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TEEMU SUOKKO

ERGONOMICS: THE DARK MATTER OF WORK SYSTEM DESIGN

UNDERSTANDING SOCIO-TECHNICAL NAVIGATION CAPABILITIES
IN THE FINNISH MANUFACTURING INDUSTRY

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Suokko, Teemu

Ergonomics: The dark matter of work system design. Understanding socio-technical navigation capabilities in the Finnish manufacturing industry

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ABSTRACT

The manufacturing industry is under constant pressure to improve its competitiveness. This requires continuous productivity growth; however, Finland's productivity development has been weak during the last two decades. At the same time, challenges have arisen in promoting well-being at work in Finland. Ergonomics could address these productivity and well-being challenges, but in the manufacturing industry, it is mainly associated with activities aimed at improving occupational safety and health (OSH) and well-being at work.

This dissertation examined how ergonomics contributes to the productivity, well-being, and financial performance of manufacturing companies. The research consists of three studies. Study I, a quantitative survey (N = 121, 42 companies), examined how Finnish manufacturing companies understand and utilise ergonomics to promote well-being, productivity, and workload management. Study II, a qualitative interview study (33 participants), introduced a unique ergonomics video assessment method and explored how the physical workload measurement data acquired with it can be utilised at different organisational levels in a manufacturing corporation. Supplementing Study II with a retrospective

longitudinal case study approach (2018–2022), Study III analysed the effects of data-driven ergonomic work-development activities on productivity, physical workload, musculoskeletal disorders (MSDs), and financial performance in two departments of a manufacturing company.

Study I found that across Finnish manufacturing companies, ergonomics is underutilised, and its broader integration into production processes remains limited. Study II showed how physical workload data can be used differently at all organisational levels. Study III found that data-based systematic ergonomic work development reduced physical workloads, decreased MSD-related sick leave, increased productivity, and improved financial performance, whereas limited ergonomic integration was associated with declining productivity and higher rates of MSDs.

Overall, this dissertation finds that systematic utilisation of ergonomic principles in practice enables high productivity while maintaining work ability and better financial performance, whereas limited consideration of ergonomics is associated with weaker outcomes.

Keywords: ergonomics, socio-technical system, productivity, physical workload, manufacturing, musculoskeletal disorders, work development.

Suokko, Teemu

Ergonomia: Työjärjestelmäsuunnittelun pimeä aine. Sosioteknisen suunnistuskyvyn ymmärtäminen suomalaisessa valmistavassa teollisuudessa.

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TIIVISTELMÄ

Valmistava teollisuus on jatkuvassa markkinoiden paineessa parantaakseen kilpailukykyään. Tämä edellyttää jatkuvaa tuottavuuden kasvua, mutta tuottavuuden kehitys on ollut Suomessa viimeiset kaksi vuosikymmentä heikkoa. Samalla työhyvinvoinnin edistämisessä on ilmennyt haasteita. Ergonomia voi vastata näihin tuottavuuden ja työhyvinvoinnin haasteisiin, mutta valmistavassa teollisuudessa se tunnistetaan pääasiassa terveyteen ja turvallisuuteen tai työhyvinvointiin liittyvänä toimintana.

Tämä väitöskirja tarkasteli, miten ergonomia edistää valmistavan teollisuuden yritysten tuottavuutta, työhyvinvointia ja taloudellista tulosta. Tutkimus koostuu kolmesta osasta. Ensimmäisessä (osatutkimus I) kvantitatiivisessa kyselytutkimuksessa (N = 121, 42 yritystä) tutkittiin, miten valmistavan teollisuuden yritykset hyödyntävät ja ymmärtävät ergonomiaa työhyvinvoinnin, tuottavuuden ja työkuormituksen hallinnan edistämiseksi. Toisessa (osatutkimus II) kvalitatiivisessa haastattelututkimuksessa (N=33) esiteltiin ainutlaatuinen videokuvaamiseen perustuva ergonomia-menetelmä ja tutkittiin, miten fyysisen työkuormituksen mittaustietoa käytettiin valmistavan teollisuuskonsernin eri organisaatiotasolla.

Osatutkimusta II täydentävässä kolmannessa (osatutkimus III) retrospektiivisessä pitkittäistutkimuksessa (2018–2022) tutkittiin dataan perustuvan ergonomisten työn kehittämistoimien vaikutuksia tuottavuuteen, fyysiseen työkuormitukseen, tuki- ja liikuntaelinten sairauksiin sekä taloudelliseen tulokseen valmistavan teollisuuden yrityksen kahdessa osastossa.

Osatutkimuksessa I havaittiin, että ergonomiaa hyödynnettiin suomalaisissa valmistavissa teollisuuden yrityksissä vähän ja integrointi tuotantoprosesseihin oli rajallista. Osatutkimuksessa II havaittiin, että fyysisen työkuormituksen tietoja käytettiin eri tavoin organisaation eri tasoilla. Osatutkimuksessa III havaittiin, että järjestelmällinen dataan perustuva ergonomian hyödyntäminen vähensi työkuormitusta ja tuki- ja liikuntaelin sairauspoissaoloja sekä lisäsi tuottavuutta ja paransi yrityksen taloudellista tulosta. Sen sijaan ergonomian heikko hyödyntäminen vaikutti tuottavuuden laskuun ja tuki- ja liikuntaelinten sairauksien lisääntymiseen.

Kokonaisuutena tulokset osoittavat, että ergonomian järjestelmällinen hyödyntäminen mahdollistaa korkean tuottavuuden vaarantamatta työhyvinvointia, parantaen siten taloudellista tulosta, kun taas ergonomian rajallinen hyödyntäminen liittyy heikompiin tuloksiin.

Avainsanat: Ergonomia, sosiotekninen järjestelmä, työhyvinvointi, tuottavuus, fyysinen kuormitus, valmistava teollisuus, TULE-sairaudet, työn kehittäminen.

ACKNOWLEDGEMENTS

While writing my dissertation summary, I read about dark matter and noticed parallels with ergonomics. Dark matter accounts for most of the matter in the universe. Although it is invisible and not directly measurable, its existence is inferred from the decisive gravitational effects that hold galaxies together. Similarly, ergonomics shapes the coherence and functioning of work systems, yet its influence is often insufficiently recognised or systematically used in organisational development.

This doctoral dissertation is the result of a long and multifaceted process combining academic research and practical work-life development. I would like to express my sincere gratitude to all those who have supported and contributed to this work in various ways.

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Lapua, June 8, 2026

Teemu Suokko

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This dissertation is based on the following original publications:

- I Suokko, T., Oksanen, T. and Reiman, A. 'Ergonomics in practice: survey evidence from Finnish manufacturing companies'. Submitted 2025.
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- III Suokko, T., Oksanen, T. and Reiman, A. (2025) 'Productivity and employee well-being in manufacturing process development – comparison study of two departments', *Applied Ergonomics*, 25, article 104460.

*The authors contributed equally to this work.

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CONTENTS

- ABSTRACT.....7**
- TIIVISTELMÄ.....9**
- ACKNOWLEDGEMENTS 11**
- 1 INTRODUCTION 19**
- 2 REVIEW OF THE LITERATURE..... 23**
 - 2.1 ERGONOMICS IN COMPLEX WORK SYSTEM DESIGN23
 - 2.1.1 Ergonomics in human–system interaction23
 - 2.1.2 Ergonomics domains25
 - 2.1.3 Participatory ergonomics interventions27
 - 2.2 ERGONOMICS' RELATIONSHIP WITH SYSTEM PERFORMANCE AND WELL-BEING30
 - 2.2.1 Ergonomics' relationship with system performance30
 - 2.2.2 Ergonomics' relationship with well-being at work33
 - 2.3 ERGONOMICS IN MANUFACTURING35
 - 2.4 SUMMARY AND RESEARCH GAPS.....37
- 3 AIMS OF THE STUDY 39**
- 4 MATERIAL AND METHODS 41**
 - 4.1 STUDY DESIGN.....41
 - 4.1.1 Study 141
 - 4.1.2 Study 241
 - 4.1.3 Study 342
 - 4.2 DATA COLLECTION AND ANALYSIS42
 - 4.2.1 Study 142
 - 4.2.2 Study 243
 - 4.2.3 Study 345
- 5 RESULTS..... 47**
 - 5.1 UTILISING AND UNDERSTANDING ERGONOMICS (STUDY 1)47
 - 5.2 ERGONOMIC DATA UTILISING (STUDY 2)48
 - 5.3 UTILISING ERGONOMICS IN PRACTICE (STUDY 3)50

5.3.1 Productivity and MSDs	50
5.3.2 Financial analysis	52
6 DISCUSSION	53
6.1 MAIN FINDINGS	53
6.2 Scientific contributions	54
6.2.1 First part (study 1).....	54
6.2.2 Second part (studies 2 and 3)	55
6.3 Practical contributions	60
6.4 Strengths and limitations	62
6.5 Future studies.....	63
7 CONCLUSIONS	65
REFERENCES.....	67

ABBREVIATIONS

CM	Corporation management
MSD	Musculoskeletal disorders
OH	Occupational health care
OSH	Occupational safety and health
PE	Participatory ergonomics
SME	Small and medium-sized enterprises

1 INTRODUCTION

The fundamental task of companies is to maintain productive and financially profitable operations. This requires them to adopt responsible actions and values that consider both short- and long-term profitability (Zink, 2007; Zwetsloot, van Scheppingen and Dijkman, 2013; Stenborg *et al.*, 2021; Jain, Zwetsloot and Torres, 2024). Striving for short- and long-term profitability also guides companies to prioritise the health, safety, and well-being of their employees (ILO, 2019; European Commission, 2024). In a broader context, companies must operate globally responsibly and sustainably. This obligates them to extend their concern beyond employees to the entire supply chain and the environmental issues (Hasle and Jensen, 2012; Bolis *et al.*, 2023; United Nations, 2023; Sigahi *et al.*, 2025). Based on these principles, companies' activities are regulated to ensure that they act in a globally sustainable manner (ILO, 2019; European Commission, 2024).

In addition to responsible and sustainable thinking, legislation requires companies to consider safety and health issues. The EU's occupational safety and health (OSH) framework is based on Directive 89/391 (1989), which sets minimum requirements and obligations for companies to promote their employees' OSH (EU-OSHA, 2025). Alongside developments in responsibility and related legislation, working life has participated in significant technological and digital advances, as reflected in the focus area of this dissertation, the manufacturing industry. From a historical perspective, this rapid development is a continuation of a series of industrial revolutions, the latest manifestation of which is considered the fourth industrial revolution, also referred to as Industry 4.0 (Groumpos, 2021; Klingerberg *et al.*, 2022). Industry 4.0 emphasises and utilises technological advancements to increase profits in the manufacturing sector (Grosse *et al.*, 2023). To broaden technology-oriented Industry 4.0 thinking, Industry 5.0 has been envisioned (European Commission, 2021; 2024). Industry 5.0 is increasingly the focus of ergonomic research because it emphasises human-centred system design. The Industry 5.0 vision

prioritises the outcomes of systems for people and aims to foster environments that support the development of human-centred, flexible, and sustainable systems (Grosse *et al.*, 2023; Trstenjak *et al.*, 2025).

A system consists of interconnected parts that work together to form a coherent, organised whole (Mele, Pels and Polese, 2010). In this thesis, systems are discussed from an ergonomics perspective. Ergonomics literature has addressed them at many scales (Moray, 2000; Thatcher *et al.*, 2017; Thatcher *et al.*, 2026). In ergonomics, a work system is a setup for producing and managing work, involving people, processes, technology, and resources to create a product or service. In ergonomics, work systems can be viewed from an individual, microergonomics perspective, i.e. as an individual's own work system, or from a broader, macroergonomics perspective, as a socio-technical work system (Carayon, 2006). In this thesis, work systems are examined at these two analytical levels: at the micro level, focusing on the individual's interaction with work, and at the macro level, where interconnected workstations, processes, technologies, and organisational arrangements are considered together as a socio-technical work system.

Ergonomics approaches work system development in a design-driven manner and aims for two related outcomes: performance and well-being (Dul *et al.*, 2012). However, productivity growth in Finland has been weak since 2008 and lagged behind that of key competitor countries (Calligaris *et al.*, 2023). Productivity growth has also been challenging in Finland's manufacturing industry (Calligaris *et al.*, 2023; Statistics Finland, 2025a). In addition, well-being is closely linked to a company's financial success (Schulte and Vainio, 2010; Bohman *et al.*, 2025; Hamza and Farah, 2025). In Finland, the trend in well-being at work has been declining for years, although recent data indicate signs of improvement (Finnish Institute of Occupational Health, 2025). Productivity and well-being can be examined systematically together; in such cases, ergonomics, as a design-driven discipline, can contribute. Research on the benefits of ergonomics has reported improvements in local working conditions, but the effects on musculoskeletal disorders (MSDs), productivity, or economic outcomes have been limited or inconsistent. These varying results can be partly

attributed to differences in intervention scope and evaluation methods, as well as limited attention paid to broader work system design (Haukka *et al.*, 2008; Rivilis *et al.*, 2008; Driessen *et al.*, 2010; Tompa, Dolinschi and Natale, 2013; Wurzelbacher *et al.*, 2020).

The potential of ergonomics in the manufacturing industry is not fully understood (Dul and Neumann, 2009; Greig *et al.*, 2019; Greig *et al.*, 2023; Mulaomerovic and Wang, 2023). Ergonomics is often viewed as an activity primarily focused on OSH and well-being outcomes, with less attention devoted to performance analysis (Russ *et al.*, 2013; Reiman *et al.*, 2024). Furthermore, the economic impact of ergonomic measures has rarely been analysed (Tompa, Dolinschi and Laing, 2009; Neubert, Bruder and Toledo, 2012; Rose, Orrenius and Neumann, 2013). This dissertation therefore examined how ergonomics contributes to the productivity, well-being, and financial performance of manufacturing companies.

2 REVIEW OF THE LITERATURE

2.1 ERGONOMICS IN COMPLEX WORK SYSTEM DESIGN

2.1.1 Ergonomics in human-system interaction

Ergonomics is the study of human-system interactions. It is a profession that applies theory, principles, knowledge, and methods to design to optimise human well-being and overall system performance (Karwowski *et al.*, 2025). As seen in Figure 1, ergonomics has three basic characteristics: (1) it is based on a systemic approach, (2) it is design-driven, and (3) it focuses on two interrelated outcomes: performance and well-being (Dul *et al.*, 2012).

