

Article

Logistics Work, Ergonomics and Social Sustainability: Empirical Musculoskeletal System Strain Assessment in Retail Intralogistics

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Abstract: *Background:* A large proportion of logistics jobs still rely on manual labor and therefore place a physical strain on employees. This includes the handling of heavy goods and physiologically unfavorable postures. Such issues pose a risk for employee health and work capability. This article provides a detailed empirical analysis and a decision process structure for the allocation of ergonomic measures in warehousing and intralogistics processes. *Methods:* The methodological basis is a load assessment of the musculoskeletal system in retail intralogistics. Based on the established measurements systems CUELA and OWAS, the specific loads on employees are assessed for four typical logistics workplace settings. These are combined with standards for efficient decision rules regarding contracting and developing ergonomic improvements. *Results:* The results suggest an increased risk of long-term low back injury for the selected four standard work situations in warehousing and likely apply to similar work environments in logistics. Using measures, posture descriptions, and international standards, we show how already few threshold values serve as sufficient conditions to decide if ergonomic interventions are required. *Conclusions:* The specific contribution is characterized by the combination of literature review results, empirical results, and the identification and discussion of specific mitigation measures. These elements are focused on the highly relevant ergonomic situation of logistics workers and present a unique contribution towards the knowledge base in this field due to the multi-perspective approach.



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Keywords: retail logistics; warehousing; ergonomics; health management

1. Introduction

Technology advances are affecting most logistics activities and processes through automatization and digitalization. Examining ergonomics in logistics jobs is warranted due to a high share of manual labor and a direct positive effect on productivity for example in intralogistics: Recent approaches adding the human factor and ergonomics to economic reasoning in warehousing show that quality and performance can be improved [1,2]. This can be connected to the overarching topic of social sustainability addressing working conditions as well as safety and health issues of logistics workers. This implies that the human factor might be highly relevant for increasingly automated and digitalized work systems in logistics. Employee health issues such as physical stress and strain translate to dissatisfaction and reduced commitment to the organization and customers, thus affecting total logistics service quality. Additionally, this extends to workers' economic welfare and quality of living within the areas of warehousing and intralogistics as investigation examples into learning effects, behavioral issues, energy expenditure, physical effort, fatigue, or other ergonomic indicators show [3]. This paper emphasizes workers' low back pain issues as it has been established as the prevalent (non-specific) ergonomic issue

affecting incapacitation for work for intralogistics professions. This is transferable towards a larger number of logistics jobs, often incorporating physical or driving tasks. Low back pain is non-specific for the majority of cases and can cause disabilities, especially in working-age groups. Even more important for logistics work, people with physically demanding jobs and low socioeconomic status are found as most susceptible to low back pain [4]. For the European Union, four factors outlining workforce health issues, three of which are interesting in the context of this paper—an aging workforce, the growing burden of chronic disease, and widening health inequalities are listed [5]. A current disparity of 1:2 between workers no older than 25 years and workers aged at least 50 years is growing, aggravating the risks of worsening health and withdrawal from the labor market. Health impediments render large parts of the elder population economically inactive already today [6]. Chronic diseases put a burden on the productive capacity of many countries: “For example, 100 million European citizens suffer from chronic musculoskeletal pain and musculoskeletal disorders (MSDs), including 40 million workers who attribute their MSD directly to their work” ([4], p. 357). Widening health inequalities play a major role in a vicious circle as for individuals, health is partly determined by income—thus by work and capacity to work. Significant inequality in the labor market extends to distortions in public health as a whole [7] as, for instance, [8] finding positive effects of private insurance on health [9]. This is important as the incentives to keep up workability are increasing for all parties involved.

This paper focuses primarily on the strain of the musculoskeletal system in intralogistics with an application to warehouse activities in retail. This is due to the fact that workers are currently, and especially in the future, very scarce in this field of logistics work. Companies, as well as workers themselves, have high priorities to keep their well-being up in terms of health and ability to work. Applying the established measurement system CUELA—computer-assisted recording and long-term analysis of musculoskeletal strain, live workplace settings from a retail logistics company are selected as examples for human postures in manual work, characterized with the help of the Ovako Working Posture Analysis System (OWAS). Comparing the two systems, OWAS is the older one and characterized by specified typical postures, to be recognized by observers and possibly newly also with camera-based motion-capture systems. Whereas CUELA already represents a digital measurement system based on motion markers.

The contribution of this paper consists of the facets that (a) retail warehouse logistics as an exemplary intralogistics job segment is addressed including ergonomic questions, (b) quantitative analysis results are presented regarding the workload of operatives, and (c) measurement options are discussed to help mitigate worker scarcity as a strategic challenge to keeping up health and workers’ abilities. The remainder of this paper is structured as follows: Section 2 provides a summary of current literature related to low back pain and its impact on health and productivity. Section 3 elaborates on research materials and methods. Section 4 presents results and Section 5 contains a discussion with respect to preventive countermeasures.

2. Theoretical Framework for Human Factors in Operations

2.1. General Systems Theory and Human-Technology Interaction

Engineered systems are sociotechnical systems and comprise social and technical elements, see Figure 1 [10]. Human factors (synonymous with ergonomics) as a scientific discipline is concerned with the understanding of the social element within these systems aspiring to optimize human well-being and the overall system performance [11]. This includes investigating the interaction of humans and other elements of a system, as well as planning, developing, applying, and evaluating methodologies that optimize the human well-being and employees’ performance within the system [11]. General systems theory is the theoretical basis for these approaches [12] and sociotechnical systems theory is one subfield within this domain. With the recent advances in artificial intelligence (AI) and robotics, sociotechnical systems theory has been developed further, leading to the formu-

lation of sociotechnical systems [13] that currently are extended to cyber sociotechnical systems theory [14], in which autonomous and intelligent software (cyber), humans (social), and hardware elements (technical) work jointly to achieve a common goal [15].

The organizational structures, policies and processes

Collaboration, socio-technical systems, environment

Increase the ease of use and user acceptance of technology:

- Robot acceptance, e.g., Yu and Xu (2020)
- Human-robot collaboration, e.g., Detzner et al. (2019)
- Human-robot collaboration and work system design, e.g., Rosen and Wischniewski (2018)

Increase user acceptance of technology and efficiency:

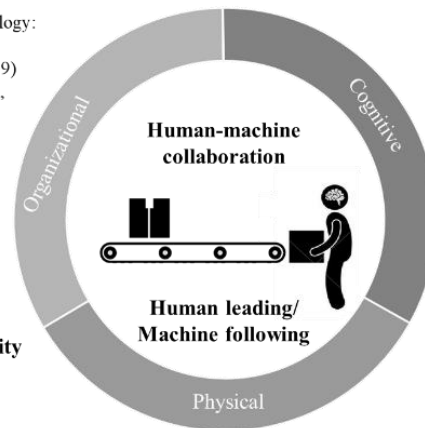
- Human-robot efficiency, e.g., Barosz et al. (2020); Golda et al. (2018)

Increase user acceptance and the role of trust:

- Trust and AI, e.g., Klumpp and Zijm (2019)
- Trust and robots, e.g., Matthews et al. (2020)

Organizational structures and physical activity

- Collaborative robot cells to lower work-related Musculoskeletal disorders, e.g., Colim et al. (2020)



Physical Activity Involved Within Work Systems

Humans Anatomy, Anthropometry, Biomechanics And Physiology

- Increasing Workers' Comfort, e.g., Nookea and Vanichinchai (2020)
- Decrease The Performance of Repetitive Tasks, e.g., Rocha Et Al. (2020)
- Decrease The Physiological Burden, e.g., Diefenbach, Emde, And Glock (2020)
- Monitor Physiological Activities, e.g., Li And Liu (2019)

Mental processes involved in work elements

Perception, memory, reasoning

Increase the safety and reliability of systems:

- Mental workload and accidents, e.g., Fan et al. (2017)
- Human errors, e.g., Caro et al. (2018)
- Mental workload and time pressure, e.g., Silva (2019)

Reliability of systems and learning in work systems:

E.G., Grosse, Glock, and Jaber (2013), Grosse and Glock (2013), Grosse and Glock (2015), Stinson and Wehking (2016)

Human perception within work systems:

- Work autonomy, e.g., Cragg and Loske (2019)

Mental processes and physical activity

- Ergonomic value stream mapping, e.g., Arce et al. (2018)
- Mental fatigue and learning effects, e.g., Winkelhaus et al. (2018)
- Standing and mental performance, e.g., Labonté-lemoyne et al. (2020)

Figure 1. Theoretical framework for the human factor in operations processes.

