in service (nursing, kitchen, and post office) and manufacturing (material handling, carpet mending, printed circuit assembly, automotive industry, clothing and furniture production). Especially, one third of the collected studies are related to nursing. That shows the MSDs issues occurred in nursing workers have been greatly concerned.
- **Intervention methods:** In the studies, we have found the following intervention methods: PE, workshops, ergonomic (re-) design of workplaces, rearranging working flow, adding assistive equipment. Five studies [26,30,31,34,35] adopted PE methods to carry out the interventions. In those studies, the participant ergonomic teams were trained and thus developed strategies and adjustments to improve their working environment. Other interventions were exercised based on the expertise of ergonomists. In the context, the ergonomists set up the measurement according to the professional experiences and the results of interviewing workers, and visiting working sites.
- **Assessment methods:** Most of the studies used questionnaires to collect and to evaluate the feedback from participant workers. The subjective judgement of effectiveness of ergonomic intervention, physical and psychological health conditions, and improvement of working environment were usually adopted as criteria in the questionnaires. Data of injuries, absences days, indemnity claims, MSDs related complaints (like shoulder and low-back disorder (LBD), etc.), and productivity between pre- and post-intervention were also collected. In the context, statistic methods were used to evaluate if the results of intervention were significant from statistic point of view. RULA technique was used in one study [27] to calculate the ergonomic risk scores of workers to determine if the ergonomics improve between pre- and post-intervention. Moreover, four studies [26,28,31,34] carried out economic analysis to estimate the benefit-to-cost ratio and the recovered years of implementing ergonomic intervention.
- **Outcome:** Generally, all the selected empirical studies stated that considering ergonomics brought about moderate or significant positive contribution to addressing MSDs and working condition issues. Injuries, lost working days (LWD), indemnity claims were reduced by and large; meanwhile, the productivity and quality of processes/products benefited from the improved working environment, flows, and worker’s health. Especially, the close relationship between MSDs and eyestrain of workers was highlighted [32]. For economic analysis, the results showed the benefit-to-cost ratios were estimated between 5 and 11 [31,34]; and the cost savings from reduced defective products were also a crucial impact [26].

To sum up, the studies showed that ergonomics supported worker's well-being by controlling MSDs and improving their working environment. Correspondingly, the organization's performance improved since the productivity and quality rose. The cost and benefit analysis also clearly indicated the ergonomic interventions obtained economic benefits. It pointed out considering ergonomics contribute to both economic and social aspects of sustainability.

4. Discussion

In the previous section, the overview of literature remarks the effectiveness of ergonomic intervention on addressing MSDs and working environment. Not only health and safety perspective, but also the productivity and quality of products are consequently improved due to enhancing ergonomics of workers. The advantages on supporting social and economic sustainability shall be noticed.

Since playing as the key role to bridge work and sustainable development, ergonomics should be considered in SLCA and other related sustainability assessment methods, especially to address the gap in the health and safety aspect. As a first step, basic screening methods, for instance, MSI Risk Factor Identification [8–10], which can provide a general overview for identifying potential risks of workplaces, are recommended to integrate into SLCA. These techniques are easily applied in industry since non-experts can use them after short training. The estimated scores can be treated as a potential health risk indicator to judge the risk level of MSDs, to identify the existing risk factors, and to provide information to decision makers for further working place improvement. Apart from using the estimated ergonomic scores, adopting tailored questionnaires to summarize workers' feedback in qualitative and/or quantitative values is an alternative. A combination of the aforementioned standardized ergonomic assessment methods and questionnaires is also recommended. By adopting the values and ergonomics scores in SLCA, the mid- and long-term consideration of the MSDs can be achieved.

However, implementing ergonomics assessments in practical may encounter some challenges. Each assessment method owns its benefits and drawbacks. Trade-off between effort and level of detail usually exists. Effort includes time, equipment cost and required expertise. Level of detail decides the measurement alternatives. There are no standardized criteria for selecting an appropriate one. The selection usually depends on the complexity of working tasks, the need of managers, and the time or financial budgets. Furthermore, the evaluation may be carried out by examiners or ergonomists based on their experiences without investigating bio-mechanic models deeply. That means the examiners or ergonomists could fail to distinguish the ergonomic scores between different working task, postures, and other ergonomic risk factors in some specific working situations. In addition, the dynamic and changing work environments, especially where lengthy follow-up times required also limit the implementation of ergonomic assessment. Furthermore, the

individual differences between workers, such as muscle strength, gender, body shape, and other chronic diseases, which may influence the ergonomic assessments but usually, are neglected in the assessments.

Another topic shall be underlined is promoting ergonomics in global value chain, especially small and medium-sized enterprises (SME) in developing countries. The SME in developing countries mainly act as main upstream suppliers of the products sold in developed countries, involving in millions of workers. However, the harsh working condition is still under debate and the health and safety issues are often insufficiently considered in developing countries. The situation is critical in developing countries where only cases that cause workers' disability are recorded [36]. Applying ergonomic assessment in SME in developing countries is necessary to reduce the costly impact on productivity and to increase workers' well-being [36].

Additionally, ergonomics should not only be considered in working place design, but also further in product design for improving consumers' comfort and safety.