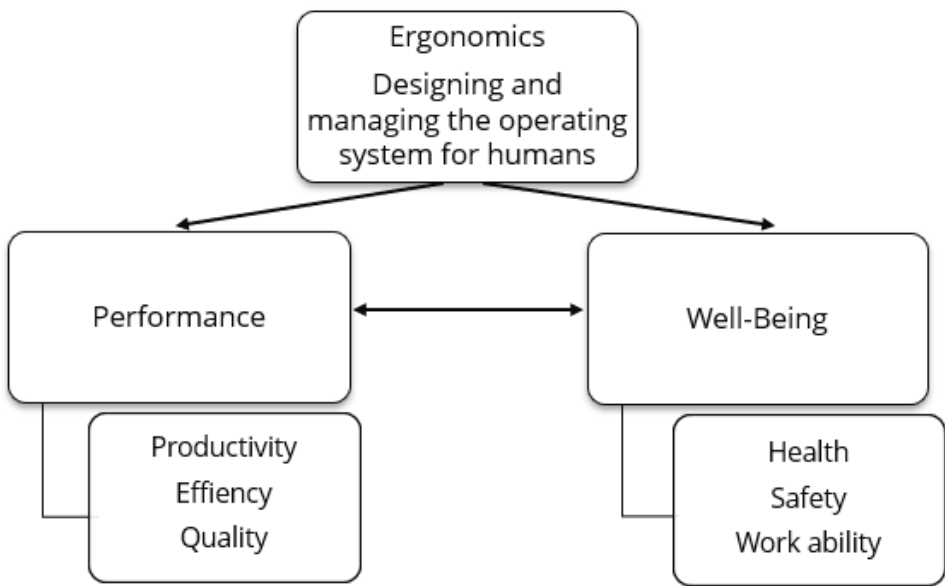


Figure 1. The ergonomic work design is adapted from Dul *et al.* (2012).

According to the international standard 'Ergonomics principles in the design of work systems' (ISO 6385:2016), ergonomics is a field of science that aims to understand the interaction between people and other parts of a system, as well as an area of expertise that applies theory, principles,

information, and methods to design for the optimisation of human well-being and overall system performance.

Work, the work environment, and people interact constantly, and disruptions among them can pose many kinds of challenges for the organisation. Disruptions at work can be reflected among personnel through various psychosocial and organisational processes (Neumann, Ekman and Winkel, 2009; Wilson, 2014; Kadir, Broberg and da Conceição, 2019). To prevent such negative effects, work should be designed to correspond to human physical, psychological, and social characteristics (Kadir *et al.*, 2019; IEA and ILO, 2021). Ergonomics enables the development of system solutions that contribute to the smooth operation of the organisation, its productivity, and the well-being and health of its personnel (Dul *et al.*, 2012). Well-implemented, practical ergonomics include an efficient, trouble-free operating system and a healthy, safe working environment in which individuals can develop (IEA and ILO, 2021). Developing and maintaining a smooth, uninterrupted work system requires extensive knowledge of ergonomics. Ergonomics ensures that work is suitable and smooth for everyone, resulting in a productive, healthy, and innovative organisation and work community (Dul and Neumann, 2009; Neumann *et al.*, 2009; Dul *et al.*, 2012).

Ergonomics measures aim to adapt work systems to human characteristics and needs. In this regard, the work system can be approached from micro and macro perspectives. When examined from a micro perspective, the focus is on individual-level work systems, whereas the macro perspective shifts attention to broader system complexities and their design and management (Kleiner, 2006). In a broader context, where multiple people interact with the work system, it is referred to as a socio-technical system (Carayon, 2006). From a socio-technical perspective, where technology and social factors are considered together, the effectiveness of a system or a workers well-being depends not only on technology (such as the work environment, tools, operating systems, and processes) or people (including teams, culture, goals, and leadership) but also on their interaction. Therefore, from a socio-technical viewpoint, work,

technology, organisational structure, and human activity must be aligned (Davis *et al.*, 2014; Hughes *et al.*, 2017; Abdous *et al.*, 2023).

Work systems consist of people, the tasks they perform, the tools and technologies they use, the ways work is organised, and the work environment. Ergonomic principles and guidelines are applied in these areas to design and manage work systems, enabling the development and maintenance of high-quality, productive, and sustainable work systems (Kleiner, 2006; IEA and ILO, 2021). System stakeholders are defined as anyone who can influence achievement of the company's objectives or is affected by its activities (Freeman, Wicks and Parmar, 2004). As shown in Figure 2, in ergonomics system design, stakeholders (people) are divided into four main categories (Dul *et al.*, 2012). This dissertation focuses on internal stakeholders (actors, experts, and decision-makers) rather than on external stakeholders (influencers).

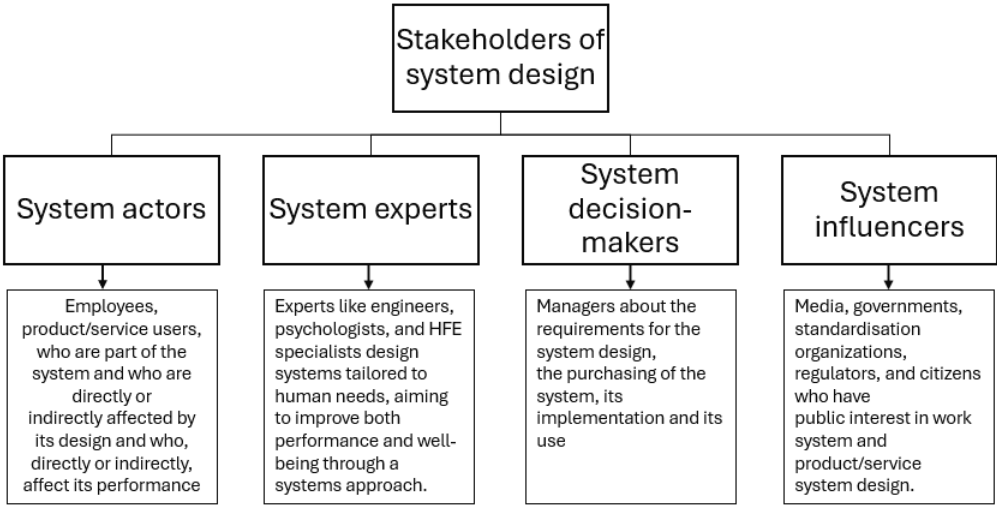


Figure 2. Main stakeholder groups in ergonomic system design (Dul *et al.*, 2012).

2.1.2 Ergonomics domains

Ergonomics is traditionally divided into three domains (physical, cognitive, and organisational), each with its own focus, topics, and objectives (e.g. Karwowski *et al.*, 2005; Wilson, 2014); see Table 1. Kadir *et al.* (2019) have

addressed these domains in the context of Industry 4.0. A well-designed work system can be created only when all these three domains are considered together. Well-designed work processes are not adequate if the work is cognitively too demanding. Clear work instructions are not adequate if the work is poorly organised. A work system is ergonomically good when the work processes place a controlled workload, the work is understandable and prevents errors, and the production system supports cooperation and smoothness (Karwowski, 2005; Wilson, 2014; Kadir *et al.*, 2019).

Table 1: The three main domains of ergonomics compiled from (Karwowski, 2005; Wilson, 2014; Kadir *et al.*, 2019).

Ergonomics domains	Primary focus	Key topics	Objectives
Physical ergonomics	Designing the work environment and the physical interaction between people and work	Work environment, tools, workstations, work methods, work movements, work postures, load/handling	Fit physical work conditions to human capabilities and limitations
Cognitive ergonomics	Adapting systems to users based on their psychological characteristics	Perception, memory, learning, language, thinking, mental workload, decision-making, work performance quality, work	Support human information processing and performance

		stress, human– computer interaction	
Organisational ergonomics	Coordinating personnel, work, and work schedule systems, developing socio- technical systems	Work planning and redesign, participatory work design, teamwork, quality development	Create a functional, collaborativ e operating system

2.1.3 Participatory ergonomics interventions

For ergonomics, it is important to involve different stakeholders in work system development (Van Eerd, 2015; Burgess-Limerick, 2018).

Participatory ergonomics (PE) is one approach to ergonomics that involves relevant actors in problem-solving. PE is not limited to employee participation or formal, representative participation. It covers all levels of the organisation and involves those who have experience with or knowledge of the problem at hand (Kuorinka, 1997; Broday, 2021). The definition of PE encompasses both macro-level (organisational, systems) and micro-level (individual) activities, and PE enables employees to apply their knowledge to address challenges in their work tasks. Involving those familiar with practical work and local conditions in the development and collaboration processes is crucial (Hignett, Wilson and Morris, 2005; Van Eerd *et al.*, 2010). At its best, participation yields practical solutions to problems as they arise (Hignett *et al.*, 2005).

PE interventions often aim to reduce MSD-related sick leave (Van Eerd *et al.*, 2015). PE can target individuals, work communities, specific jobs, the entire organisation (Broday, 2021), or more specific design workstations, implement broader organisational reforms, reduce sickness rates, or support ageing personnel (Neumann *et al.*, 2009; Tompa *et al.*, 2009). In PE

interventions, the occupational health (OH) service has traditionally played a significant role (Hignett *et al.*, 2005). Additionally, clear communication between stakeholders is necessary for effective oversight of the PE development process (Koningsveld *et al.*, 2005; Tompa *et al.*, 2010; Van Eerd *et al.*, 2010).

A systematic review of randomised controlled trials examined the effectiveness of ergonomic interventions for workers' low back and neck pain. Ten studies found that physical and organisational ergonomic measures were not effective in reducing the incidence rates or prevalence of lower back and neck pain (Driessen *et al.*, 2010a). A similar result was observed in an intervention targeting kitchens, in which 402 work development measures were implemented but had no effect on MSDs (Haukka *et al.*, 2008). Another study evaluated the cost-effectiveness of a PE intervention compared to a control group over a 12-month period. PE did not reduce lower back or neck pain, nor did it improve work ability or lower sick leave rates. The costs were higher in the PE group, and, from the company's perspective, PE resulted in financial losses, and the PE intervention was neither cost-effective nor cost-beneficial (Driessen *et al.*, 2012). However, another study followed 33 employers and 535 workers for five years to assess the effects of ergonomic interventions on material handling. Among those highly exposed to heavy loads, workers who regularly used ergonomic interventions reported less upper-extremity pain than those who relied solely on body strength. The interventions showed some effectiveness in reducing pain among workers with the heaviest physical loads (Wurzelbacher *et al.*, 2020).

There is also evidence that PE positively impacts employee health. A systematic literature review analysed 12 studies on PE targeting various sectors. Interventions provided ergonomics training and implemented changes to the physical design of equipment and workplaces, and some also changed work tasks. A review found partial-to-moderate evidence that PE interventions can reduce MSDs, accidents, and sick days and absences (Rivilis *et al.*, 2008).

In a recent systematic review, 22 eligible studies examining ergonomic interventions, including ergonomic training, PE, and workstation design,

were identified. The findings showed that feedback, PE in short-term follow-ups, job rotation, and ergonomic guidelines did not significantly reduce psychosocial risk factors. However, workplace improvements were associated with a significant reduction in upper-limb MSDs. One study suggested that no single study design or intervention type consistently improved ergonomic outcomes, and a multicomponent intervention could be more effective for enhancing employee health and improving system productivity (Heidarimoghadam *et al.*, 2022). In addition, a review focusing on health care nurses found that multicomponent ergonomic interventions, especially those that include physical activity or exercise, are more effective at reducing the risk of work-related MSDs than single-component approaches. However, the long-term effects on MSD reduction, sickness absence, and work performance remain uncertain (Krishnanmoorthy *et al.*, 2025).

It is important to recognise that changes at work may cause doubts among workers or management (Rothmore, Aylward and Karnon, 2015; Horváth and Szabó 2019). A recent review suggested that successful PE starts from worker needs, a positive implementation climate, clear roles and responsibilities, sufficient resources, and strong managerial commitment to OHS (Hansen *et al.*, 2024). However, assessing the effectiveness of ergonomic PE interventions has been difficult, and research evidence of their usefulness in MSDs is rather weak (Haukka *et al.*, 2008; Rivilis *et al.*, 2008; Driessen *et al.*, 2010b; Wurzelbacher *et al.*, 2020). Furthermore, the effectiveness of interventions is mainly monitored in studies from the perspective of well-being at work. The impact of the interventions on performance is described only to a limited extent in the articles, which focus on cost changes rather than productivity indicators (Mäki-Ullakko, Reiman and Kekkonen, 2026). The shortage of research evidence might stem from the fact that, although researchers develop scientifically valid interventions, these are often not adopted in the workplace on their own terms (Takala, 2018). For example, there are high expectations for PE, but research does not support that participation would systematically lead to better health, fewer sick days, or cost savings if participatory efforts are not accompanied by changes in work

organisation, technologies, and production system design. Moreover, it has been suggested that ergonomic measures have minimal effect on industrial practices, which are primarily driven by regulatory compliance and profit goals (de Winter and Eisma, 2024).

2.2 ERGONOMICS' RELATIONSHIP WITH SYSTEM PERFORMANCE AND WELL-BEING

2.2.1 Ergonomics' relationship with system performance

Continuous improvement of work systems, productivity, and quality is part of daily operations for manufacturers (Ivarsson and Eek, 2015; Neumann, Kolus and Wells, 2016). Performance is a broad concept that refers to how well a system works as a whole (Hamza and Farah, 2025). In ergonomic literature, productivity is part of performance (Dul *et al.*, 2012). From a productivity perspective, streamlining production involves maximising financial performance with minimal resources (Falck, Örtengrena and Högberg, 2010; Tompa *et al.*, 2013; Zare *et al.*, 2016). Improvements are commonly pursued through the implementation of new manufacturing technologies and the digitalisation of production processes. However, technological development also affects how individuals work by creating new demands for skills and knowledge (Kadir *et al.*, 2021; Reiman *et al.*, 2021).

Production quality is a central indicator of operational performance in the manufacturing industry. Previous research has shown a consistent association between poor ergonomic conditions and increased quality defects, particularly in manufacturing contexts characterised by manual and repetitive work, such as the automotive industry (Zare *et al.*, 2016; Kolus, Wells and Neumann, 2023). Systematic reviews suggest that physically demanding tasks, awkward postures, and high workloads are linked to higher error rates and reduced product quality. However, despite this evidence, research has so far struggled to demonstrate how the different domains of ergonomics (physical, cognitive, and organisational)

interact and jointly influence product quality outcomes (Zare *et al.*, 2016). Empirical evidence from the automotive industry further illustrates the link between ergonomics and quality. Large-scale observational studies have reported that the risk of quality defects increases with the physical demands of assembly tasks: quality defects were found to be 5–8 times more common in tasks with a high ergonomic workload compared to those with a low workload. These studies also demonstrated that early detection of errors significantly reduces repair and intervention costs, emphasising the importance of classifying tasks by physical demand when analysing quality performance. Despite strong evidence at the task level, less is known about how ergonomic risks are systematically integrated into production planning and quality management systems (Falck *et al.*, 2010; Falck and Rosenqvist, 2014).