This indicates that the technical element can take various forms, including advanced technologies, e.g., artificial intelligence (human-AI system) and robots (human-robot system), as well as non-advanced technologies, e.g., machines (human-machine system) [16]. Additionally, the interaction may occur in the form of coexistence (shared work time and workspace), cooperation (shared work time, workspace, and work objective), or collaboration (shared work time, workspace, work objective, and work contact) [17]. Furthermore, humans or technical elements may lead this interaction resulting in human leading/technology following or technology leading/human following relationships [18].

To further specify the underlying work task, [19] differentiations between routine tasks that follow a set of rules that can be computerized and non-routine tasks that are, at a certain point in time, not sufficiently well-understood to be computerized and executed by machines [20]. Non-routine tasks are divided further into abstract non-routine tasks that require intuition or creativity, and manual non-routine tasks [21]. This taxonomy is also applicable to picker-to-parts order picking systems and grasping and stacking processes represent a manual non-routine.

In summary, we position our empirical research and our contribution to the existing literature within the area of non-advanced human-machine interaction assigned to sociotechnical systems theory as a subfield of general systems theory. Additionally, we are concerned with the aspect of collaboration in a human leading/technology following relationship in manual material handling of picker-to-parts order picking systems as a manual non-routine work task.

2.2. The Human Factor in Human-Machine Collaboration

For many years, productions and operations management (OM) was concerned with the optimization of flows and the reduction of bottlenecks by applying methodologies from the domain of operations research [22]. This led to the development of theories that focus on swift and even material flow while proposing that humans play a subordinate role in the outcome of operations, e.g., the theory of swift and even flow [23]. Although it

is possible to automate warehouse processes, for example, human workers' activities are still required [24].

Therefore, leading scholars claim that human behavior is essential for the understanding of operations [25,26]. Following these calls, we can observe the emergence streams incorporating the social aspect of human-technology interaction, e.g., behavioral operations management from an OM perspective [27–29] and human factors from an engineering perspective [30,31]. Because behavioral operations management is more concerned with cognitive aspects and resulting decisions of human operators, our empirical research is more associated with the physical ergonomics area of human factors. To foster the understanding for this subfield and further position our contribution, we review literature including physical ergonomics and the overlaps towards organizational and cognitive ergonomics. Additionally, our review is directed towards the design of warehouse and picking workplaces, possible measures to mitigate ergonomic issues, and leveraging the burden of logistics workers in warehousing processes as outlined in later sections of this paper.

2.2.1. Organizational Ergonomics

Organizational ergonomics, also commonly referred to as macro-ergonomics, centers on optimizing socio-technical systems and organizational structures, e.g., policies, organizational structures, and processes [32]. The primary goals are to increase the ease of use of new technology, often leading to work system design-related questions and to foster the technology acceptance of blue-collar, as well as white-collar workforces.

Positioned in the research stream regarding the ease of use of new technology, Rosen and Wischniewski elaborate on how to design hybrid work systems using lightweight robots [33]. The analyses reveal that task variability, timing, and method control have a substantial impact on employees' wellbeing. Stadnicka and Antonelli develop a framework for the collaborative teamwork process between human workers and intelligent machines and propose a concrete redesign of industrial assembly cells [34]. Ender et al. outline a human-centered design solution for industrial workplaces, particularly considering the needs of workforces within human-robot collaboration [35]. Regarding technology acceptance, the question concerning the level of control transferred to machines is relevant, addressing different levels of acceptance and trust in human-computer interaction, as well as the possible danger of an artificial divide at the individual and firm level [36]. Other researchers investigate predictors of trust in an autonomous robot detecting threat on either a physics-based or psychological basis. The results indicate that the negative attitudes toward robots scale are specifically associated with lower psychological trust [37]. Barosz et al. present a simulation-based analysis of productivity in a manufacturing line where machines can be operated by humans or robots [38]. The authors propose to implement a robotic line from an industry based on the results for the overall factory efficiency metric. Yu and Xu review the influencing factors of robot acceptance from three aspects: robot factors, human factors, and human-robot interaction factors [39]. Datzner et al. present a novel task description language for human-robot interaction in warehouse logistics to let human workers interact with robots naturally [40].

Altogether, it can be stated that there are studies addressing the changes for socio-technical systems and organizational structures through the increasing automation of operational processes. However, the intersection of organizational structures and physical ergonomics is hardly addressed and we aspire to contribute to this intersection by empirical and practice-oriented research.

2.2.2. Cognitive Ergonomics

The goal of cognitive ergonomics is to increase the safety and reliability of systems, as well as to decrease fatigue and physical stress. Within the first stream of memory and reasoning of the human workforce, Caro et al. develop a model for the cognitive architecture for a dry foods company's semi-mechanized order picking operation when aspiring to decrease human errors and, therefore, increase service level [41]. Silva examines the mental

workload, tasks, and activities of press operators in a recycling cooperative that works under various time pressures, physical loads, stresses, and tensions [42]. Furthermore, Fan et al. study the mental workload, attention, or fatigue of seafarers and propose to optimize the crew training system based on simulators [43]. A second research field in cognitive ergonomics is human learning within operations systems. Stinson et al. conducted an experimental analysis of manual order picking processes in a learning warehouse [44] and Grosse et al. present an experimental investigation of learning effects in order picking systems at a manufacturer of household products [45]. Further contributions related to learning curves in order picking develop analytical models, simulations, or theoretical frameworks, aiming to describe the process of learning in order picking [46–48]. A third research stream in cognitive ergonomics investigates the perception of humans, e.g., the perceived work autonomy of human order pickers in manual man to good order picking systems [49].

In summary, cognitive ergonomics and especially learning processes are well-examined fields in engineering-driven human factor analysis. The intersection of cognitive and physical ergonomics is highly relevant for routine tasks. However, addressing this intersection requires a detailed understanding of physical factors in human-machine collaboration where we aspire to contribute to a more solid foundation.

2.2.3. Physical Ergonomics

In manual and labor-intensive blue-collar operations processes, the investigation of physical activity involved within work systems and its impact on human anatomy, anthropometry, biomechanics, and physiology is of specific interest [50]. Therein, the goal of physical ergonomics is to improve the working environment by (1) increasing workers' comfort, (2) decreasing the negative impacts of repetitive tasks, (3) decreasing the physiological burden, and (4) monitoring physiological activities. As the contribution of physical ergonomics depends on the research perspective, we additionally structured the research streams in planning work systems, designing work systems, evaluating work system practices, and the relationship of employee health and performance. Before creating a working system, the planning of work systems is required, which is increasingly done by using digital human models [51]. Although there are only a few contributions in warehouse logistics, e.g., an approach developing a digital human model within a logistics sorting operation system to improve the working efficiency and workers' comfort [52], the methodology is well developed for production scenarios [53–59].

Designing the work system in the next step is examined for more than four decades [60–62]. Plonka proposes the application of autonomous mobile robots for the automation of transporting trolleys in hospital logistics, aspiring to relieve the human workforce from frequently carrying high loads and performing repetitive tasks [63]. When focusing on the evaluation of practices in work systems, Diefenbach et al. investigate the physiological stress of handling bins on different levels of a tow train wagon by a computational study that proposes an optimal storage plan, which can significantly ease the physiological burden on the workforce [64]. Another research stream within workplace practices in physical ergonomics is represented by studies dealing with wearable sensors for continuous health monitoring, movement analysis, or rehabilitation [65]. After planning and designing the work system or evaluating workplace practices, the relationship of employee health and performance is the last relevant field in the physical-oriented stream of ergonomics. One example is a study examining how to increase picking efficiency and decrease the physiological burden on the workforce by storing products in bins at an appropriate height. The results indicate that bending and tiptoe significantly decreased by 71.3% and 100%, and the efficiency was improved by 15% [66].