5. Conclusion

This paper highlights the lack of considering mid- and long-term health and safety issues, especially MSDs of workers, in SLCA. Adopting ergonomic assessments to SLCA is suggested as a solution to address the challenge. Through the overview of the selected literature, ergonomic interventions are approved with positive contribution in reducing MSDs, increasing workers' well-being, enhancing productivity and quality in working tasks and products. The results also acknowledge that ergonomics can support social and economic sustainability in global value chain, especially critical for developing countries.

As a first step, coarse screening methods which can provide an overview for identifying potential risks of workplaces are recommended to integrate into SLCA. The estimated scores can be treated as a potential health risk indicator to judge the risk level of MSDs for further working place improvement. Despite the estimated scores, summarizing workers' feedback in qualitative or quantitative values by using questionnaires is also recommended as an additional subjective indicator in SLCA.

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Table 1. Overview of the selected ergonomic intervention studies

Literature	Application	Background	Intervention & assessment	Outcome
Marras et al. [24]	Materials handling tasks (US)	Staffs with no low-back pain were fitted with the lumbar motion monitor.	19-month intervention: the addition of lift tables, the installation of lift aids.	The interventions lead to mean reductions of 7.42 LBD and 6.18 injuries per 100 full-time employees per year.
Owen et al. [25]	Nursing in hospitals (US)	Stressful patient handling tasks: transferring, lifting up, and toileting patients in bed.	Staffs were trained in 2.5 h to use the five devices. The injury data were collected for the 18 months pre- and post- intervention.	The injuries decreased to 40%, the LWDs decreased from 64 down to 3, and restricted days decreased to 20%.
Yeow & Sen [26]	Printed circuit assembly (Malaysia)	Poor workstation design, mix-up of (un)tested boards, incorrect test steps, and unclear color inspection.	PE intervention: Workstation with space for resting arms and the oscilloscope; clear segregation of boards; retraining of operators; and color reference for effective recognition.	Arm and trapezius muscles static work fatigue were dropped. Average savings in annual rejection cost (US\$574,560), increase in monthly revenue and productivity were shown.
Choobineh et al. [27]	Carpet mending (Iran)	72 menders were questioned regarding MSDs. Knees, back and shoulders problems were more prevalent.	RULA technique was used to calculate scores for the posture of body parts in the operation of the tasks pre- and post-intervention. The mending table with an attached seat was redesigned.	RULA scores showed improvement in ergonomics. 57% of the menders found working on the table better than working in the traditional conditions.
Nelson et al. [28]	Nursing facilities (US)	Nurses have one of the highest rates of work-related musculoskeletal injury of any profession.	Patient handling assessment, new equipment, and after action reviews, etc. Injury rates, lost work days, modified work days and other criteria were compared over two nine-month periods.	Significant decrease in musculoskeletal injuries rate as well as the number of modified duty days taken per injury (from 1,777 to 539 days). Initial investment for the equipment was recovered in 3.75 years
Fujishiro et al. [29]	Healthcare facilities (US)	The high incidence of MSDs among healthcare workers.	Statewide program provided ergonomic consultation and financial support for purchasing ergonomic devices.	Median MSD rate decreased from 12.32 to 6.64 per 200,000 employee-hours.
Pehkonen et al. [30]	Municipal kitchens (Finland)	Over the last 3 months, 87% of workers had reported pain related to MSDs.	The 11–14-month PE intervention: workshops to train staffs to plan the targets and implementation.	Workers estimated the effects of the intervention on musculoskeletal load and disorders positively.
Tompa et al. [31]	Automotive industry (Canada)	Few studies investigate the cost and consequences of participatory ergonomics	11-month PE intervention: The staffs received training, identified and implemented change projects.	Weekly indemnity claims was reduced by 52%. The benefit-to-cost ratio was 10.6.
Hemphälä & Eklund [32]	Post offices (Sweden)	The lighting systems were old and insufficient.	Visual ergonomics intervention: new lighting systems were developed to provide uniform light. The labelling strip lettering was enlarged; and the angle of racks was adjusted.	The subjective experience of the general lighting and sorting time improved. Close relationship between eyestrain and MSDs exist: Those with eyestrain had three times as much MSDs.
Szeto et al. [33]	community nursing (Hong Kong)	High physical demands at work result in MSDs to the nurses.	8-week intervention program: Ergonomic training, daily exercise program, equipment modification, computer workstation assessment.	Significant improvement in musculoskeletal symptoms and functional outcomes.
Tompa et al. [34]	Clothing manufacturing (Canada)	Few studies investigate the cost and consequences of participatory ergonomics.	2-year PE intervention: The ergonomist trained the members to assess the ergonomic risk factors of the identified jobs, and develop solutions.	First aid incidents, modified duty episodes, casual absences, long term sickness absences and product quality were greatly affected. The benefit-to-cost ratio was 5.5.
Guimarães et al. [35]	Furniture manufacturing (Brazil)	Body pain of workers was associated with repetitive work, inappropriate postures and materials handling.	4-month PE intervention: richer teamwork, adoption of safe motion and postures, reduced load handling and elimination of manual transportation.	Workload was reduced by 42% and productivity increased by 46%.

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