In addition to task-level evidence linking ergonomics to quality outcomes, the literature indicates that ergonomics can be integrated more broadly into work systems. Goggins, Spielholz and Nothstein (2008) collected 250 case studies examining the effects of ergonomic programmes and management measures. The results showed a reduction in the number of work-related MSDs, as well as in lost and restricted working days and employee compensation costs associated with them. In addition, effects on productivity, quality, turnover, and absenteeism were reported. The payback period for most work-development investments was less than one year. The article provides strong empirical justification for the use of ergonomics, but the reliability of cost–benefit models built on this basis depends heavily on context and metric choice. For example, the amount of the investment was not reported separately (Goggins *et al.*, 2008).

Some economic evaluations have demonstrated that ergonomic interventions can be highly cost-effective in terms of health, even when based on relatively low-cost and technically simple measures. In manufacturing contexts such as the automotive components and garment industries, reported benefit–cost ratios have ranged from 5.5 to over 10, with substantial positive net present values. The economic benefits were primarily driven by reductions in work disability days and compensation-

related costs. Notably, these studies used follow-up periods long in ergonomic intervention research, ranging from nearly two years to over four years, thereby strengthening the credibility of the reported long-term financial outcomes. However, a limitation of these studies is that potential productivity effects were explicitly excluded from the analyses (Tomba *et al.*, 2009; Tomba *et al.*, 2013).

From the perspective of promoting productivity, ergonomic benefit gains remain limited. Only a small number of case studies have reported direct productivity improvements following ergonomic interventions, such as a 45% increase in furniture manufacturing (Guimarães *et al.*, 2015) or more modest gains of around 4% in targeted interventions (Domínguez-Alfaro *et al.*, 2023), highlighting a notable gap in the literature between demonstrated economic benefits and systematically measured productivity effects.

Despite evidence of economic returns from ergonomic interventions, the financial performance of ergonomics has rarely been systematically analysed (Tomba, 2009; 2013). Determining the monetary impact of interventions targeting system performance is particularly challenging, as large-scale development measures often involve diverse, interconnected factors, making productivity calculations difficult. Conversely, measures aimed at reducing workload on the musculoskeletal system may show effects only over an extended period (Hignett *et al.*, 2005; Falck *et al.*, 2010; Tomba *et al.*, 2010; Falck and Rosenqvist, 2014). Ergonomists must be aware of the financial indicators that companies aim to influence in their work environment development. Linking to business objectives does not mean compromising personnel's OSH or well-being (Dul and Neumann, 2009). On the contrary, it has been suggested that, particularly in industry, development measures implemented on economic grounds may be the most effective means of promoting both economic performance and well-being (van Rhee, 2025). Although the benefits of ergonomics in improving system performance are recognised, the manufacturing industry does not fully recognise its value to business (Greig *et al.*, 2019; Neumann *et al.*, 2021).

2.2.2 Ergonomics' relationship with well-being at work

Well-being at work is a comprehensive concept that describes the quality of working life, including OHS aspects, and it may be a key factor influencing productivity at individual, organisational, and societal levels (Schulte and Vainio, 2010). This broad understanding of well-being highlights its close connection to how work systems are designed and managed.

According to socio-technical system theory, optimal system performance is achieved when the technical and social aspects are optimised together rather than separately (Carayon, 2006; Davis *et al.*, 2014; Karlton *et al.*, 2017). Therefore, understanding personnel and their work is essential to developing work systems. This is particularly true in the manufacturing industry, where technology and digitalisation are constantly evolving. Promoting personnel well-being is central to the development of a socio-technical system. However, well-being is often treated broadly and abstractly, with limited attention paid to how it is operationalised or systematically linked to concrete design and management decisions in production systems (Neumann *et al.*, 2021; Reiman *et al.*, 2021).

Poorly designed work systems expose workers to physical or cognitive discomfort and harm. Such risks emerge from physical workload factors as well as from organisational and cognitive conditions, such as interruptions and information overload (Kalakoski *et al.*, 2020; Slama *et al.*, 2024). Consequently, the risks reflect not only individual work tasks but also broader system design choices, making their identification a prerequisite for preventive and sustainable work system development (Village *et al.*, 2015; Brito *et al.*, 2018; Papetti *et al.*, 2020).

Research indicates that ergonomics and workplace risk management are predominantly operationalised from an individual-centred perspective rather than as part of work system design. Analyses of OSH practices show that musculoskeletal and mental health risks are mainly managed using individual-level measures, while structural and organisational sources of risk remain largely unaddressed (Oakman *et al.*, 2018). This orientation is reinforced by commonly used risk assessment methods, which tend to

guide interventions towards individual tasks or workers rather than support system-level redesign (McCormack *et al.*, 2021). Although psychosocial stressors are widely recognised as important contributors to MSDs, they are rarely integrated into system-level ergonomic decision-making, as assessment frameworks continue to prioritise physical factors despite their connection to organisational ergonomics and work system design (Macdonald and Oakman, 2022). An intervention study aligned with this perspective, suggesting that even well-implemented cluster randomised controlled trial PE interventions addressing industrial workers' physical and psychosocial factors have shown limited effects on work ability, well-being, and productivity when underlying work system structures remain unchanged (Gupta *et al.*, 2018).

This individual-centred orientation is also evident in more recent ergonomics research, including studies framed within the Industry 5.0 paradigm. A systematic review of physical and cognitive ergonomics monitoring highlights advances in individual-level measurement technologies, such as wearable sensors, camera-based systems, and physiological indicators, with the primary focus on assessing employee well-being (Antonaci *et al.*, 2024). Similarly, a review of intervention studies suggests that well-being and, in some cases, performance can be improved with training, participatory approaches, and combinations of training and work redesign, although evidence on the effectiveness of PE interventions remains mixed and highly context-dependent (Daniels *et al.*, 2017).

The literature on socio-technical system design suggest that the core objective of ergonomics is to combine productivity and employee well-being through the design and redesign of work systems. From this perspective, system designers should address fundamental questions related to system boundaries, stakeholder roles, information use, and the integration of performance management, key performance indicators, and managerial practices into work system design. While the information required to support such integrative design already exists, its systematic use in development processes remains limited (Edwards and Jensen, 2014). This becomes particularly evident in the manufacturing industry, where complex production systems, performance pressures, and organisational

structures strongly influence how ergonomics is understood and applied (Edwards and Jensen, 2014; Karlton *et al.*, 2023; Reiman *et al.*, 2024; Karlton *et al.*, 2025).

2.3 ERGONOMICS IN MANUFACTURING

To improve system performance and employee well-being, companies need data on their operations (Dul *et al.*, 2012). With advances in technology and digitalisation, it is also possible to obtain more data on working environments, working conditions, and related human work (Machado *et al.*, 2022; Fekrisari and Kantola, 2024). Collected data guide companies' strategic decision-making aiming to produce better decisions that promote performance and business objectives (Baskerville and Dulipovici, 2006; Fteimi and Lehner, 2018; Machado *et al.*, 2022). However, when data on work and working conditions are not systematically linked to organisational performance, managerial decision-making rests on a weak foundation, limiting the potential of ergonomics to inform production system design and development (Rose *et al.*, 2013). Survey studies of manufacturing managers have concluded that they view ergonomics primarily as an OSH prevention tool rather than as a means of cost savings and waste reduction. This reinforces its role as a support function rather than a strategic component in production system design and performance management (Zare, 2016).

Business data are considered the primary indicators for companies in the manufacturing sector. They are utilised in managerial decision-making and in executing plans to enhance work processes. Investments in work development are typically grounded in business performance data and the objectives that arise from that data (Greig *et al.*, 2019; Greig *et al.*, 2023; Mulaomerovic and Wang, 2023). Managers usually support ergonomics projects financially only when a reliable cost-benefit analysis is available. It has been suggested that ergonomists typically have no training in management or business administration. As a result, business-related topics such as cost justification, cost-benefit analysis, or productivity gains are often not included in the ergonomics toolkit (Hendrick *et al.*, 2003;

Theberge and Neumann, 2013). In the manufacturing context, ergonomics data are frequently used for OSH purposes, but they appear somewhat disconnected from the company's core business data. This separation limits the role of ergonomics in production system development and reinforces its perception as a support function rather than a strategic design resource. Therefore, ergonomics becomes institutionally embedded in OSH functions rather than in production system design, which fundamentally influences how ergonomics expertise is developed and applied in manufacturing companies (Greig *et al.*, 2019; Greig *et al.*, 2023; Mulaomerovic and Wang, 2023).

Manufacturing companies often struggle to fully implement ergonomics because expertise is primarily derived from OSH, which can lead to overlooking the potential of system design (Russ *et al.*, 2013; Reiman *et al.*, 2024). Ergonomics recognises the importance of systems design and the use of ergonomics data by companies, but its methods do not yet adequately capture the dynamics of complex work systems, which limits the impact of ergonomics on truly system-level design and risk management (Salmon *et al.*, 2017). This leads to the application of ergonomics in workplaces being often inconsistent and fragmented (Karlton, 2017; Read *et al.*, 2018; de Winter and Eisma, 2024; Salmon *et al.*, 2024; Endsley and Sasangohar, 2025; Karwowski *et al.*, 2025).

Although many methods exist for assessing physical workloads, the success of ergonomic work development relies less on measurement alone than on how data are incorporated into organisational decision-making (Takala *et al.*, 2010; Pollard and Dempsey, 2015). Converting workload data into practical actions requires cooperation among stakeholders, a shared understanding of development needs, and adequate skills at all organisational levels (Falck and Rosenqvist, 2014; Burgess-Limerick, 2018; Machado *et al.*, 2022). However, to secure managerial approval and funding, ergonomic initiatives often need to be presented in business terms, linking workload reduction to productivity, performance, and economic outcomes. Without such integration, ergonomic data risk remaining isolated at the operational level, which limits its influence on work system development (Hendrick, 2003; Hendrick, 2008).

2.4 SUMMARY AND RESEARCH GAPS

Ergonomics is a broad, multidisciplinary field that can be approached from multiple perspectives, including physical, cognitive, and organisational aspects. As a design-oriented discipline, ergonomics strives to optimise both system performance and human well-being. However, in practice, it is often understood and utilised in a more limited way, mainly concentrating on individual tasks or specific working conditions. This narrow perspective has also shaped the development and assessment of ergonomic interventions, which have frequently targeted particular symptoms or exposures rather than the entire work system. Studies that report economic benefits are based on specific case settings where the scope of investments, metrics, and comparison basis remains unclear. Research on productivity effects is limited and varied, which restricts the generalisability of its findings. Additionally, the long timeframes, complex cause-and-effect relationships, and simultaneous development measures make it challenging to evaluate the separate economic impact of ergonomics.

In the manufacturing industry, ergonomics is mainly seen as an OSH activity. Research on the productivity and economic effects of ergonomics is limited and inconsistent, which is why ergonomics may not become a standard element of production system development. As a result, the socio-technical potential of ergonomics remains largely unrealised in manufacturing industry work and production systems. This justifies the need for further research, particularly long-term, multidimensional, and business-related studies. To address the above-mentioned knowledge gaps in existing research, this study examined how ergonomics contributes to the productivity, well-being, and financial performance of manufacturing companies.

3 AIMS OF THE STUDY

This doctoral thesis is focused on ergonomics in the Finnish manufacturing industry. In Finland, there are over 28,000 manufacturing companies, of which 97.5% are small or medium-sized companies (SMEs) (Statistics Finland, 2025b). For Finland to succeed in international competition, it is essential that manufacturing companies remain competitive while supporting the health and well-being of their personnel. Therefore, the first part (study 1) of this dissertation aimed to provide an overview of ergonomics understanding among manufacturing companies. In the second part (studies 2 and 3), which focused on one company, more detailed analyses were conducted to determine what could be achieved through ergonomics. The overall aim of this dissertation was to examine how ergonomics contributes to the productivity, well-being, and financial performance of manufacturing companies.

The specific study aims were as follows:

Study 1: How is ergonomics understood and utilised in manufacturing?

Study 2: How are physical workload data utilised at different organisational levels in manufacturing?

Study 3: What can be achieved in terms of system performance and well-being in manufacturing through systemic utilisation of ergonomics?

4 MATERIAL AND METHODS

4.1 STUDY DESIGN

4.1.1 Study 1

The first study sought to collect comprehensive insights into how manufacturing companies perceive and apply ergonomics. The study was conducted as a quantitative survey to investigate manufacturing companies' perceptions and practical implementations of ergonomics. The study was cross-sectional, with data collected in a single measurement session to map companies' current status and views on ergonomics. A structured questionnaire was sent electronically to a targeted group of manufacturing companies. The questionnaire included closed-ended questions to map their perceptions and practices regarding ergonomics. A total of 121 individuals — 84 white-collar and 37 blue-collar workers — from 42 manufacturing companies participated in the survey. Among the companies, 27 were SMEs and 15 were large companies.

4.1.2 Study 2

A qualitative interview study was conducted to determine how data on physical workload have been used to improve manufacturing processes at different organisational levels of a manufacturing corporation. The article also presents a unique video analysis method in detail, used to collect physical workload data for the tasks. The research design employed semi-structured focus group interviews to gain an in-depth understanding of the views and experiences of different stakeholder groups regarding the subject. The data were collected in nine focus group interviews with 33 participants from different organisational levels: company management, white-collar, blue-collar, and OH. The data were examined using inductive content analysis to identify recurring themes, perceptions, and opportunities for development in the utilisation of physical workload data.

Participants provided informed consent regarding the study's purpose and data processing prior to the interviews. All responses were treated confidentially, and no individuals can be identified from the report.

4.1.3 Study 3

This retrospective longitudinal case study analysed the effects of work development over five years (2018-2022) in a manufacturing company's assembly line and welding unit. The target company was one of the corporation's subsidiaries discussed in study 2. The goal was to assess the impact of development activities on system performance and employee well-being. Designed within a macroergonomics framework, the study aimed to (1) evaluate how manufacturing process improvements affected employee well-being, focusing on physical workload and sick leave rates due to MSDs. Additionally, it sought to (2) measure system performance improvements by tracking productivity gains.

4.2 DATA COLLECTION AND ANALYSIS

4.2.1 Study 1

The data were collected through an online questionnaire distributed via an open link to manufacturing companies, who themselves decided whether they were eligible to respond. The questionnaire link was disseminated to potential respondents via multiple channels. First, in February-March 2022, the link was sent directly to 57 manufacturing companies; 18 responded. Secondly, in October-November 2022, the link was sent to three pension insurance companies, which then forwarded it to their client networks, which collectively covered hundreds of manufacturing companies.