Positioned at the overlap of cognitive and physical factors, research streams investigate physiological factors that influence cognitive factors of the human workforce. Researchers address the overlap of cognitive and physical factors when studying the effects of human fatigue on learning in an explorative experimental analysis—findings show that mental

fatigue appears to have a negative influence on learning effects [67]. A further example for an investigation positioned at the intersection of cognitive and physical factors is a study to determine if using a standing desk would affect the productivity of workers, based on the type of work they perform. The researchers found out that a standing desk had no negative effect on performance or perception, but it did lead to increased brain activity [68]. Aspiring to merge ergonomics and performance, current research approaches propose the application of ergonomic value stream mapping [69]. At the interface of organizational and physical factors, research streams investigate the impact of automation on physical activity involved within work systems. Other authors claim that work-related musculoskeletal disorders are one of the leading occupational health problems and develop a physical ergonomics framework at an assembly workstation of a large furniture enterprise and derive requirements for the creation of a collaborative robot cell [70]. Similar results are presented by a study applying the concept of overall equipment effectiveness, to find out how to model robotized, and manually operated workstations through computer simulation software [71].

Altogether, we identify a research gap for empirical investigations focusing on the aspect of physical ergonomics in retail logistics, especially with a comprehensive perspective on blue-collar workers and routine tasks including order pickers, as well as forklift operators, or industrial truck drivers. Furthermore, measures derived from quantitative analyses, possibly introduced in the context of an operational health management program, are, to the best of the authors' knowledge, hardly addressed in logistics-oriented scientific contributions. Although performance and quality are discussed as the primary outcomes of operations systems, our contribution lies in quantifying workers' well-being as a third dimension for sustainable productions and operations systems.

2.2.4. Impact of Low Back Pain

Low back pain is identified as a widespread symptom occurring in countries of all incomes and overall age groups [72,73]. 100 million European citizens have been reported [5,74] to suffer from chronic musculoskeletal pain and musculoskeletal disorders, generally affecting their work performance and to a significant proportion (40 Million) [75] resultant from work activities. In 2015, the prevalence of activity-limiting low back pain was 7.3%, corresponding to 540 million affected people. In 2015, low back pain accounted for 60.1 million lost healthy life years, an increase of 54 million since 1990. [4]. Figure 2 represents typical bowing in warehouse picking leading—among other factors—to such back pain issues as an example, including the torque measures included.

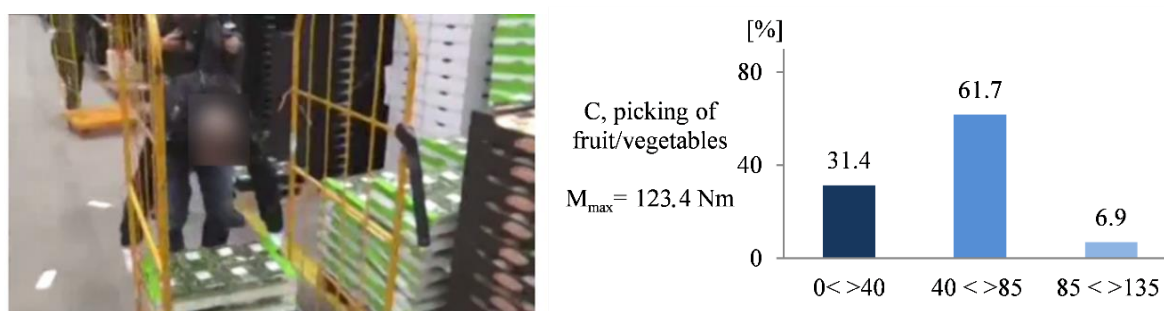


Figure 2. Picking of fruit and corresponding torque in the lumbar spine area (%). (Nm).

Most low back pain issues are classified as non-specific, as single-cause explanations are rare. Analogously, the condition affects a range of dimensions (biophysical, psychological, social, social participation, individual finance) and affects both healthcare and social support systems [4,76]. With respect to relatively affluent societies, concerns have been raised regarding the burden of low back pain treatments on healthcare systems [77]. While low back pain is identified by its location, a specific source is usually not identified, and the condition is thus classified as non-specific [78]. Most cases of persistent low back pain

are accompanied by pain in other sites, and the prevalence of general health problems, both physical and mental (comorbidity) [79]. A number of potential contributors to this multi-causal condition have been investigated, e.g., intervertebral disc, facet joint, vertebral endplates [80–84]. The rare specific pathological causes include vertebral fracture, axial spondylarthrosis, infections, and malignancy, among others [85–87].

As it remains non-specific for the majority of cases, causes disability, especially in working age groups and as people with physically demanding jobs and low socioeconomic status are listed as most susceptible to low back pain [4], examining workplace settings for jobs intensive in manual labor in logistics appear worthwhile. While many physical contributors seem likely, it is essential to note that psychological factors (psychological distress, depression, anxiety) are often present, contribute in ways, which are not fully understood, and merit close investigation and acknowledgment in remedial and preventive activities [88,89]. Instances of treatment methods focusing primarily on beliefs and behaviors rather than direct pain alleviation have been reported for chronic pain treatment before [90]. Also, demographics need consideration, as “low back pain is most prevalent and burdensome in working populations, and in older people low back pain is associated with increased activity limitation” [4], p. 2364.

Statistics for Germany (where the study took place) list musculoskeletal pain and mental illness as the top two diagnostic causes of work disability, measured in days away from work (Figure 3) [91].

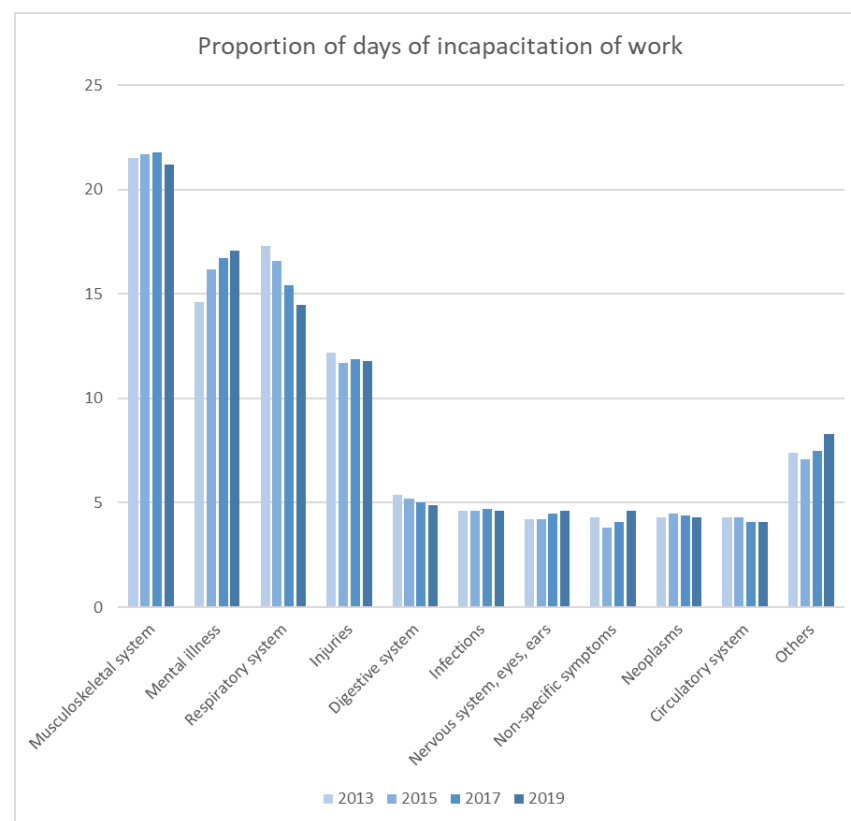


Figure 3. Causes of incapacitation for work (days of absence, Germany) [91].

Structural and muscular strain, e.g., in the lower back area, can be caused by the handling of heavy weights and prolonged maintenance of static postures. Both pose a major cause for injuries, pain, and related symptoms in logistics and production. Working under such conditions for extended periods is extremely likely to induce back injuries and pain, as studies such as the one by Garg et al. [92] show.

2.3. Low Back Pain and Ergonomics in Retail Operations

A number of activities common to occupations in warehouse logistics and in retail, both inside storage facilities and at the point of sale (e.g., replenishment, retrieval, picking), promote exposure of the lumbar spine (especially L4/L5 & L5/S1; compare, e.g., to compression forces at both unhealthy levels and durations [93]). The high operating cost contribution of warehousing activities [94] has been an incentive for research and optimization efforts into layouts [95], storage assignment [96], and processes such as replenishment and retrieval [97], thus generally aiming at the minimization of travel time and/or distance [98,99]. As long as human workers are involved in warehousing processes such as manual order picking, these objectives need to be characterized as short-term oriented and non-sustainable, as adverse health effects and their cost (e.g., exposure of the lumbar spine to unhealthy levels of compression forces) are either ignored or externalized [100,101] to employees and (public) health insurance. Under time and/or distance objectives, items may be located such that movements and efforts (bending, rotational movements with heavy loads) are imposed on workers who expose, e.g., their spine to hazardous conditions. “Low back disorders, which are the most common type of musculoskeletal disorders, have been shown to occur especially in risk environments where human workers have to move heavy and difficult to handle items in awkward body postures” [102], p. 516—which aptly characterizes the situations observed for the current research.

Figure 4 [103] presents a 2D-model (sagittal plane, right part of Figure 4) exposing the most critical components of forces exerted on the lumbar spine for cases of weight handling with some trunk inclination (e.g., forward bend) [104,105].

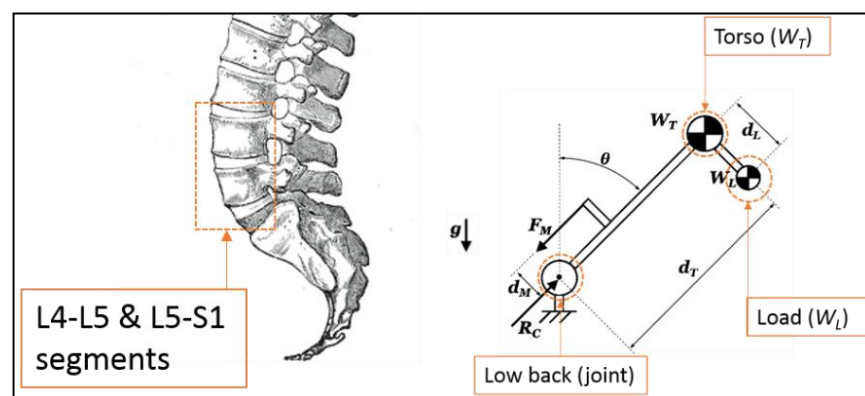


Figure 4. Segments of the lumbar spine and compressive loads [103], p. 6.

This is sufficient for a general qualitative understanding of the biomechanics of the lumbar spine during a lifting task, which is, of course, varied and extended, e.g., by rotation in the four activities examined in this paper. It should be noted that considerable lumbar compression forces are generated by the spinal muscles. Compensation of forces generated by loads carried usually requires the spinal muscles to generate large counteracting forces as their closeness to the vertebrae prohibits any considerable leverage. Further, inertial forces add to the load on the lumbar spine (e.g., by rapid movements and rotation) [106]. A detailed description is given in [104]. Here, the lumbar spine is modeled as a rotational joint that connects the torso mass W_T to the pelvis. To simplify matters, the pelvis is treated as if attached to the ground. The spinal muscles, responsible for back extension, are not explicit in the figure, but represented by force F_M , directed parallel (at distance d_M) to the spine. Force R_C , reacting at the joint, captures the lumbar compressive loads. The external object (e.g., crates, packages, etc. being carried by workers) is represented by mass W_L , rigidly (and perpendicular for simplicity) connected to the upper body.

3. Research Methods

3.1. Case study Description and Task Selection

Since most retailers have not yet automated the majority of their warehouse processes, blue-collar workers are facing labor-intensive work tasks characterized by a high amount of manual effort. Aspiring to keep the existing workforce healthy, companies started to implement operational health management programs. In this paper, we present the before-vs-after impact of such a program, as well as the elaboration of suitable healthcare measures derived from the quantitative evaluation of the individual physiological burden.

The case study is conducted within a warehouse of a large German full-range food retailing company and included $n = 60$ blue-collar workers. The cooled and non-cooled warehouses are responsible for the supply of 485 grocery stores located in the south of Germany. Orders are fulfilled by human order pickers in a picker-to-parts order picking system. Therein, stock-keeping units are grasped from unit loads stored at the ground level. The pickers are traveling within the aisles through vehicle support by non-intelligent intestinal trucks. The upper shelf levels are used as reserve areas for unit loads. This requires manual material handling and replenishment operations by human operators. They are using non-intelligent forklifts for storage and retrieval operations.

As the order picking system in the examined company is a manual man-to-good system, the investigation of order pickers' (group 1) physiological burden is of central interest. Furthermore, when aspiring to get an extensive overview of the physiological burden of blue-collar workers in retail logistics, the integration of supporting processes, e.g., the replenishment of storage locations through forklift operators (group 2) and industrial trucks (group 3) was included in the analysis. In the first step of the operational health management program, a kick-off event was organized to inform participants about the process of the health program and to survey the current physical complaints.

The data for the perceived body condition before the program at t_0 was gained through a paper-based questionnaire asking the participants for current physical complaints. The perceived body condition after the program was obtained equally. Our dataset included seven body parts and complaints were rated through a five-point Likert scale (1 = no complaints, 5 = strong complaints): (1) neck, (2) shoulder/arms, (3) upper back, (4) lower back, (5) hip, (6) knee, and (7) feet. All questionnaires were finished completely and within a time frame of two to eight minutes. Figure 5 illustrates the questionnaire results with $n = 20$ participants per group.

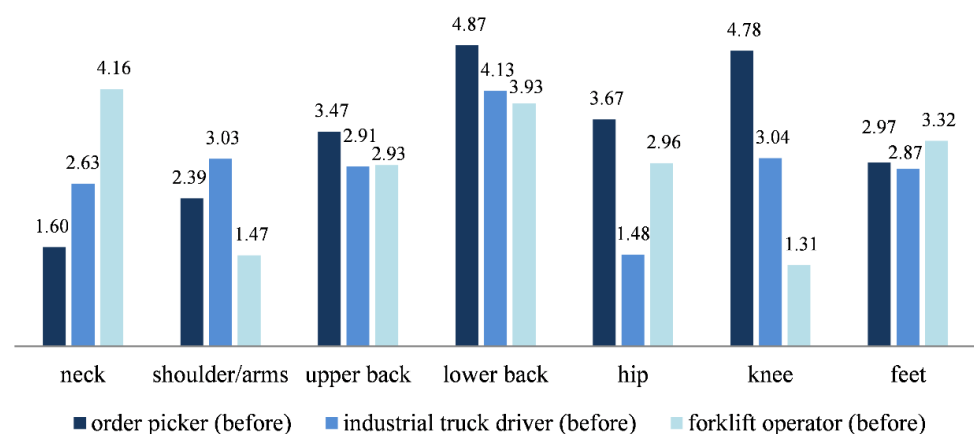


Figure 5. Perceived physiological complaints per body part at t_0 before the health program.

The results for order pickers indicate that the highest complaints result from the lower back, upper back, and knee. In the next step, the quantitative OWAS and CUELA were chosen for measurements and evaluation, as the concepts are applicable to a wide range of blue-collar work systems with extremely heterogeneous work tasks. The data was obtained in a one-week period and during the regular working process of the workers. The

warehouse examined in the case study is divided into a cooled area and a non-cooled area. One dataset for all order picking activities in the non-cooled warehouse contained about 100,000 picks per day for a total of 117 order pickers. The beach batch contains a mean of 76 picks. The dataset also contained product-related data on article dimensions, travel distances, and the weight per pick. This is also the case for the cooled warehouse, where about 72,000 picks are performed per day by a total of 45 order pickers. The 60 workers selected for the case study were selected randomly and the participation was voluntary without proposing or giving any kind of monetary incentive.