The questionnaire was developed by the authors based on scientific literature on ergonomics. The full questionnaire is attached to the original article. For the purposes of the study, the questionnaire aimed to provide an overall picture of the understanding and utilisation of ergonomics in manufacturing companies. Survey items had a Likert scale with the option to select 1) Very little, 2) Quite a little, 3) Some, 4) Quite a lot, or 5) Very

much or were open-ended, allowing for both quantitative analysis and qualitative examination.

The study used six items: two on workload ('Does your company systematically use ergonomics to reduce workload?' and 'To what extent has personnel workload been considered in production?'), two on well-being ('Does your company use ergonomics to improve well-being?' and 'Have targets been set for well-being in work development?'), and two on productivity ('Does your company use ergonomics to increase productivity?' and 'Have targets been set for productivity in work development?'). Responses were grouped as either 'a little' (very little, quite little, some) or 'a lot' (quite a lot, very much). Companies were classified as large (personnel over 250) or SMEs (1-249). Additionally, the data were examined separately regarding where stakeholders receive ergonomics instruction and advice and the types of tasks or situations they address. Cross-tabulation and chi-square tests were used to analyse relationships between categorical variables. A p-value below 0.05 indicated a statistically significant association. Distributions were further described by observed frequencies and percentages. Analyses were performed using IBM SPSS Statistics 29.0.2.0.

4.2.2 Study 2

The study was conducted at a Finnish manufacturing corporation that employs over 950 people globally. In Finland, the corporation has four subsidiaries. The corporation conducted physical workload measurements, carried out by the group's OSH manager and OH physiotherapist. A total of 237 work tasks were measured for physical workload between 2015 and 2021. The measurement method focused on the percentage of time spent in harmful work postures, including raising the arms above shoulder level, bending and twisting the back, standing, sitting, squatting, and handling loads by hand. In the analysis, the percentage of harmful postures was measured from video material using a stopwatch, and the results were presented as a percentage of the task workload.

In addition to harmful working postures, the load imposed by handling was assessed using load-handling coefficients. There were six coefficients: the lowest (1.0) applied to light and easily handled loads and minor load handling in slightly harmful postures, while the highest coefficient (2.0) referred to very heavy and difficult-to-handle loads and extensive load handling in mainly harmful working postures. The relative proportion of harmful working postures in the task and the load-handling coefficients enabled an expert to determine the task's load level. There were five load levels ranging from level 0 (optimal) to level 4 (significant burden on the musculoskeletal system). A more detailed description of the load-handling coefficients and workload factors is provided in the attachments to the original article.

The study recruited participants from corporation management (CM), OH, and white- and blue-collar workers from each subsidiary. The sample consisted of 39 individuals. The corporation's OSH manager was responsible for recruitment, which was done in October 2021. Recruitment yielded 33 participants: 3 at the corporate level (representing CM, the OH physician, and the OH physiotherapist) and 14 white-collar and 16 blue-collar workers at the subsidiary level. Data collection involved nine semi-structured focus group interviews at the subsidiary level. Larger subsidiaries had two white-collar focus groups, while two smaller subsidiaries with shared management formed a single group. Blue-collar workers were divided into four focus groups. Basic demographic data from participants included age, gender, and work experience in the industry and corporation, collected via a short questionnaire. The average age was 44.7 years (range 28-56), with 81.8% (n = 27) male.

The semi-structured interview guide was based on two themes: experiences of using physical workload data and collaboration in work development. It aimed to explore how physical workload data influenced the development of participatory work at different organisational levels. All interviews were conducted in November 2021. The interview data were examined using inductive content analysis (Elo and Kyngäs, 2008). Two researchers reviewed interviews to understand the data. The analysis initially focused on the interview material from CM and OH, identifying

meaning units related to the research question. These units from the CM and OH interviews were compared. A similar comparison was made for three white-collar and four blue-collar focus group interviews. The units were grouped into three categories: combined CM and OH, white-collar workers, and blue-collar workers. The process involved developing main categories and concepts for each group. Two researchers conducted the complete analysis collaboratively.

4.2.3 Study 3

Data for the study were collected from four sources: 1) personnel demographics, 2) work measurements, 3) physical workloads, and 4) costs for development activities. Personnel demographics were retrieved from the human resources databases. The number of workers on the assembly line ranged from 27 to 31 during the monitoring period, and from 17 to 20 in the welding unit. All workers were men, and the mean age exceeded 40 years in both departments. On average, welding unit workers had slightly more work experience at the company than those on the assembly line. In addition, the annual accumulation of MSDs was used for both departments.

Work measurements were performed on the assembly line (28 work tasks) and on the welding unit (8 work tasks) using the Maynard Operation Sequence Technique (MOST) (Zandin and Schmidt, 2021). The MOST is a predefined motion time system primarily used in industrial settings to determine the standard time for a worker to complete a task. From this analysis, normal times are derived, which can be employed to design work tasks and methods (Wells *et al.*, 2007; Harari, Riemer and Bechar, 2018; Zandin and Schmidt, 2021). Understanding the time required for specific tasks helps achieve and sustain high utilisation rates of personnel, materials, and equipment (Karim, Tuan and Kays, 2016; Harari *et al.*, 2018; Zandin and Schmidt, 2021). Work measurement data were used to calculate annual productivity figures. The productivity rate was calculated by dividing normal working time by actual working time. The actual time taken to manufacture the products was obtained from the company's

production management system. A productivity rate of 1 referred to the normal work time for the products produced during the year. Productivity rates above 1 referred to improved productivity.

Physical workload measurement used the same method described in study 2. Accordingly, all work tasks in these two departments (28 on the assembly line and 8 in the welding unit) were video-recorded and later analysed. The measurements were conducted on the assembly line in 2015 and 2021 and in the welding unit in 2018 and 2022. Individual video recordings ranged from 583 s (9.7 min) to 1603 s (26.7 min).

Regarding costs for the development activities, four company representatives in development management positions were consulted to identify departmental development measures. Development was based on results from work measurement analyses and physical workload measurements and was carried out by development engineers, the assembly line supervisor, and the production manager. The production development engineers were responsible for evaluating the investments; investment in the 30 development activities for the assembly line was estimated at €177,000. Two development measures were carried out in the welding unit, totalling €35,000.

Productivity was calculated by comparing the wage costs of workers at actual productivity levels to those at productivity level 1, which represents a normal work pace. The cost of a sick leave day was estimated at €370 (Confederation of Finnish Industries, 2023). Employee wages were calculated by multiplying the hourly wage by the number of employees and the number of hours worked per day and dividing the result by productivity and the number of working days per year.

5 RESULTS

5.1 UTILISING AND UNDERSTANDING ERGONOMICS (STUDY 1)

The manufacturing companies made relatively little systematic use of ergonomics, regardless of whether they were SMEs or large companies. The promotion of productivity, workload, and well-being at work through ergonomics was limited, and no statistically significant differences were observed. However, the SMEs generally used ergonomics slightly more than the large companies. Nevertheless, most companies' responses indicated limited use of ergonomics for productivity (72%), well-being (62%), or workload development (58%).

When respondents were asked about their sources of ergonomics advice and guidance, OH professionals emerged as the predominant providers. Physiotherapists were particularly prominent in the responses of all the companies (76%). OH nurses (56%) and OH physicians (47%) also provided ergonomic guidance to the companies, but there was no statistically significant difference for company size. In addition, the companies received a lot of ergonomic guidance from colleagues or their representatives (53%), but again there was no statistically significant difference according to company size. In addition, internal manufacturing stakeholders, supervisors, production managers, and designers received limited ergonomic guidance (20%, 9%, and 11% in SMEs; 18%, 9%, and 7% in large companies). Guidance from ergonomists, well-being consultants, and HR was also low, with a significant difference in HR input between SMEs (11%) and large companies (30%; $p = 0.01$)

Ergonomics guidance was generally limited to workplace design and development, with a focus more on office work at all companies regardless of size. Large companies provided more advice on remote work than SMEs (37% vs. 12%, $p = 0.01$), while SMEs provided more guidance on workstation design (47% vs. 27%, $p = 0.03$) and technological systems (12% vs. 0%, $p = 0.01$). Most ergonomic advice focused on office furniture, display terminals, and working postures or manual handling, although

differences across company sizes were not statistically significant. In general, ergonomics played a minimal role in product design, work processes, and the design of work environments. As seen in Figure 3, the utilisation of ergonomics to promote productivity, workload, and well-being was low in both SMEs and large manufacturing companies. Ergonomic guidance was most frequently obtained from OH and colleagues and less frequently from internal or external experts. The guidance focused on office work, working postures, and manual lifting; ergonomics was used very little in production processes and product design.

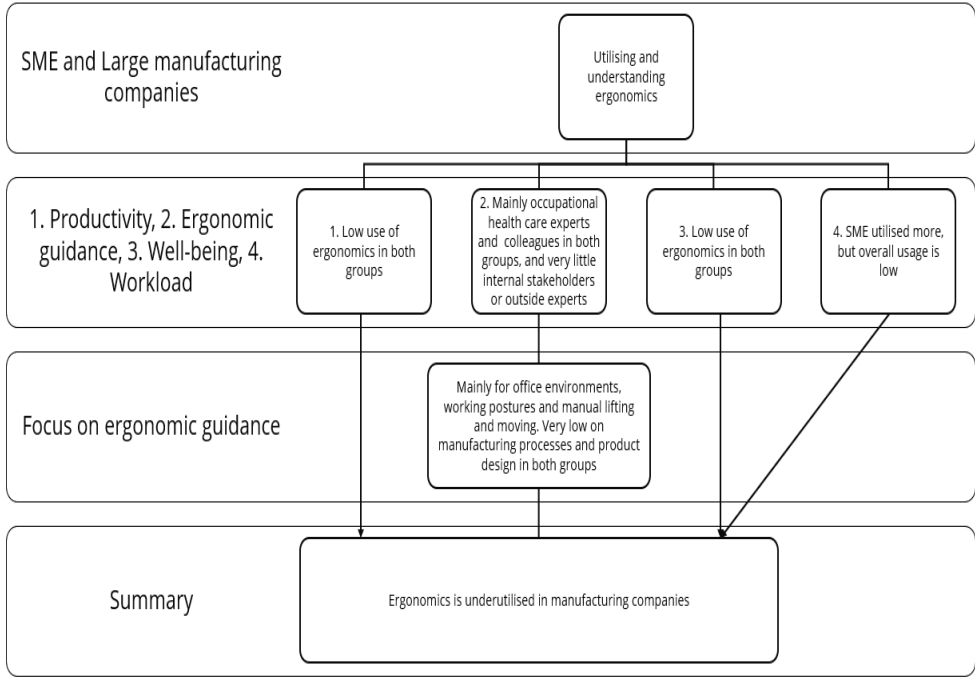


Figure 3. How manufacturing companies utilise ergonomics.

5.2 ERGONOMIC DATA UTILISING (STUDY 2)

The manufacturing corporation had access to unique, extensive data on physical workload measurements collected from various tasks within the organisation. The data were available at different levels of the organisation and to various OH professionals. CM made much more extensive use of the data than other personnel groups, such as OH and blue-collar workers.

These groups focused more on the micro level of maintaining and promoting health than on improving business performance. Conversely, the group's management and executives highlighted factors related to employee work ability and business performance. Secondly, white-collar workers and CM collaborated to view data as a means of justifying investments in robots and new technologies to enhance manufacturing processes.

By utilising the data, management sought to achieve results that would improve competitiveness and the work ability of all personnel. In addition, measuring workload was seen as a socially sustainable practice and a meaningful way to show employees how valuable they are. On the other hand, white-collar workers also saw the use of data as affecting the work and productivity of their own subsidiary's personnel, as well as the development of work processes. However, they felt they had to struggle to find a balance between productivity and promoting work ability.

Blue-collar workers believed that combining their practical work knowledge with workload measurement data could enhance and sustain their own work ability. OH also made more individualised use of the data, for example, in individual health negotiations, in planning alternative work, and in modifying workstations. On the other hand, collaborative use of data with blue-collar and white-collar workers was also seen as promoting smaller investments, such as furniture and lifting aids. In addition, collaboration enabled job rotation and layout changes. Job rotation was viewed as a way to balance workload from both mental and physical perspectives. Figure 4 shows how different personnel groups utilised physical load measurement data.

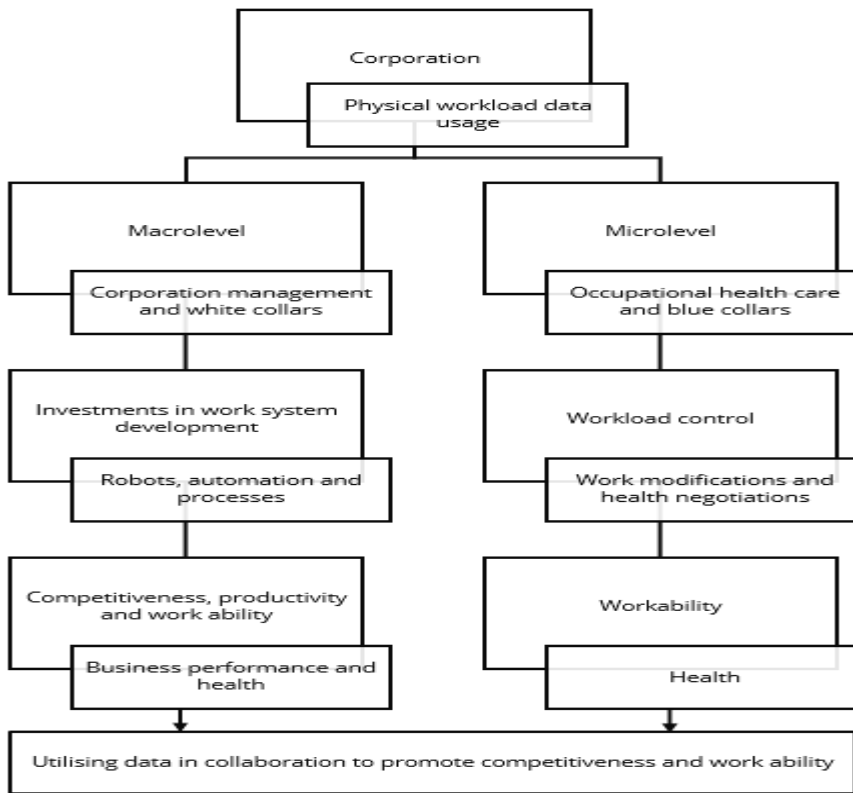


Figure 4. Summary of physical workload data usage in a manufacturing corporation.