The cooled area stores the four product groups, (1) fruit and vegetables, (2) dairy products, (3) frozen products, as well as (4) fresh fish and fresh meat and the non-cooled warehouse stores, e.g., nutriment, pet food, detergents, as well as alcoholic and non-alcoholic beverages. As a suitable object of research is order picking with the maximum possible musculoskeletal load, we analyzed the average weight per stock-keeping unit (SKU) for all warehouses and product groups: As the highest average weights per SKU in the cooled warehouse are assigned to the product group of fruit and vegetables, this manual picking process is of certain interest. The same logic applies to the non-cooled warehouse, where alcoholic and non-alcoholic beverages have the highest average weight per SKU and were thus chosen for deeper analysis.

Altogether, four activities have been selected: Picking of alcoholic and non-alcoholic beverages (A) weighing up to 12.5 kg per package, driving an industrial truck controlled by a sitting operator (B), picking of fruit and vegetables (C), weighing up to 20 kg per package, and forklift operation (D), including the movement of weights up to 10 kg with comparably strong flexion of the upper body. We chose these activities as they are typical manual non-routine work tasks in material handling of picker-to-parts order picking systems. Additionally, the products chosen for (A) and (C) have a similar dimensioning and volume which is relevant for the manual grasping and stacking process.

This is due to the fact that they are commonplace in retail and warehouse logistics operations processes for blue-collar workers. The weight frames were selected related to average weight data in the relevant retail warehousing operations. The activities exhibit characteristic posture patterns (see Figure 6).

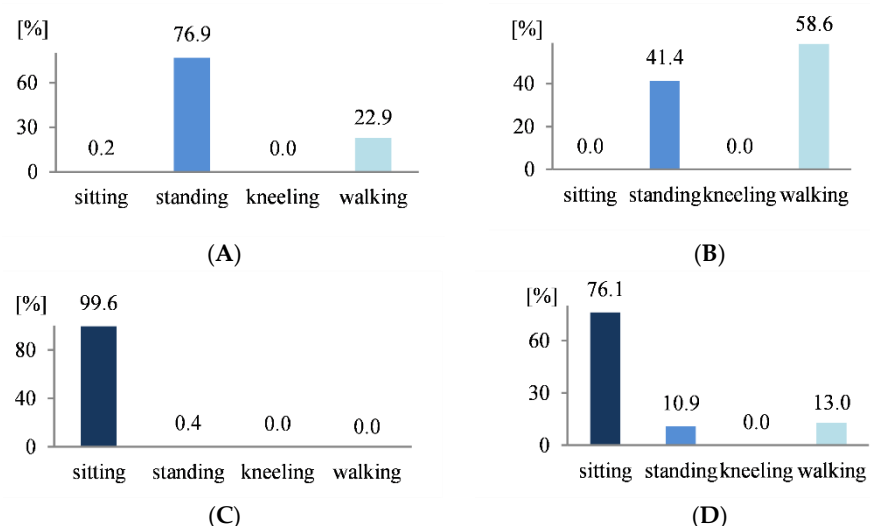


Figure 6. Characteristic basic posture patterns for selected activities. (A) picking of (non-) alcoholic beverages; (B) driving an industrial truck controlled by sitting operator; (C) picking of fruit/vegetables; (D) forklift operation.

Regarding four postures, the four activities can be classified by the relative frequencies of sitting, standing, kneeling, and walking.

3.2. Methods for Measurements and Evaluation: OWAS and CUELA

The included selection of the results of the measurements has been made with the CUELA measuring system [107]. CUELA (German acronym for computer-based measurement and long-term analysis of stresses upon the musculoskeletal system) is a personalized measuring system developed by The Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA) for automated recording of body postures and movements as well as for the estimation of handled load weights [107]. The measuring system was worn over the working clothes of the test person. CUELA allows to measure reaction forces by pressure-sensitive insoles. This enables to precisely differentiate certain steps within a given work task, e.g., sitting, walking, and standing. With a sample rate of 50 Hz, the sensors can capture and map dynamic movements [108]. With it, strains of the musculoskeletal system, such as those prevalent in occupational activities in, e.g., warehouse logistics, can be measured under working conditions. An associated software (WIDAAN) allows for automated evaluation of measured data according to ergonomic and biomechanical criteria. We utilize the CUELA measuring system because it can capture the dynamic movements of human-machine collaboration scenarios while allowing full freedom of movement for the human operator. This allows us to fully capture the physical movement of operators while maintaining the natural working environment.

The Ovako Working Posture Analysis System (OWAS) [109] has been developed from 1973 onward with the aims of (i) simplicity of use, such that it could be employed without requiring education in ergonomics, and (ii) unambiguity of results, erring on the side of simplicity over meticulousness. The Finnish Centre for Occupational Safety actively disseminates the method in publications, education, and training. The method had been developed to gain reliable information on body postures taken on during work and their time slices regarding activities. It enables registering and classification of body postures as well as their respective strain on the musculoskeletal system. By classifying and ranking activity profiles with the procedure, rankings of activities by the need for improvement (e.g., of employee health) [110,111] can be established. We employ the OWAS as it allows us to fully operationalize the manual routine task of material handling in a picker-to-parts order picking system. The grasping and stacking steps include repeated movements where capturing the duration, frequency, and magnitude/amplitude is highly relevant. There would be other methods to capture these manual processes without disruptive intervening measures in the routine. However, these do not represent the acting forces, which are of enormous relevance in the present work.

Empirical applications for these methodologies include improvement of existing and development of new workplaces, processes, and job descriptions with reduced musculoskeletal load [112], ergonomic and workplace-safety examinations as well as research and development. Applying OWAS corresponds to a procedure in two parts, (i) systematic observation of body postures during some activity, and (ii) their evaluation. Step (i) consists of a researcher recording body postures taken on during regular occupational activities. This ensures that both data on types of postures and duration/succession are obtained.

An OWAS-code as used in this article is a sequence of four digits, such as $\sigma_{ij,t} = (x, y, z, w)$ with classes and respective codes $x \in \{1, 2, 3, 4\}$; $y, w \in \{1, 2, 3\}$; $z \in \{1, 2, 3, 4, 6, 7\}$. Participant and activity are marked with (i, j) , t indicates the time (s). Activities may be denoted at pre-defined time intervals (e.g., 30 s) or whenever a change in posture is observed. As can be gathered from Table 1, postures for the back, arms, and legs are obtained separately and classified into 3 (arms), 4 (back), or 7 (legs) classes. Including another call for head posture and movements has been proposed before [113]. Further, a fourth class (load) documents weights handled into one of three subclasses (with $N = \text{kg} \cdot \text{m}/\text{s}^2$). The definition may be extended beyond weight handled to any currently effected force by some load.

Table 1. Postures and OWAS coding.

Class	Code	Posture
Back	1	Straight
	2	bent (forward/backward)
	3	turned or bent sideways (left/right)
	4	turned and bent or bent sideways and forward
Arms	1	both below shoulder height
	2	one arm at shoulder height or above
	3	both arms at shoulder height or above
Legs	1	sitting
	2	standing, both legs straight
	3	standing on one leg
	4	standing, knees bent
	5	standing, one knee bent
	6	kneeling (one or both legs)
	7	walking/moving
Load	1	<10 kg (\approx 100 N)
	2	10 to 20 kg (\approx 100–200 N)
	3	>20 kg (\approx 200 N)

Any OWAS-coded body posture used in this article consists of four digits. With the OWAS method, postures are classified according to simple criteria and assessed with regard to their health risk and may be correlated to muscle activity or subjective measures (e.g., from interviews like discomfort, see Table 2) [114]. Postures of the upper body, the legs, and the arms, as well as handled loads, are first classified separately and then put into relation. In addition to the OWAS procedure, individual body angles are assessed on the basis of standards DIN EN 1005-4 and ISO 11,226 [115,116] with the CUELA system described above. A distinction is made between “acceptable” (neutral), “conditionally acceptable” (middle-grade), and “not acceptable” (terminal) joint angle positions. Compare Table 2 for a compilation of joint angles, and position ranges as gathered from recommendations in standards DIN EN 1005-4 and ISO 11,226 [115,116].

Table 2. Joint angles and position ranges according to standards EN 10,054 & ISO 11,226 [115,116].