5.3 UTILISING ERGONOMICS IN PRACTICE (STUDY 3)

5.3.1 Productivity and MSDs

Thirty work development activities were carried out on the assembly line, with a total cost of €177,000. In these development activities, assembly line workers experienced reduced physical workload and harmful postures due to improved ergonomics, reducing awkward postures such as leaning forward and/or twisted body positions, as well as working with hands above the shoulder level. Handling different loads also took less time. The average total workload decreased from 2.6 to 1.7 across all assembly line tasks. Conversely, the welding unit undertook two development activities totalling €35,000, and the average workload remained stable, decreasing slightly from 3.0 to 2.8 in 2022.

Productivity consistently exceeded the normal work pace (1) on the assembly line. In 2021, assembly line productivity declined as planned due to the launch of new products. In addition, productivity increased to 1.2 during the most recent monitoring period. However, higher productivity did not adversely affect employees' MSDs. MSD-related absences fell from 12.1 to 0.4 sick days per person during the follow-up period. Productivity in the welding unit declined. Productivity declined towards the end of the monitoring period, falling below the normal work pace of 0.97 during the last year of monitoring. In addition, MSD sicknesses per person remained at a high level, with 18.7 sick days per person in the last monitored year (Figure 5).

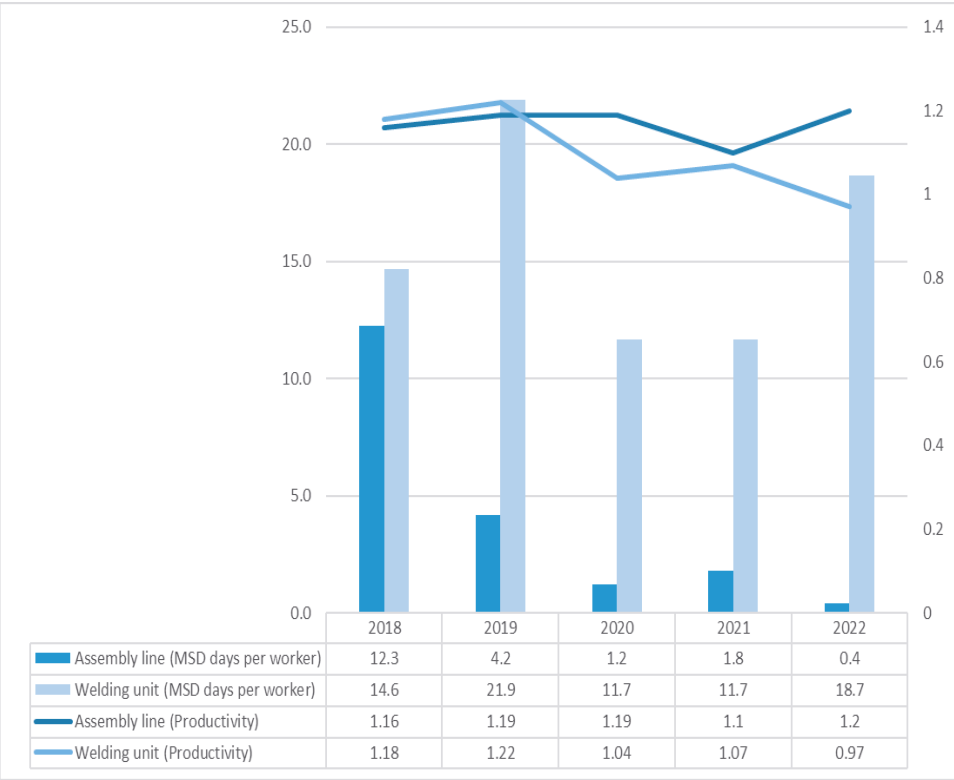


Figure 5. How work development activities affected productivity and MSDs on the assembly line and in the welding unit in the follow-up period (2018-2022).

5.3.2 Financial analysis

On the assembly line, maintaining higher productivity and significantly reducing MSD-related illnesses yielded substantial financial benefits for the company. The annual benefit exceeded €200,000 after the first monitoring year and reached €300,000 by the final year. In cumulative total, productivity gains and cost savings yielded approximately €1.1 million in profits for the company during 2018-2022. In the welding unit, declines in productivity and increases in MSD-related illnesses negatively impacted financial results. Although profit remained positive for four years, it was significantly weaker than the assembly line's, and the trend was negative. In the final year of monitoring, productivity declined below the normal level, and MSD rates increased, resulting in higher costs for the company. Over the 2018-2022 monitoring period, the company accrued approximately €270,000 in financial benefits in the welding unit (Figure 6).

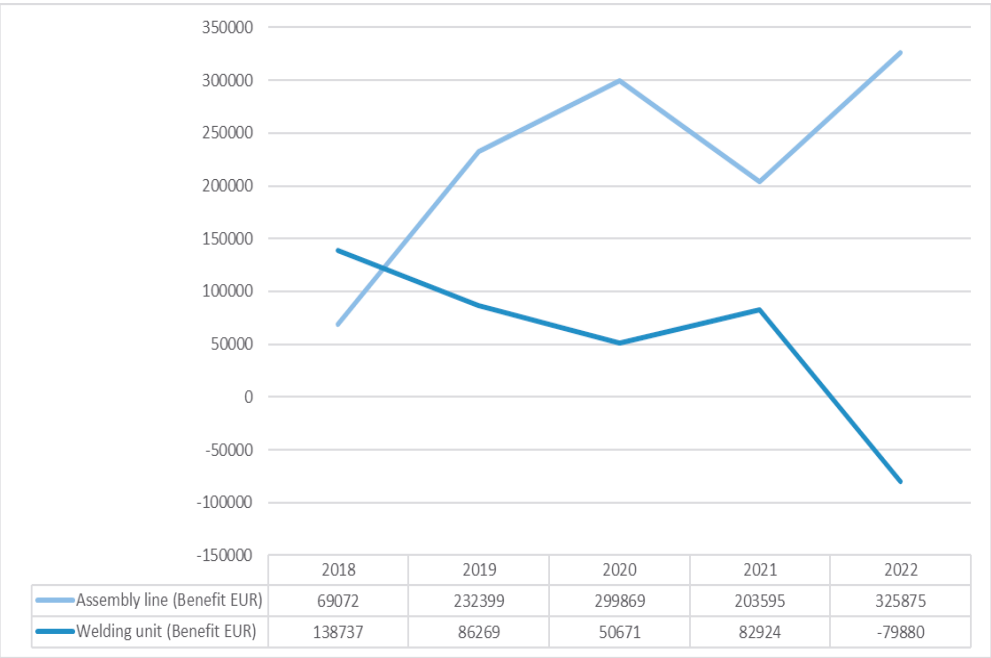


Figure 6. Financial analysis of annual benefits on the assembly line and in the welding unit.

6 DISCUSSION

6.1 MAIN FINDINGS

Ergonomics in the manufacturing industry can be understood as both an explicit and an implicit element of work system design. While certain ergonomic aspects, such as physical workload or workstation design, are recognisable, many effects remain embedded in the interaction between social and technical components and are therefore not systematically recognised or assessed. Overlooking implicit ergonomic factors in system design can lead to long-term issues like decreased productivity, well-being, and competitiveness, causing unrecognised economic losses from suboptimal work systems, so-called phantom profits (Sgarbossa *et al.*, 2020; Grosse *et al.*, 2023).

In this thesis, it was found that manufacturing companies have not widely recognised the opportunities that ergonomics offers to increase productivity, improve well-being, and reduce workloads. In addition, ergonomic guidance, mainly from OH, focuses primarily on office environments rather than production processes. It was also observed that blue-collar and OH utilise ergonomic physical workload data at the micro level, while management strives to utilise it to support macro-level decision-making. Further, the findings suggest that incorporating ergonomics into operations could yield significant benefits for both personnel and the company. This requires diverse data on work and personnel, including physical workload data, and processing them into a form suitable for practical use. Investments in work development enables increased productivity and reduced workloads and MSDs, thereby improving financial performance. Increased productivity and reduced sick leave contribute to the company's competitiveness and the well-being of its personnel.

6.2 SCIENTIFIC CONTRIBUTIONS

6.2.1 First part (study 1)

Study 1 showed that, in general, manufacturing companies do not recognise the opportunities that ergonomics offers to promote productivity and well-being. This aligns with previous research (Dul and Neumann, 2009; Tompa *et al.*, 2009; Neubert *et al.*, 2012; Rose *et al.*, 2013; Greig *et al.*, 2019; 2023). Surprisingly, it also found no major differences between SMEs and large companies. In this regard, ergonomics is primarily viewed as a tool for improving office work rather than as a driver of the development of production processes and the work environment. Companies should aim for a culture in which ergonomics is seen as added value rather than a cost, and literature suggests that successfully embedding ergonomics into a company's operations requires strong management commitment (Hansen *et al.*, 2024). However, strategic ergonomics management shouldn't rely solely on individual measures or advice for office environments; instead, it should be integrated into the organisation's structures, processes, and culture.

Integrating ergonomics into an organisation's operating practices can be challenging, especially when the link between ergonomics and performance is not clearly recognised (Neumann and Dul, 2010). Study 1 suggests that ergonomics' potential to support manufacturing process development and productivity may therefore remain limited. This is not unexpected, as ergonomic guidance is predominantly provided by OH professionals rather than by stakeholders responsible for production system design or managerial decision-making. When ergonomic input originates mainly from stakeholders without formal authority over work system design, its integration into manufacturing processes may remain limited. In line with Reiman *et al.* (2021; 2024), this may reflect a lack of maturity in strategic management processes, in which the scope and potential of ergonomics in production system design are not yet fully recognised.

The findings of study 1 therefore support the need to shift the focus of ergonomics from individual-level guidance onto systematic development of work systems and processes, through stronger integration of ergonomic expertise into management, production planning, and OH practices. However, in the manufacturing industry, development priorities are commonly guided by business metrics such as cost, speed, and production volume. In addition, previous research suggests that this orientation reflects managerial decision-making focused on short-term economic outcomes, while the broader performance and system-level benefits of ergonomics remain less visible or difficult to quantify (Hendrick, 2003; Greig *et al.*, 2019; da Silva *et al.*, 2012; Mulaomerovic and Wang, 2023). Study 1's findings suggest that ergonomics remains underutilised in manufacturing not due to limited relevance but because it is not integrated into production system design and, by extension, managerial decision-making.

6.2.2 Second part (studies 2 and 3)

Study 2 presented a method for collecting measurement data on physical workload and described how the data were used at different organisational levels. In study 3, physical workload measurement data were part of the company's other measurement data, which were utilised as a whole in the company's work development. Interpreting diverse data in practice requires collaboration. In the literature, PE is widely used, for example, to reduce MSD prevalence and facilitate manual work (Haukka *et al.*, 2008; Rivilis *et al.*, 2008; Driessen *et al.*, 2010; Burgess-Limerick, 2018; Wurzelbacher *et al.*, 2020), and PE points out that organisational stakeholder groups approach work development from different viewpoints.

As demonstrated in study 2, while management and personnel generally share broad goals such as safety, health, productivity, and competitiveness, they interpret and implement these goals at different system levels. Management adopts a macro-level perspective emphasising system performance and long-term competitiveness, whereas workers

tend to focus on micro-level aspects such as workload and their individual work ability. This divergence does not indicate conflicting objectives but instead highlights a coordination challenge within the socio-technical system. Without a shared interpretive framework, development efforts may become fragmented or limited to isolated improvements. Bridging these perspectives involves integrating technical solutions, organisational structures, and human experiences into cohesive development actions. Previous research suggests that combining stakeholders' expertise improves the application of technology and automation, supporting both system performance and well-being (Carayon, 2006; Davis *et al.*, 2014). In this context, successful work system development depends on management's socio-technical navigation capabilities, that is, the ability to synthesise diverse stakeholder insights into aligned design choices that enhance both productivity and well-being.

Furthermore, in study 3, productivity and cost savings were gained through work development, which reduced the workload. OH expertise can be utilised for work development, but, as study 2 shows, at the micro level. However, micro-level insights become meaningful at the system level when they are interpreted within the organisation's socio-technical decision-making. Under the Finnish Occupational Health Care Law (1383/2001), OH's role is to anticipate challenges to work ability in cooperation with other stakeholders. The law does not directly require OH professionals to promote productivity or competitiveness and thus may leave another ergonomic goal (performance) unexplained. Furthermore, they may lack the technical and practical skills to develop a work environment themselves. This emphasises the importance of cooperation between different stakeholders in work development.

Supporting practical implementations of technology requires human-centred work design (European Commission, 2024), and earlier studies indicate that predictive methods are essential tools for long-term well-being (Loch *et al.*, 2010; Neumann and Dul, 2010; Mulaomerovic and Wang, 2023). Although the relationship between work and well-being is complex, the findings of study 3 indicate that system-level data integration enables proactive interventions that address this complexity in practice. In this

context, the challenge is how to promote the well-being of all personnel (Bohman *et al.*, 2025; Hamza and Farah, 2025). In study 3, a manufacturing company had analysed the work system and collected data on performance and personnel in many ways. The data collected on the work system were processed into knowledge, which was applied through work development activities. Understanding work through diverse data provides objective information to support the company's decision-making. Management (or other system stakeholders) need not rely solely on subjective impressions or individual feedback; instead, data enable knowledge-based strategic solutions. Hence, work development grounded in integrated system-level data enabled a proactive influence on personnel's work ability and well-being, rather than reactive responses to emerging problems.

From the perspective of well-being or work ability, it is therefore not irrelevant what conditions, tools, or methods are used. Previous research suggests that development work requires careful design of products, workstations, the work environment, and work processes, with people as part of the system (Kadir *et al.*, 2019). Without this understanding, work interruptions, heavy workloads, system disruptions, or poorly designed products, tools, and methods reduce productivity and harm personnel's well-being (Kalakoski *et al.*, 2020; Slama *et al.*, 2024). Study 3 shows that continuous development of companies' work systems appears to support a high-quality working life in practice. Its findings suggest that work system quality and employee well-being are not outcomes of isolated interventions but of continuous, integrated system development.

Earlier studies have shown that there are countless ways to develop work using ergonomic methods, and technological constraints, personnel creativity, and the number of insights act as limiting factors (Davis *et al.*, 2014; Neumann *et al.*, 2016; Hughes *et al.*, 2017; Kadir *et al.*, 2019; Abdous *et al.*, 2022). In study 3, the work was continuously developed over a five-year monitoring period. It should therefore be noted that work development is not always possible in the short term. For example, reducing the workload may be technically challenging due to the nature of the work, or the technology may not yet be sufficiently advanced to

address the identified problem. For companies, it could be simpler and less expensive to purchase lifting tables or other aids to reduce the workload, for example, than to make changes that require a significant investment. Larger changes to the work environment or processes may involve adopting new technologies and automation and can be more challenging to implement. In addition, the company will incur a substantial financial risk in such cases. On the other hand, redesigning products to reduce workload, for example, may be a long-term goal aimed at enhancing personnel's work ability and productivity. Based on studies 2 and 3, work development is not merely a technical or economic challenge but a socio-technical navigation task requiring organisations to prioritise and sequence interventions in ways that support both system performance and employee well-being over time.