Parameter	Evaluation (Boundaries in $^{\circ}$, Absolute Values)		
	Acceptable	Cond. Acceptable	Not Acceptable
Head tilt	0 to 25	25 to 85	>85 (flexion) <0 (extension)
Head tilt (side)	10		>10
Neck torsion	45		>45
Neck bend	0 to 25		>25 (flexion) <0 (extension)
Trunk inclination	0 to 20	20 to 60	>60 (flexion) <0 (extension)
Trunk inclination (side)	10	10 to 20	>20
Back bend	0 to 20	20 to 40	>40 (flexion) <0 (extension)
Back torsion	10	10 to 20	>20
Shoulder joint (abduction/adduction)	0 to 20	−20 to −60	<−60 (abduction) >0 (adduction)
Shoulder joint (flexion/extension)	0 to 20	20 to 60	<0 (extension) >0 (flexion)
<i>Boundaries in Nm</i>			
L5/S1 external moment	0 to 40	40 to 85	85 to 135
L5/S1 compressive forces (men)	0.7 to 2.3	2.3 to 3.2	>3.2
L5/S1 compressive forces(women)	0.7 to 1.8	1.8 to 2.5	>2.5

Boundaries are provided for postures and forces as well as moments relevant to the results presented in this paper. The posture data are the basis for estimating compression forces in the lumbar spine. This is done by applying biomechanical models [103,117]. For the assessment of short-term exposure through manual handling of loads, the Dortmund Guidelines [118] apply, which provide age and gender-specific recommendations for lumbar disc pressure. The lumbar spine external moment is calculated based on weight handled, posture, and weight of the individual participant. Insufficient detail, examined activities are described as follows: Activity A, picking of alcoholic and non-alcoholic beverages, potentially incurs health risks mainly due to trunk/back inclination, back torsion, torque in the area of the lumbar spine, and head tilt is present, e.g., when moving packages close to ground level or during wrapping. Further, upper arm inclination (one and occasionally both, compare Table 2) is present and associated with the handling of weights (majorly within the 0–10 kg range). It is notable that this activity implies excessive upper arm inclination far above shoulder level—this may not be obvious from OWAS-classifications alone. Considerable lumbar spine/disc compression forces occur whenever loading of a cart requires bending forward and leaning to its far side while handling loads with arms extended.

Activity B, driving an industrial truck controlled by the sitting operator, near exclusively takes place while seated and involves considerable torque, shear, and compression forces. These are caused by high ratios of overstretching of the operator's back, back torsion, overstretching of the neck as well as head torsion, while the activity as a whole is conducted with the sitting operator positioned facing shelves, thus perpendicular to the direction of the vehicle's movement. Considerable forces are exerted on the spine since these movements are often executed abruptly. These sudden movements are due to the rather frequent occurrence of obstacles confining an operator's view. Due to the one-handed operation of the steering wheel located to the left, one-sided (supported) arm-inclination occurs.

Activity C exhibits some similarity to activity A regarding load movements close to ground level and the related moments in the lumbar area. Considerable forces are exerted in the area of the lumbar spine whenever the activity requires moving loads close to the floor with the back/trunk strongly inclined/forward bent. Further health risks result from (partly) sideward-bent positions (with back turned) assumed when (un-)loading pallets.

Activity D, forklift operation, offers apparent potential for improvement and mitigation of health hazards with regards to overstretching of the back and head torsion demanded of an operator assuming a position seated perpendicular to the direction of the vehicle's movement. In addition, lifting and lowering of comparably heavy loads near to a ground level with bending movements cause increased disc compression forces and lumbar spine external moments. OWAS-coded, the activities relevant to this contribution are provided in the next section.

4. Results

This section is describing the empirical results obtained from a German retail warehouse setting. Results and measurements resulting from applying OWAS are reported in this section. In particular, critical issues are mentioned with regard to the activities posing health risks (see Table 3).

For picking (activities A and C in Figure 6), most of the loads (for activity A 97% and for activity C 70%) weighed less than 10 kg. In activity A (picking non-alcoholic and alcoholic beverages), 281 load weights were moved during the measurement (equivalent to 219 load weights per hour). Most packages weighed between 5 and 10 kg. Beverage packages with a weight of up to 12.5 kg were moved. High intervertebral compression forces can occur, in particular, when load weights are moved away from the body, for example, with arms stretched out, while simultaneously assuming an unfavorable posture. For example, in Activity A, this was the case when a package was placed on the opposite side, and the

upper body was leaning in areas further from the body. This results in maximum disc compression forces in the lumbar spine area of 4.9 kN (Figure 7).

Table 3. Observed OWAS-body postures for activities A–D.

Class	Code	Posture	Ratios per Activity (%)			
			A	B	C	D
Back	1	Straight	75.0	92.1	84.4	92.2
	2	bent (forward/backward)	16.1	1.8	8.9	4.9
	3	turned or bent sideways (left/right)	8.5	6.0	6.2	2.8
	4	turned and bent or bent sideways and forward	0.3	0.0	0.5	0.1
Arms	1	both below shoulder height	94.7	96.6	92.9	97.6
	2	one arm at shoulder height or above	4.7	3.3	5.8	2.4
	3	both arms at shoulder height or above	0.6	0.2	1.4	0.0
Legs	1	Sitting	0.2	99.6	0.0	76.1
	2	standing, both legs straight	65.4	0.4	40.7	8.2
	3	standing on one leg	0.0	0.0	0.0	0.0
	4	standing, knees bent	11.5	0.0	0.7	2.7
	5	standing, one knee bent	0.0	0.0	0.0	0.0
	6	kneeling (one or both legs)	0.0	0.0	0.0	0.0
	7	walking/moving	22.9	0.0	58.6	13.0
Load	1	<10 kg (\approx 100 N)	99.5	100.0	100.0	99.8
	2	10 to 20 kg (\approx 100–200 N)	0.5	0.0	0.0	0.2
	3	>20 kg (\approx 200 N)	0.0	0.0	0.0	0.0

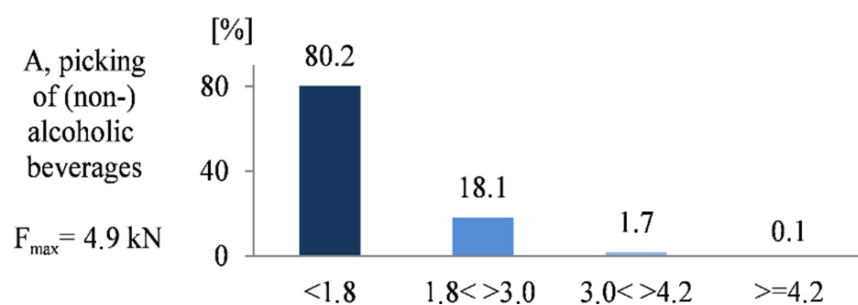


Figure 7. Disc compression forces in the lumbar spine area for picking activity A.

According to the Dortmund guidelines of Jäger et al. [118], these compression forces should not exceed 5.4 kN in men between 20 and 30 years of age. For men up to 40 years old, this guideline is 4.1 kN; up to 60 years old, 2.2 kN. During the measurement, the intervertebral disk compression forces were considerably low for about 80% of the time (<1.8 kN, compare Figure 7). During handling of load balances with a flexed-back posture, larger intervertebral disc compression forces (about 18% between 1.8 to 3.0 kN and about 2% between 3.0 to 4.2 kN) occurred regularly. Particularly large intervertebral compression forces (>4.2 kN) were measured, as mentioned before, during the loading of vehicles whenever a package was placed on the far/opposite side (see Figure 8 for an example). Occasionally, this resulted in measurements reporting a short-term overrun of the above guideline values (about 0.1% of instances).

During the measurement for picking of fruit/vegetables (activity C), a total of 184 load weights or 166 load weights per hour were moved. High load weights of up to 20 kg occurred when carrying several heavy packages at once and heavy individual packages such as banana or potato crates. The maximum value of a 3.0 kN disc compression force also occurred when the upper body was leaning forward (see Figure 9). Otherwise, 90.2% of the disc compression forces were quite low (<1.8 kN). During the handling of load weights in flexed back posture, larger intervertebral disc compression forces (about 10% between 1.8 to 3.0 kN, Figure 9) occurred regularly.



Figure 8. Left: (Un)-Loading with packages. Right: Sitting vehicle operation.