Companies need to be competitive and productive (Zare *et al.*, 2016), yet little research has examined the economic impacts of ergonomics (Tomba *et al.*, 2009; Neubert *et al.*, 2012). In Finland, both in general and in manufacturing, productivity development has long faced challenges (Calligaris *et al.*, 2023). In addition to productivity and business development, companies seek to reduce costs by reducing work-related sick leave. Study 2 showed that CM uses physical workload data to enhance business performance and overall personnel health. As seen in study 3, poor ergonomics negatively affected both productivity and the incidence of MSDs. On the other hand, good ergonomics significantly contributed to high productivity, low MSD levels, and the company's improved financial performance. Based on study 3, it is possible that when a work system is designed ergonomically, high productivity supports personnel's work ability. This is also the strategic goal of ergonomics: to improve productivity and well-being through work development (Dul *et al.*, 2012). The findings indicate that achieving both high productivity and sustained work ability is not a trade-off but a socio-technical navigation challenge requiring organisations to align ergonomic knowledge with technological and economic decision-making.

Integrating productivity, technology, digitalisation, and well-being at the system level often requires investment. However, the practical benefits of

ergonomics have long been discussed (Karlton, 2017; Read *et al.*, 2018; de Winter and Eisma, 2024; Salmon *et al.*, 2024; Karwowski *et al.*, 2025; Endsley and Sasangohar, 2025). It seems that investments in work development are necessary to make the usefulness and benefits of ergonomics visible. Investment needs are often based on calculations of factors such as investment payback time, production efficiency, or productivity growth. Based on studies 2 and 3, it can be argued that potential cost savings related to work ability and well-being should be included in business calculations to support investment. Investments necessary for work development are more likely to be secured through financial calculations.

It has been suggested that many manufacturing tasks remain human-centred (Katiraei *et al.*, 2021). Therefore, it is vital to maintain personnel's work ability. Work development plays a significant role in reducing workloads and may be essential for maintaining employees' work ability. Nevertheless, companies do not have unlimited resources and cannot invest anywhere they want. Studies 2 and 3 indicate that an investment can be justified by analysing the work and personnel. Areas for development must be identified and investments made where the benefits to the company and its personnel are most significant. In an open-market economy, however, everyone can invest in similar technologies. A competitive advantage can likely be achieved by applying data collected on work systems and human resources and by collaborating to adapt solutions to practical needs. In other words, the work must be understood to target investments where the potential to improve productivity and well-being is greatest. This underscores that competitive advantage in manufacturing increasingly depends on socio-technical navigation capability: the ability to understand work systems deeply and to align human-centred insights with investment and development decisions.

6.3 PRACTICAL CONTRIBUTIONS

There is a constant need for manufacturing development, and prioritising measures can be difficult. The thesis suggests that work development can be understood as based on systematic collection of diverse data and the investment decisions derived from it, which contribute to improvements in productivity, well-being, and work ability. This means better working conditions for personnel and greater competitiveness for companies. Companies that have the courage and ability to apply the latest technology and utilise their personnel's expertise have a better chance of succeeding in the global market. From this perspective, the challenge is not only how development priorities are set but also how different stakeholders contribute to addressing productivity, workload, and well-being in practice.

The results of the studies help identify common ground between OH and companies operating in manufacturing. Resources can be effectively targeted to maintain and support employees' work ability by developing the work environment and work processes. Thus, investments in work development can be seen not only as a means of increasing productivity and competitiveness but also as an investment in personnel's work ability and well-being. In addition, it is possible that system decision-makers' approach to ergonomics reflects differences in how the concept is understood and framed rather than a lack of engagement with it. From an Industry 5.0 perspective, ergonomics can be operationalised as practical activities implementing human-centric system design. The current situation offers companies an opportunity to promote ergonomics, as the focus in the EU and in international markets is shifting from technology-centric to human-centric industries (European Commission, 2024).

This dissertation indicates that ergonomics in work development is not just about responding to challenges in the work environment and work community but also a process of continuous development. This requires understanding and the capability to integrate the social system into the technical system. To support this, this thesis presents a model of socio-technical navigation capabilities, as described in Figure 7.

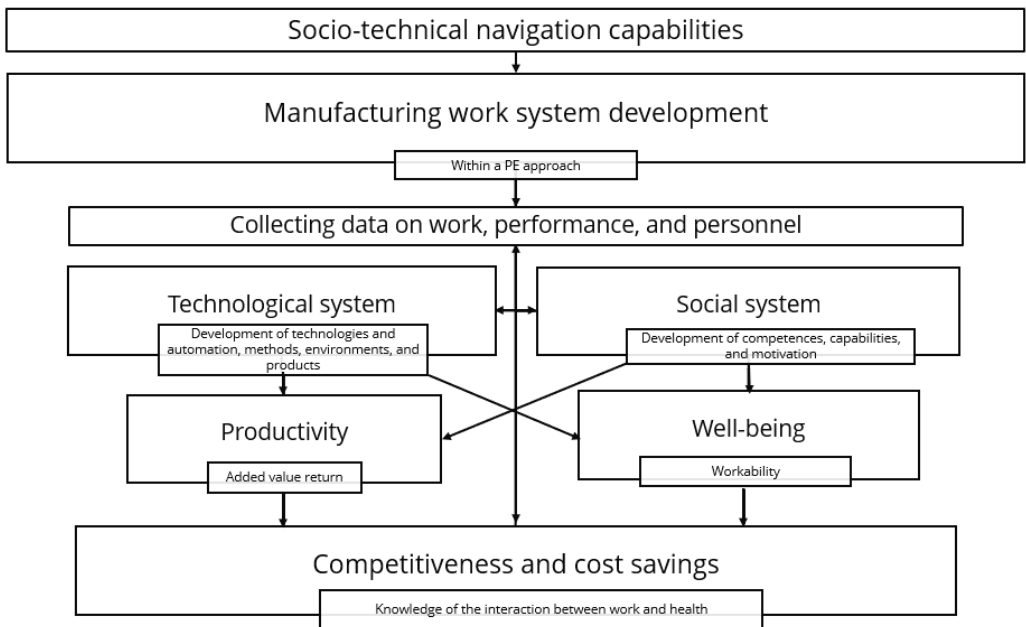


Figure 7. Model of socio-technical navigation capabilities.

Socio-technical navigation capabilities describe an organisation's ability to view the work system as a whole. The starting point for development is participatory and systemic utilisation of ergonomics based on diverse data. In this approach, the competitiveness and cost savings of manufacturing companies are built within a system in which technical and social systems interact continuously. Thus, productivity and well-being arise where technological solutions, collaboration, competence, motivation, and work organisation meet. It also involves the organisation's ability to integrate knowledge about the interaction between work and health into decision-making at all levels. Without this ability, a company could only develop technology without understanding its impact on workload, well-being, and work ability. Or, conversely, well-being could be promoted in isolation from the work. Neither is sufficient on its own, so improving productivity and well-being must not be separate goals but part of the same work system development.

When a company takes care of the technological system (work), its structures, workload, environment, processes, and workflow, in return, take care of its personnel. This principle summarises the key message of

socio-technical navigation capabilities: mind the work, and well-designed work supports the personnel's well-being and work ability and enhances productivity. This enables companies to achieve economic and social success. Socio-technical navigation capabilities do not entail presenting a perfect solution for working life. They offer a clearer map that enables companies and their stakeholders to steer towards work systems in which boosting financial performance and well-being are not conflicting goals but rather the objectives of developing a collaborative work system.

Perhaps ergonomics is the dark matter of working life, invisible, but a decisive force. Its effects are significant, even if they are not consistently recognised. The challenge for ergonomics is to make this invisible force visible. By implementing ergonomics in manufacturing, companies could realise their full potential.

6.4 STRENGTHS AND LIMITATIONS

Limitations must be acknowledged. The survey response rate could not be determined because the total number of manufacturing companies that received the survey is unknown. Consequently, assessing the representativeness of the respondent group is uncertain, which should be considered when interpreting the generalizability of the findings. The results primarily reflect respondents' views but still offer valuable insights into the phenomenon under study. The dissemination of the questionnaire within each company was managed by the company's contact person, and it is unclear how effectively it was distributed. In addition, it is not known what kind of ergonomic background the respondents generally had. Also, the study had a small respondent pool of manufacturing companies ($N = 42$), and the higher proportion of white-collar workers might have biased responses towards office work.

The studies also focused on a Finnish manufacturing corporation. The results may not be directly generalizable to other national or organisational contexts with different regulatory, cultural, or OH frameworks. The author was employed at the corporation during the studies. This presents both a strength and a limitation. Through this

connection, he gained access to company-specific data for research. However, this relationship also introduces the potential for bias, especially regarding objectivity.

The physical workload data were analysed using a self-developed method. Physical workload data on corporate work tasks were gathered over seven years, and the corporation was committed to using this method to obtain the data. Despite being self-developed, the method was applied systematically over an extended period in real work environments, which supports its ecological validity and suitability for analysing longitudinal changes in physical workload associated with work system development. In addition, an OH professional participated in data collection and analysis. The ergonomist (the author) and the OH physiotherapist knew the work and the workers well. This allowed for in-depth analysis of the ergonomics data. This increases the credibility of the data. On the other hand, the physical workload dataset was not the only one; the empirical data were collected in part through established methods (MOST analysis, demographic data, and other company figures) and with non-validated, more practical tools.

The strength of the dissertation lies in its unique focus: no similar research in Finland has examined the effects of ergonomics on productivity, well-being, workload, and economic outcomes over a long period. It offers detailed, multi-source data that highlight the significance of ergonomics in manufacturing.

6.5 FUTURE STUDIES

This thesis combined ergonomics, well-being, and economic outcomes. However, a more in-depth analysis of the economic impacts of ergonomics is needed. It would be valuable to study how different types of investments, such as automation (robots, cobots), workstation redesign, and process reconfiguration, affect productivity, well-being, and economic performance over time. It would also be valuable to explore where and how companies could obtain the expertise in applying ergonomics described in this dissertation. Is such support available through OH, or

should OH's operations be further developed to meet the company's system-level development needs? Or, on the other hand, should manufacturing companies themselves increase their own ergonomics expertise, for example, by enhancing engineers' knowledge of ergonomics? Or should companies procure system-level ergonomics expertise as an outsourced service, and, conversely, is such expertise available? If ergonomic recommendations are disconnected from the broader context, they may not translate into concrete actions, and outcomes such as productivity, well-being and workability may be difficult to measure. These issues can create a gap between research and practical ergonomics.

7 CONCLUSIONS

Manufacturing companies have utilised ergonomics only to a limited extent to enhance well-being at work, increase productivity, and improve workload management. However, the underutilisation of ergonomics is not due to a lack of willingness on the part of companies but rather to issues related to expertise, cooperation structures, and data utilisation. When ergonomic data are incorporated into design and the business data used by management, ergonomics becomes an investment that builds competitiveness and sustainable performance rather than a cost. Ergonomics is perceived differently by different groups: employees and OH mainly view it in terms of individual work arrangements (the micro level), while management sees it as a tool for organisational development (the macro level).

The use of diverse work and system data from different sources creates the conditions for human-centred development of work and production systems. Human-centred design and Industry 5.0 offer an opportunity to strengthen ergonomics' strategic role in manufacturing. To support this, companies need socio-technical navigation capabilities: the management ability to reconcile technological solutions, personnel well-being, and production targets in ways that support proactive decision-making.

Systematic utilisation of ergonomic principles in a socio-technical system enables high productivity while maintaining personnel well-being. Conversely, neglecting ergonomics weakens both the system's performance and personnel well-being in the long term. Effective integration of new technology, productivity, and workplace well-being requires targeted investments, which may be encouraged by economic policies such as tax incentives for socio-technical solutions that enhance ergonomics.

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LIST OF ORIGINAL PUBLICATIONS

This dissertation is based on the following original publications:

- I Suokko, T., Oksanen, T. and Reiman, A. 'Ergonomics in practice: survey evidence from Finnish manufacturing companies'. Submitted 2025.
- II Suokko, T.,* Patama, J.,* Oksanen, T. and Reiman, A. (2024) 'Integrating HF/E knowledge into manufacturing process development: qualitative study on utilising physical workload data', *International Journal of Human Factors and Ergonomics*, 11(4), pp. 331-349.
- III Suokko, T., Oksanen, T. and Reiman, A. (2025) 'Productivity and employee well-being in manufacturing process development – comparison study of two departments', *Applied Ergonomics*, 25, article 104460.

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ORIGINAL PUBLICATIONS (I-III)

I

**Ergonomics in Practice: Survey Evidence from Finnish Manufacturing
Companies**

Suokko T, Oksanen T, Reiman A

Submitted 2025

II

Integrating HF/E knowledge into manufacturing process development: qualitative study on utilising physical workload data

Suokko T, Patama J, Oksanen T, Reiman A

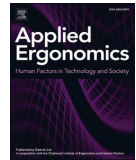
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III

Productivity and employee well-being in manufacturing process development – Comparison study of two departments

Suokko T, Oksanen T, Reiman A

Applied Ergonomics, 125, 104460, 2025



Productivity and employee well-being in manufacturing process development – Comparison study of two departments

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ABSTRACT

Manufacturing companies constantly seek opportunities to improve operational efficiency without compromising employee well-being. Ergonomics can contribute to both goals, but its role is often limited to well-being. This longitudinal corporate case study followed retrospectively the effects of work development for five years in a manufacturing company's assembly line and welding unit. The aim was to analyse how these development activities impacted employee well-being and productivity. In the assembly line, ergonomics-oriented development processes led to a profit of EUR 1,130,810 and a reduced physical workload. In contrast, the welding unit implemented only two development activities, resulting in a smaller profit of EUR 278,721, with no noticeable decrease in physical workload. This study suggests that continuous activity in production development utilising ergonomics data collected from the work leads to sustainable productivity and improvements in employee well-being.

1. Introduction

Work and work processes are constantly being developed in the manufacturing industry to ensure production performance and efficiency. These development activities, often technology-dominated and business-oriented, can provide a competitive edge for the company through the introduction of new and advanced technologies and automation. There is, however, a threat to successful performance and employee well-being if human-system and human-technology interfaces are not designed with enough deep ergonomics expertise. The potential benefits for ergonomics development in the manufacturing industry can be significant when these challenges are handled with the right approach (Boff, 2006; Carayon, 2006; Punnett et al., 2009; Gualtieri et al., 2020; Reiman et al., 2021; Reiman et al., 2023; Abdous et al., 2023; Slama et al., 2023).

If work, work environment, and personnel and their interactions are not adequately considered, different disruptions between them can arise, posing multifaceted challenges for the company. These disruptions may adversely affect personnel through various psychosocial and organizational processes (Neumann et al., 2009; Wilson, 2014; Caputo et al., 2019; Sormunen et al., 2022; Hansen et al., 2024). As a scientific discipline, ergonomics aims to understand, design and develop work

from a socio-technical work systems' perspective. In this regard, the system can be approached from micro and macro perspectives. When examined from the micro perspective, the focus is on individual level work systems whereas the macro perspective on work systems shifts the focus on broader system complexities and their design and management. In the ergonomics literature, such systems are discussed under the microergonomics and macroergonomics domains. As described by Kleiner (2008) macroergonomics as a sociotechnical systems theory focuses on organizational design aspects and the design configuration is then carried down to the microlevel, i.e. to the workplace, or workstation level, i.e. to the level where the actual work is performed. At the heart of such macroergonomics socio-technical system development is that there is evidence-based microergonomics knowledge of the factors that influence or disturb the smooth functioning of work and employees' workload (Davis et al., 2014; Neumann et al., 2016; Kadir et al., 2019; Hughes et al., 2017; Abdous et al., 2023).

With the advancement of manufacturing technologies, there has been a growing need for more holistic work system design (Neubert et al., 2012; Papetti et al., 2021; Domínguez-Alfaro et al., 2023). In this regard, companies' development processes should address a holistic macroergonomics system perspective where employees, work processes, methods, systems, environments, tools, machinery and equipment, and

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the output products and services are all simultaneously considered. Usually this requires that microergonomics knowledge is systematically applied with a macroergonomics holistic development approach (Hendrick, 2003).

Influencing companies' business performance requires an awareness of the economic metrics companies seek to influence (Dul and Neumann, 2009; Greig et al., 2019; Greig et al., 2023; Domínguez-Alfaro et al., 2023). In that respect, in manufacturing, ergonomics is, however, often considered too narrowly only from a health and safety development perspective, and not for productivity development, hence neglecting the potential it could have from a business performance development perspective (Dul and Neumann, 2009; Greig et al., 2019; Greig et al., 2023). Often, the need for ergonomics development arises only from the need to reduce costs associated to occupational health and safety, for instance, by minimizing the number of musculoskeletal disorders (MSDs) (Falck et al., 2010; Halling et al., 2019; Kolus et al., 2023; Tompa et al., 2009a; Tompa et al., 2009b; Tompa et al., 2013). However, it is not always understood that these development activities may also improve work productivity (Guimarães et al., 2015; Papetti et al., 2021; Niekurzak et al., 2023).

Isolating ergonomics development activities from other development activities is often challenging, and the effects that can be direct or indirect may only become apparent in the long term (Hendrick, 2003; Hignett et al., 2005; Tompa et al., 2009a; Tompa et al., 2009b; Tompa et al., 2013; Falck et al., 2010; Rose et al., 2012; Falck and Rosenqvist, 2014; Burgess-Limerick, 2018; Heidarimoghadam et al., 2022). Therefore, evaluating the effectiveness of ergonomic interventions is challenging, and epidemiological research evidence, for example, on physical ergonomics, has been relatively scarce and sometimes even contradictory (Haukka et al., 2008; Rivlis et al., 2008; Driessen et al., 2010; Wurzelbacher et al., 2020). Also the need to examine the economic benefits of ergonomics has been recognised for a long time (Beevis and Slade, 2003; Hendrick, 2003; Goggins et al., 2008; Hendrick, 2008; Tompa et al., 2009a; Da Silva et al., 2014), yet ergonomics research still lacks properly conducted economic analyses and calculation methods and tools that consider the variety of potential cost savings and productivity improvements, as evidenced by different indicators (Tompa et al., 2009a; Neubert et al., 2012; Rose et al., 2012).

This study aimed to investigate the effects of development activities on system performance and employee well-being in one large international manufacturing corporation based in Finland. The corporation employs over 950 people globally and has subsidiaries in Finland, Germany and Slovakia. The study focused on a Finland-located company and its' two departments: assembly line and a welding unit and their development activities between 2018 and 2022. For both departments, ergonomics data were collected through physical workload measurements and work measurement analyses. In the first one, these data were systematically applied to use when designing development activities, whilst, in the latter one, development activities were more modest when it came to their amount and the use of ergonomics. Within our macroergonomics study setting, the aim was to (1) analyse how manufacturing process development activities contributed to employee well-being regarding the physical workload and the number of sick leaves from MSDs. Further, this study aimed to study the (2) system performance development perspective by following the productivity rate developments and calculating cost-benefit ratios for the development activities conducted in these two departments.

2. Methodology

2.1. Study context

In both departments (assembly line and welding unit), various work tasks were performed manually or with hand tools, and the employees constantly handled parts of different sizes, weights, and shapes. The assembly line had 13 work stages (see Table 1). In those 13 work stages,

Table 1
Departments' work stages and development activities.

Department	Work stage	Development activities (n)
Assembly line	1 Dashboard	3 (2 x modifications of the lifting aid, new installation point)
	2 Electrical switchboard	4 (3 x modifications of the lifting aid, new assembly jig and sub-buffer)
	3 Electrical wiring	3 (Buffer modification, product lifting table, flow control wire installation jig)
	4 Exterior roof	4 (Modification of the lifting aid, new buffer, additional space to streamline roof handling, person working platforms)
	5 Interior roof	1 (More suitable machinery for the work)
	6 Heating system piping	1 (Storage rack)
	7 Rear window/windscreen	4 (Modification of the lifting aid, product lifting table, buffer replacement, raiser for pallets)
	8 Control panel wiring	3 (Modification of the mounting bracket, storage rack for jigs, product lifting table)
	9 Interior Cladding	0
	10 Headlights	2 (Parts to be assembled moved up on the workstation, buffer for parts)
	11 Hydraulic piping	3 (2 x product lifting tables, tool trolley)
	12 Doors	1 (More lighting)
	13 mudguards	1 (Lifting aid)
Welding unit	1 Part loading	2 (Parts collection trolley modification, reversing of load racks)
	2 Frame welding	0
	3 Finishing welding and grinding	0
Total		32

there were altogether ca. 800 parts to be assembled, weighing between 100 g and 80 kg. The final weight of the finished product was 800 kg. At each work stage, the workers' tasks involved assembling various product parts to be manufactured using hand tools. The parts were transferred to the product by hand or with the help of lifting aids. One or two workers manned each work stage. The assembly line had balanced the same task time requirements at all work stages. After a defined task time, the product was automatically transferred to the next work stage. The assembly line was developed with 30 activities in 2018–2022 (see Table 1).

There were three work stages in the welding unit: part loading, frame welding, and finishing welding and grinding (Table 1). In these work stages workers handled 60 different parts, the weight of which varied between 100 g and 55 kg. The final weight of the finished product was 300 kg. Part loading and frame welding stages employed three to five workers. In the finishing stage, there were seven to ten workers. Part loading requires using a lifting aid or moving metal parts of various sizes, shapes, and weights into the welding jig by hand. The metal parts were attached to the jig with jig clamps, closed by hand and then moved automatically to the welding robots. In frame welding, workers used a lifting aid to transfer the parts to an assembly welding robot, which welded the product to its final shape. The last work stage was finishing welding, where workers welded the product and manually grinded the welded seams. Only two development activities were made in the welding unit as can be observed from Table 1.

2.2. Methods and materials

This was a five-year longitudinal corporate case study that was retrospectively designed. Four data types were collected for this study: 1) personnel demographics, 2) work measurements, 3) physical workloads, and 4) costs of the development activities. They were collected to form a comprehensive analysis of the development activities and their effects on the system performance and employee well-being.

2.2.1. Personnel demographics

Personnel demographic data was retrieved from the HR databases.

Personnel at the two departments were considered reasonably comparable regarding their annual number of personnel, mean age and working experience, and worker turnover rate (see Table 2). By introducing a new eHealth system in 2018, the company could separate the annual sick leave days from MSDs from other sick leave days. All workers were male, with an average age of 40 throughout the follow-up period. The number of workers ranged from 27 to 31 in the assembly line and 17 to 20 in the welding unit.

2.2.2. Work measurement analysis

During the study period, work measurements were performed using the Maynard Operation Sequence Technique (MOST) (Zandin and Schmidt, 2021). The MOST is a predefined motion time system mainly utilised in industrial environments to establish the standard time for a worker to complete a work task. As a result of the MOST analysis, so-called normal times are produced. These can be used to design work tasks and methods (Wells et al., 2007; Harari et al., 2018; Zandin and Schmidt, 2021). Normal time is required from a qualified worker, working at a pace ordinarily used by the workers when capably supervised to complete a work task by following a prescribed method and without interruptions (Zandin and Schmidt, 2021). Knowing the time to complete specific work tasks can enable and maintain high utilisation rates of personnel, material, and equipment (Karim et al., 2016; Harari et al., 2018; Zandin and Schmidt, 2021).

All work tasks (28 in the assembly line and 8 in the welding unit) were measured. Work measurement data were used to calculate annual productivity figures. The productivity rate was calculated with the following formula:

$$\text{Productivity rate} = \frac{\text{Normal time}}{\text{Actual working time}}$$

The actual time taken to manufacture the products was obtained from the company's production management system. In this study, productivity rate 1 referred to the normal work time for the products produced during the year. Productivity rates above 1 referred to improved productivity.

2.2.3. Physical workload measurement

Physical workload measurements were conducted for the same tasks as the MOST analysis using a method developed by the authors. Accordingly, all work tasks at these two departments (28 in the assembly line and 8 in the welding unit) were video recorded and later analysed. The measurement process has been described earlier by the authors (anonymised for blind review). The measurements were made in the assembly line in 2015 and 2021. In the welding unit, the measurements

were made in 2018 and 2022. The video recordings were collected by the authors supported with an occupational health physiotherapist. All work tasks on an assembly line and welding unit were video recorded. Individual video recordings lasted from 583 s (i.e. 9.7 min) to 1603 s (26.7 min).

In the analysis of the video recordings, the aim was to identify harmful working postures and to calculate their proportions of the overall working time of the task being performed using a stopwatch. The ergonomics expert (one of the authors) and the occupational physiotherapist conducted the analyses. A simple checklist was used to support the analysis. In the checklist, harmful working postures observed were covered. These included: hands raised above shoulder level, bending, twisting of the back, standing, sitting, squatting, and manual handling of loads. As an example, in Fig. 1, a worker is manually performing a work task on welding (at the final welding and grinding work stage), standing and back leaning forward. For that work task, the proportion of those harmful working postures was standing at 60.7 % and back leaning forward at 28.8 % of the total working time.

The analysis was supplemented with subjective assessments of the impact of load handling in a work task. This was assessed using load handling coefficients (see Table 3). The proportions spent on harmful working postures in a particular task and the load handling coefficient assessed enabled an evaluation to determine the physical workload level of the task. The scale for these workload levels was evaluated on a scale from 0 to 4 (see Table 3).

2.2.4. Costs for the development activities

Four company representatives were consulted to identify the development activities that had been conducted at the departments. These informants worked in managerial positions at the production development department and had access to documentation and cost calculations for the activities.

Needs and ideas for the development activities had emerged through the outputs acquired from the work measurement analyses and physical workload measurements. The development was the responsibility of the production development engineers, the assembly line supervisor and the production manager. Formal and informal meetings were held between different personnel groups to discuss alternatives for development activities. As an example, Fig. 2 shows a part of the assembly line where development activities had been conducted.

The calculations of investment in work development activities were also the responsibility of the production development engineers. The estimated total investment for developing the assembly line was EUR 177,000, including all 30 development activities (see Table 1). On average, the cost of one development measure was EUR 5900. Only two development activities comparable to those made in the assembly line were made in the welding unit during the study period. First, in the part loading stage, the parts collection trolley was modified to be more suitable for parts handling in 2018, and second, in 2019, the orientation

Table 2

Personnel demographics in 2018–2022 collected from the company's human resources databases.

Year	2018	2019	2020	2021	2022
Assembly line					
Workers (n)	27	27	26	31	31
Mean age (years)	41.5	41.5	42.3	40.7	42.2
Years in the company	9.4	9.8	9.5	10.5	10.8
(mean ((range)))	(1–21)	(1–22)	(2–23)	(1–24)	(2–25)
Worker turnover rate (%)	0.0	12.9	3.7	0.0	8.8
MSD sick leave days (n)	331	113	32	55	12
Welding unit					
Workers (n)	17	18	18	18	20
Mean age (years)	42.5	44.3	45.1	46.7	43.5
Years in the company	14.3	14.5	14.2	15.2	14
(mean ((range)))	(1–29)	(1–30)	(1–31)	(2–32)	(1–33)
Worker turnover rate (%)	0.0	5.6	0.0	0.0	8.7
MSD sick leave days (n)	249	394	210	210	373



Fig. 1. An illustration of a work task in the final welding and grinding work stage highlighting the harmful work postures the employee has.

Table 3
Load handling coefficients and workload levels utilised in the analysis.

Load handling coefficients	Description
1.0	The loads are light and easy to handle. There is little handling of the loads and the working postures are somewhat harmful.
1.2	The loads are light and reasonably easy to handle. There is little handling of the loads and there are some nuisances in the working postures.
1.4	The loads are reasonably heavy and reasonably easy to handle. There is some handling of the loads and there is some nuisance in the working postures.
1.6	The loads are reasonably heavy and difficult to handle. There is a lot of handling of the loads and there are some nuisances in the working postures.
1.8	The loads are heavy and difficult to handle. There is a lot of handling of the loads and the working postures are harmful.
2.0	The loads are very heavy and challenging to deal with. There is a lot of handling of the loads and the working postures are generally harmful.
Workload levels	Description
0	The functionality of the work environment and work performance is an optimal/somewhat burdensome for the musculoskeletal system.
1	The functionality of the work environment and work performance is a somewhat burdensome for the musculoskeletal system.
2	The functionality of the work environment and work performance is a burden for the musculoskeletal system.
3	The functionality of the work environment and work performance is a major burden for the musculoskeletal system.
4	The functionality of the work environment and work performance is a significant burden for the musculoskeletal system.