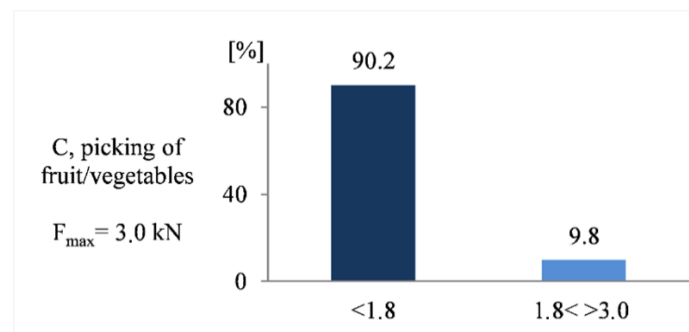


Figure 9. Intervertebral disk compression forces for picking activity C—larger values (blue bar) occurred in flexed back posture.

In activity D (forklift operation), with 36 measured load weights or 45 load weights per hour, fewer load weights were moved than during picking. Due to the close proximity of the ground and the associated strong flexion of the upper body when transferring loads of up to 10 kg, compression forces in the lumbar region L5/S1 to 3.6 kN were measured. Figure 10 shows box plots of the distributions of the disc compression forces (left) and of the torque in the lumbar spine area (right). Figure 11 shows a distribution of trunk inclination (in degrees, °) for all four activities. For activity A, picking of non-alcoholic and alcoholic beverages, all unfavorable factors trunk inclination, back torsion, torque in the area of the lumbar spine, and head tilt may be present simultaneously during movement of parcels near ground level and during wrapping. Measures enabling handling packages at chest level would reduce that burden considerably.

The presented analysis of four activities and their distinctive posture patterns suggests an efficient procedure for the (i) risk assessment of service activities in general and (ii) decision criteria for the initiation of ergonomic measures. Based on the parsimonious descriptions and thresholds provided by OWAS and CUELA, we show how ‘archetypal’ postures can be derived, which do not necessarily correspond to one particular body movement or stance but rather serve the purpose of capturing a variety of movements or stances prevalent in service activities. Thus, testable hypotheses can be provided, which may guide the collection of a few measurements and efficient decision-making towards the allocation of research and development resources for ergonomic improvements in logistics occupations. With the provided combination of OWAS and CUELA (the latter being informed by standards ISO 11226 and EN 1005-4) [115,116] it is possible to derive sets of statements of near-minimum size on core postures for activities to formulate testable hypotheses to identify service activities in need of ergonomic improvement.

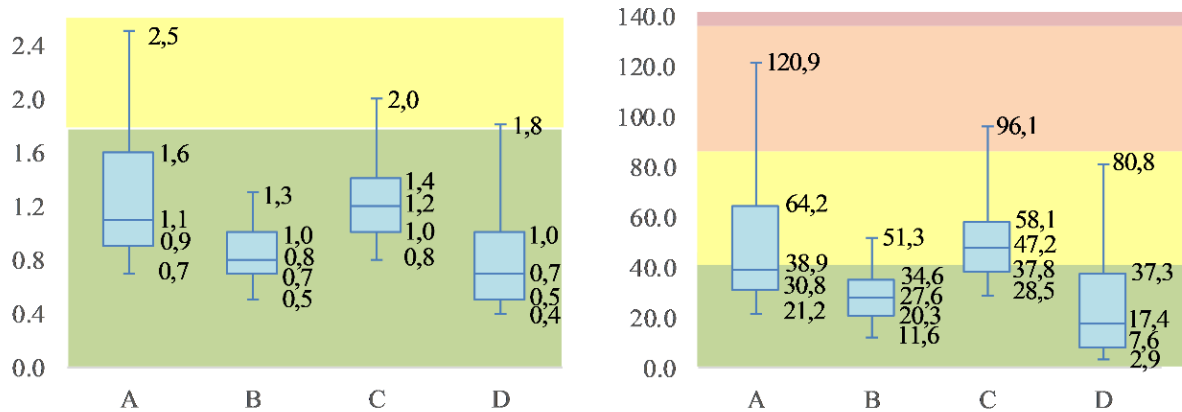


Figure 10. Distributions of disc compression forces (kN, left) and torque in the lumbar spine area (Nm, right). Note the strain levels for picking activity A, due to the presence of all factors trunk inclination, back torsion, torque in the area of the lumbar spine and head tilt during movement of parcels near ground level and during wrapping. Handling packages at chest level would reduce that burden.

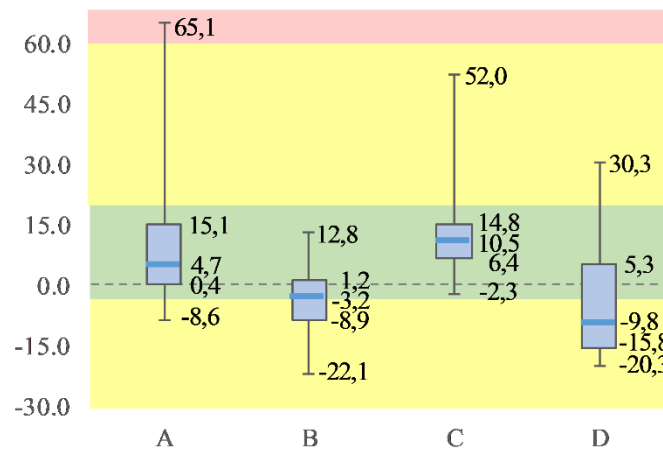


Figure 11. Distribution of trunk inclination (°) for each of the four activities.

Given many activities, a small number of postures serve as ‘limiting factors’ in the sense that surpassing one threshold value is sufficient to indicate the need for ergonomic improvement, compare Table 4 below and compare with Tables 2 and 3 above, EN 10054, ISO 11226 [115,116]. These can be derived by combining OWAS-descriptions and threshold values from the international norms EN 10054, ISO 11,226 [115,116].

Table 4. Examples for activities and representative postures with thresholds listed as sufficient.

Activity (Example)	Example Postures (OWAS, CUELA)	Thresholds	Ergonomic Measures (Example)
Operation of warehouse vehicle, sitting, facing shelves	3111	Head tilt (side) > 10°	Variations in rack layouts and pallet storage systems [119]
Picking	2141, 2142	For 2141: Shoulder joint flexion > 60° For 2142: weight > 10 kg or shoulder joint flexion > 20°	Variations in rack layouts and pallet storage systems [119]
Picking, Carrying of loads (walking)	217x, e.g., 2171	Trunk inclination > 20° and/or weight > 10 kg; any back curvature > 20°	Exoskeletons

5. Discussion

5.1. Areas for Improvement

The body of knowledge from trials is distorted towards treatments for low back pain. “Evidence about prevention, particularly primary prevention, is inadequate. Most of the widely promoted interventions to prevent low back pain (. . .) do not have a firm evidence base” [120]. The authors list workplace education, no-lift policies, ergonomic furniture, mattresses, back belts, and lifting devices as examples. In this case study, several optimization options for reducing the physiological burden of order pickers were derived from the quantitative findings of the previously described analysis. These measures are, among others, the results of the operational health management program in the analyzed company. Retracing the movements of the order pickers allowed the deviation of three major fields, (1) optimizing the workplace, (2) lower burdens and educating the workforce, as well as (3) improving the work object, meaning the order picking system, as well as the SKUs to pick (see Table 5).

Table 5. Measures in operational health management program derived from quantitative analysis.

Field of Activity	Measures in Operational Health Management Program
Workplace	Warehouse layout optimization with regard to the average weight of SKU, e.g., article placement always in the storage place best accessible in an ergonomic human perspective Opening of a fitness room for free use to enable warm-up stretching and stretch breaks, as well as a workplace athlete training
Workforce	Implementation of a job rotation mechanism to avoid that order pickers are only employed in warehouse areas with a disproportionately high average weight per SKU Implementation of a voluntarily and free of charge education program for employees focusing on proper lifting techniques
Work object	Relocation of articles in the dry assortment with a high average weight per SKU and at the same time moderate turnover to a semi-automated central warehouse Integration of SKUs weight and stability into a continuous improvement process regarding packaging design trademarks and branded products Increasing the usage of industrial trucks for order picker to decrease the distance traveled on foot

After the implementation of all measures mentioned in the table above, a qualitative ex-post analysis was conducted to assess the perceived improvements or deteriorations. The data for the perceived body condition after the operational health management program at t1 was gained in the same fashion as in t0, meaning the same order pickers and the same survey design described in Sections 3 and 4 ($n = 60$). The results in Table 6 indicate that the perceived physiological complaints were reduced in the group of order pickers and especially for the upper and lower back. The second remarkable improvement for the order-picking group addresses the body parts knee and feet, possibly resulting from reduced walking distance. Further positive impacts can be observed for the groups of industrial truck drivers and forklift operators regarding the upper and lower back, as well as the knee (for industrial truck drivers) or hip (for forklift operators), see Table 6.

Further research needs to assess specific physical and psychological demands of workplace situations and intended remedial measures (e.g., all wearable devices), as both dimensions are likely to contribute to the prevalence of physical symptoms such as low back pain. Thus, the study presented here may be regarded as a mere start and an example of assessments to be held in many industrial and intralogistics settings. To impose some structure on further research efforts, it may be worthwhile to describe archetypal patterns of strain along both dimensions (physical and psychological) for logistics jobs and tasks.

Table 6. Perceived physiological complaints per body part before (t_0) and after (t_1) the health program.

	Order Picker (Before, t_0)	Order Picker (After, t_1)	Industrial Truck Driver (Before)	Industrial Truck Driver (After)	Forklift Operator (Before)	Forklift Operator (After)
neck	1.60	2.12	2.63	1.71	4.16	2.17
shoulder/arms	2.39	1.89	3.03	3.66	1.47	1.60
upper back	3.47	3.16	2.91	1.80	2.93	1.87
lower back	4.87	2.75	4.13	3.62	3.93	2.31
hip	3.67	3.06	1.48	1.90	2.96	2.71
knee	4.78	3.89	3.04	2.26	1.31	1.97
feet	2.97	2.01	2.87	1.62	3.32	1.20

5.2. Options for Automation and Digitization

Automation and digitization, particularly the former, provide a vast array of measures to mitigate adverse health effects from indispensable physical labor activities in warehouse contexts, differing in suitability and maturity. Most of the change activities are driven by the need for ergonomic workplace design. In addition, the work environment of employees in operative logistics will change dramatically through digital technologies and thus change the subtasks and competence requirements for operational employees [121]. In order to efficiently tap into the potential offered by digital and automation technologies, training measures and suitable technical support need consideration as well. Initiatives are required that improve the working processes in the industrial areas of logistics from an automation and ergonomics point of view in order to ensure the competitiveness of logistics actors in the context of digitization and Industry 4.0. Quite some effort has been documented in the literature regarding this continuing inclusion of human factors in logistics processes, as for instance order picking and -planning [122–124], e.g., order picking by rotating pallets [102]. A sustainable implementation is conditional on acceptance by end-users, which means workers in logistics who are going to integrate new tools, processes, wearables, etc. into their daily work routines, usually on a long-term basis. At this stage, actual trial runs, including the very workers addressed, are necessary though not sufficient. One way to ensure to select an accepted measure (not make workers accept a measure) is to assess trial runs along sufficiently many dimensions relevant to work routines, which may be determined by employees (e.g., health, flexibility, versatility, simplicity). An Action Research-based approach [125] may be suitable for many intra-industry or intra-firm settings in logistics. In fact, Action Research cases may advance both practice and science and appear suitable for a field that requires systemic thinking and multi-disciplinary, mixed-method approaches for complex and ill-structured problems [126–128]. Action Research has dual significance as a process: First, it describes a succession of measures and events to take place at every step (data collection, feedback, data evaluation, action derived from preceding steps). Second, an iterative procedure repeats those steps multiple times for every incremental development. In employing the approach for organizational development regarding the improvement of ergonomic performance, stakeholders and processes in an organization (e.g., firm) are involved as follows: During an initial step, employees (workers) are interviewed with a focus on ergonomics and their work (questionnaires, semi-structured interviews). This is evaluated to identify jobs and affected parts of the musculoskeletal system causing discomfort, pain, etc. (problem definition). The following step, solution design, is comprised of the development and building of a prototype aimed at solving the identified problem. Implementation includes training employees to adequately use the solution/prototype. An evaluation with respect to target compliance (as described in step problem definition) is conducted by employees. Depending on the degree of target fulfillment, iterations may be run. The Action Research approach is intended to enable capacity building among employees since any measure taken should be preceded by detailed analysis and diagnosis involving the very people who are going to use them routinely. Further, the approach includes numerous benefits of the iterative/agile project management paradigm. Further, as considering an individual's readiness for change in implementing intervention strategies is likely to improve uptake and success [129,130],

procedures such as the state of change model can prove useful as an addition to an Action Research approach. This view assumes that behavioral change is a dynamic process and that an individual can be assigned to one of the following five stages: 1. Pre-contemplation (unaware or unconcerned about workplace hazards); 2. Contemplation (considering change but not yet ready to act); 3. Preparation (intend to change in the near future); 4. Action (made changes in the previous 6 months); 5. Maintenance (made a change and are working to consolidate gains and avoid 'relapse' into old unfavorable habits or routines). As an instance of a particular, tangible workplace solution, exoskeletons have been suggested and assessed [103,131].

5.3. Further Preventive Measures

Further preventive measures that have been characterized as appealing to 'common sense' are a variety of regular physical training activities: If considerable amounts of leisure time are spent physically passive, this adds especially to the one-sidedness of physical work tasks. As some authors suggest, performing strength training using free weights and static bodyweight exercises may reduce the incidence of workplace injuries, prevent long-term harm and improve overall health and motivation [132–136]. This could be supported by company programs and health plans within the HRM domain. Motivational and (positively) habit-forming effects can be added, e.g., with wearable technology, high-intensity interval training, involvement of educated, certified, and experienced fitness professionals, or participation in worksite health promotion and group personal training [137]. Finally, the OWAS method applied in the reported research may be exposed to critique, e.g., for its simplicity or perceived oversimplification. Mistakes may occur due to the choice of time intervals at which recorded material is evaluated for postures. One straightforward remedial measure is to note posture data and time whenever a change in posture occurs, rather than fixing evaluation intervals beforehand. Another rather interesting shortcoming of the discrete features of the OWAS-procedure is the classification of loads/acting forces. Again, classification after (exact) measurements have taken place would be more revealing. For instance, the data analyzed in the current research do not reveal how close to the 10 kg-mark weights have been. This could be mitigated by more accurate evaluation and measurement schemes in the future, based on the presented analysis.

6. Conclusions and Further Research

This paper has shown for the exemplary case of retail logistics jobs that health risks pose an imminent threat to social sustainability in human work with retail and logistics firms. This translates into further economic disadvantages as injuries and downtimes are hampering logistics efficiency and major revenue and profit sources. This is relevant across many other service sectors. Therefore, the outlined analysis concepts and countermeasures are potentially important to many firms and workplaces. As also in many industry sectors like automotive or machinery warehouses and intralogistics processes are incorporated, such industry fields could also be a primary field of further inquiry and health management measures on this topic.

Our contribution is centered in the area of physical ergonomics for blue-collar workers performing routine tasks within human-machine collaboration. Contributing to sociotechnical system theory with human leading/machine following relationships, we build foundations for further content- and methodology-related research. Although performance and quality have been important outcomes for operations systems, our analysis centers on workers' well-being in terms of physical burden. We claim that this third dimension is highly relevant for the development of sustainable productions and operations systems in the sense of the triple-bottom-line approach.

Regarding the presented analysis method, as well as transferring the health issue and possible measures to other service industries, is highly warranted. A profound improvement for employee health and efficiency should be provided by efforts integrating the steps video analysis, classification, and threshold comparison as well as recommen-

dation of ergonomic improvements (e.g., with an individual smartphone app). From a content-related viewpoint, the empirical analysis can be easily transferred to advances in human-technology systems, e.g., human-robot collaboration concepts. Moreover, it might be interesting to change the interaction aspect and compare collaboration and cooperation scenarios to evaluate how technology can contribute to increasing workers' well-being. This is in line with recent research on the importance of the human factor in logistics and supply chain management in general [16,138–144].

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