Fig. 2. Assembly line overview after development activities. In the figure, development activities like the product lifting table can be identified.

of the load racks was reversed to provide additional space for parts. The estimated investment cost for these two development activities was EUR 35,000.

A cost-benefit ratio for the activities was calculated with the following formula:

$$\text{Cost – benefit ratio} = \frac{\text{total monetary benefit acquired}}{\text{Total costs}}$$

A cost-benefit ratio of over 1 indicates financial benefit to the company (Verbeek et al., 2009; Ramos et al., 2017). Total costs included monetary investments for the development activities, and the monetary benefits were calculated from the productivity figures and MSD sick leave days. Productivity was calculated using the wage costs of workers at actual productivity levels compared to productivity level 1, which

refers to a normal work pace. The costs per sick day was calculated using national estimations by the Confederation of Finnish industries (2023), which state that one sick leave day in industrial work in Finland costs EUR 370. Employee wage costs were collected with the following formula:

$$\text{Costs} = \text{Hourly wage} * \text{Number of employees} * \frac{\text{hours worked}}{\text{Day}} * \frac{\text{Workdays per year}}{\text{Productivity}}$$

3. Results

3.1. Physical workload

In the assembly line, physical workload decreased, and the proportion of harmful working postures reduced from 2015 to 2021. For example, development activities contributed to better ergonomics, and working at awkward working postures, i.e., leaning forward with and/or twisted position and working with hands above shoulder level, decreased. In addition, time spent on handling different loads decreased. The total workload for all work tasks on average at the assembly line decreased from 2.6 to 1.7, as shown in Table 4. In the welding unit, the average physical load remained almost the same (3.0 in 2018 compared to 2.8 in 2022) (Table 4).

Table 4
Results of the physical workload measurements, showing the mean average value (%) for all individual work tasks and their development between the two measurements.

Assembly line	2015 (% of the working time, on average)	2021 (% of the working time, on average)	Change (2015–2022)
Leaning forward and/or twisted body position	18.1	5.8	–12.3
Hands above shoulder level	12.2	5.9	–6.3
Handling loads	65.2	55.1	–10.1
Standing	73.6	76.8	+3.2
Moving	11	8.2	–2.8
Sitting	7.2	9.6	+2.4
Kneeling	3.5	3	–0.5
Squatting	4.8	1.8	–3
Lying down	0.0	0.5	+0.5
Load handling coefficient (1.0–2.0)	1.2	1.2	0
Workload level (0–4)	2.6	1.7	–0.9
Welding unit	2018 (% of the working time, on average)	2022 (% of the working time, on average)	Change (2018–2022)
Leaning forward and/or twisted body position	15.2	12.4	–2.8
Hands above shoulder level	13.1	13.1	0
Shoulders stretched forward	3.9	2.0	–1.9
Handling loads	80.3	80.1	–0.2
Standing	62.4	60.5	–1.9
Moving	31.9	33.8	+1.9
Sitting	5.4	5.6	+0.2
Kneeling	0.2	0.2	0
Squatting	0.2	0	–0.2
Load handling coefficient (1.0–2.0)	1.4	1.4	0
Workload level (0–4)	3	2.8	–0.2

3.2. Productivity

As can be seen from Table 5, productivity remained higher than the normal pace of work in the assembly line. As an exception, in 2021, the productivity was purposefully lower due to planned model changes in production. Still, the productivity exceeded the normal working pace by 10%. At the same time, the number of sick leave days resulting from MSDs decreased. In 2022, only 12 MSD sick days were recorded in the databases of assembly line workers; in 2018, there were 331 sick leave days. In the welding unit, productivity showed a downward trend. In 2022, productivity had decreased below the normal level and was 0.97. In addition, workers' MSD sick days increased over the years and in 2022, workers had 373 MSD sick days (Table 5).

In the assembly line, maintaining high productivity meant a total of EUR 896,370 lower wage costs over the five-year monitoring period compared to the normal pace of work. In addition, the reduction in MSD-related sick leave days resulted in cost savings for the company. During the monitoring period (2018–2022), there were 543 sick days for MSD, resulting in total costs of EUR 200,910. Compared to the level of sickness absence in 2018, the total cost savings for the company amounted to EUR 411,440 for the total period. Regarding productivity in the welding unit, the company had EUR 384,391 fewer wage costs compared to the normal pace of work. For MSDs, costs increased. In the welding unit, the total number of MSD days was 1436, which resulted in total costs of €531,320. Compared to the level of MSD in 2018, the company incurred EUR 70,670 more in costs for the total monitoring period. In the welding unit, a decrease in the highest achieved productivity level from 1.22 to 0.97 meant that about six more workers would have had to be hired to achieve the same output.

Fig. 3 Summarises how work development activities have affected workload, productivity, and MSD on the assembly line and welding unit. Based on the estimations of the investment values, the cost-benefit ratio for the assembly line was 7.4, but for the welding unit, it was even higher, 9.0.

4. Discussion

Manufacturing companies operating in global markets must continuously improve their performance to maintain and develop their competitiveness. Advances in technology and automation may further accelerate their development processes, however, ergonomics should not be forgotten (Hendrick, 2003; Tompa et al., 2009b; Neubert et al., 2012). In this study, we collected data from one major manufacturing corporation and its two departments. These departments shared many similarities when it comes to personnel demographics. Further, in both these departments, employees performed physically demanding tasks, even though the tasks differed to a certain extent. In the assembly line, the corporation actively developed human work with microergonomics

work stage level data collected through work measurement analyses and physical workload measurements, with 30 development activities identified throughout the five-year study period. In the welding unit, development activities were rare, with only two activities conducted comparable to those in the assembly line.

In our macroergonomics analysis, we examined these processes from the perspectives of employee well-being and overall system performance. Employee well-being was examined by comparing the developments in physical workload and MSD-related sick leave days. From the system performance perspective, we focused on the developments in productivity ratios, economic benefits and cost-benefit ratios between these two departments. Our analysis showed that the physical workload in the assembly line was reduced during the study period, whilst this development was marginal in the welding unit. There are several possibilities for these results. First, we argue that this resulted from the continuous development process where new development activities were conducted yearly in the assembly line using ergonomic knowledge acquired through work measurement analyses and physical workload measurements. Second, we state that whilst this development was identifiable, the levels of assessed physical workloads remained still rather high (1.7 on average) compared to 0, which is considered optimal in our evaluation scale. Hence, we speculate, that achieving an optimal physical workload level with only minor level development activities might still not be possible due to the nature of manual work in the case company. A similar positive development trend can be identified when looking at the developments in the number of sick leave days resulting from MSDs and our productivity ratio calculations.

Interestingly, the investment cost-benefit ratios favoured the welding unit (9.0 compared to 7.4. In the assembly line). Looking merely at these ratios might still be misleading, as the overall trends in all examined areas (sick leave days, physical workload, productivity ratios) all support active and continuous development (that was not the case in the welding unit). Therefore, we conclude that continuous development activity can simultaneously contribute to the system performance and employee wellbeing (Dul et al., 2012).

4.1. Managerial contributions

In this study, development activities play a significant role in reducing workload. Similar observations can be found also in the past ergonomics literature (Falck et al., 2010; Tompa et al., 2013; Kolus et al., 2023). There are numerous ways to develop work through ergonomic methods, with technological constraints and personnel creativity and insights acting as potentially limiting factors (Davis et al., 2014; Neumann et al., 2016; Kadir et al., 2019; Hughes et al., 2017; Abdous et al., 2023). Large-scale technological facelifts are often expensive, and arguments on potential long-term savings that can be acquired through improvements in the workload may be inadequate or too difficult to

Table 5
Annual data on work development, productivity and MSD.

Year	2018	2019	2020	2021	2022
Assembly line					
Work development activities (n)	14	5	2	5	4
Productivity (1 = normal working pace)	1.16	1.19	1.19	1.10 ^a	1.2
Effect on wage costs (EUR)	−166,072	−192,239	−192,239	−118,975	−226,845
MSD sick leave days (n)	331	113	32	55	12
Costs on sick leave days (EUR)	122,470	41,810	11,840	20,350	4440
Accidents at work (n)	0	1	0	0	0
Welding unit					
Work development activities (n)	1	1	0	0	0
Productivity (1 = normal working pace)	1.18	1.22	1.04	1.07	0.97
Effect on wage costs (EUR)	−143,737	−169,919	−36241	−68494	34,000
MSD sick leave days (n)	249	394	210	210	373
Costs sick days (EUR)	92,130	145,780	77,700	77,700	138,010
Accidents at work (n)	0	0	1	0	5

^a Productivity decline planned due to new models in production.

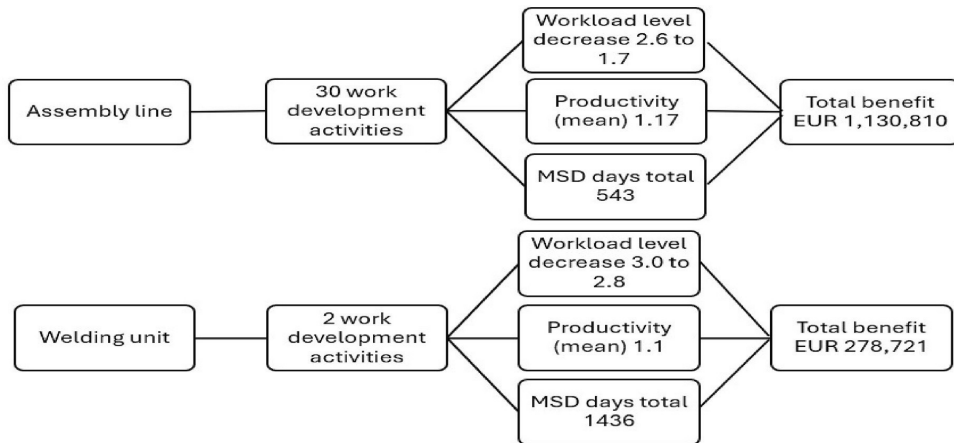


Fig. 3. Summary of the development activities 2018–2022 and identified effects on physical workload, productivity ratios, number of sick leaves on MSDs and the total benefits acquired.

justify from the business development perspective. In this regard, it is likely considered more straightforward and cost-effective to invest in smaller-scale investments like lifting tables or lighting devices, as was the case in this study. This study shows that such investments can also be highly profitable when the examination period is long enough.

Although the development activities in this study can be considered low-cost (EUR 5900 on average in the assembly line and EUR 17,500 in the welding unit) and to a certain extent as “low-hanging fruits” (see Hendrick, 2008), they still seemed to contribute to employee well-being and system performance in the assembly line. A key observation in this regard was that these development activities were specifically tailored to meet the microergonomics needs observed through physical workload measurement and work measurements analyses systematically during the inspection period. We interpret this as a practical use case how to implement microergonomics in macroergonomics system level development.

In manufacturing, optimising the macroergonomics socio-technical system for economic performance requires an understanding of the microergonomics capabilities and limitations of the workforce at hand and their potential to use assigned technologies (Davis et al., 2014; Neumann et al., 2016; Kadir et al., 2019; Abdous et al., 2023). In this study, physical workload was measured using a unique method. It seems that the workloads assessed and their development parallel the development trends observed from the productivity perspective. Reducing the workload in the assembly line helped to maintain and develop productivity. On the other hand, it is not possible to know with certainty at what level of physical workload employees' workability would start deteriorating (Haukka et al., 2008; Rivilis et al., 2008; Driessen et al., 2010; Wurzelbacher et al., 2020). In future studies, it would be worth examining whether a certain physical workload level (measured in this study on a self-made scale from 0 to 4) could predict potential challenges to work ability and productivity. As another topic for future studies, microergonomics considerations should be expanded to cognitive and psychosocial perspectives when examining the overall employee well-being perspective.

4.2. Limitations

We studied physical workload measurements, work developments and MSD-related sick leaves in a manufacturing plant's assembly line and welding unit. In the welding unit, the workload measurements were conducted in 2018 and 2021, whereas in the assembly line they were

conducted in 2015 and 2022. Because sick leave data was only available from 2018 onwards, the study period was 2018–2022. A manufacturing plant is a continuously evolving complex work system. Our study was retrospective; thus, it is not possible to separate the effects of possible other changes in the plant on productivity and employee well-being. It is possible that some development activities were undertaken in the assembly line before the start of the 2018 monitoring period. However, their possible effect on MSDs cannot be verified, as they were only identifiable from 2018 onwards. The main author worked in the corporation. This is both a strength and a limitation. Through this connection, the authors had access to company-specific data for research purposes. On the other hand, this relationship includes the potential for biases, especially concerning objectivity.

Empirical data were collected partially through established methods (MOST analysis, demographics data and other company figures) and with non-validated, more practical tools. The method of measuring the physical workload was invented for work development purposes and not scientifically validated. However, as a sign of its usability, the company has been committed to using the data obtained from the method to support work development. The physical workload data were collected with a relatively long time between the measurements. On the other hand, this data was not the only data in this study, and a professional from an occupational health care service also participated in data collection and analysis. The ergonomist and occupational physiotherapist know the work and the workers well. This allowed for an in-depth analysis of the ergonomics data. This increases the credibility of the data. Validating the physical workload measurement method is a topic for future research.

This study was partially conducted during the COVID-19 pandemic. In the company, COVID-19-induced rules and regulations concerning social interactions, such as keeping distance, wearing PPE and not coming to work when sick, were applied. The production and welding personnel were still working as usual during the pandemic and the production was not affected. In this study, we only followed sick leaves due to MSD, not infections. Moreover, had the COVID-19 infection spread around the personnel, it would have affected both assembly and welding lines similarly.

5. Conclusions

This study showed how ergonomics improvements are potentially connected with industrial gains. We also found that while work

development positively effected the system performance, it also enhanced employee well-being. In this regard, continuous ergonomics-oriented work development is an opportunity to influence well-being and productivity. It is possible to maintain a high level of productivity without compromising work ability if work is developed using ergonomic methods. On the other hand, if ergonomics is not used when developing work, it can have a negative impact on both the system performance and employee well-being. Future studies in diverse industrial settings are needed to confirm our findings.

CRedit authorship contribution statement

Teemu Suokko: Writing – review & editing, Writing – original draft, Resources, Project administration, Investigation, Formal analysis, Data curation. **Tuula Oksanen:** Writing – review & editing, Writing – original draft, Supervision. **Arto Reiman:** Writing – review & editing, Writing – original draft, Methodology.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: The main author is employed by the corporation under the study.

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This dissertation demonstrates that ergonomics in manufacturing contributes to well-being, productivity and financial performance. The findings indicate that ergonomics remains underutilised in Finnish industry. However, systematic, data-driven ergonomic development can reduce physical workload and MSD-related sick leave while improving productivity, organisational performance, and longer-term business competitiveness.



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