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Leveraging Exoskeletons to Reduce Musculoskeletal Disorders in Aluminum Forging: A Case Study

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ABSTRACT

The paper deals with the implementation of exoskeletons in a aluminum forging company to reduce musculoskeletal disorders (MSDs) and improve ergonomic working conditions. It describes the recording of the current situation through employee surveys, the application of the key indicator method and observations at the workplace. The aim is to reduce the physical strain on employees and promote the acceptance of exoskeletons. The project includes a pilot study, training for employees and a comprehensive data analysis to evaluate the effectiveness of the exoskeletons. The results should lead to higher employee satisfaction and productivity in the long term.

Keywords: Human systems integration, Assistive technology, Case study

INTRODUCTION

The advancement of automation and technologization in manufacturing brings numerous benefits, but also poses new challenges for the health and safety of employees. Particularly in areas with repetitive and physically demanding activities, such as aluminum production, musculoskeletal disorders (MSDs) are widespread and can lead to considerable downtime and a reduced quality of life for employees (Heinrich et al., 2022).

It is in this context that the project to integrate exoskeletons in a aluminum forging plant was launched. The aim of the interdisciplinary project is to research the potential benefits of exoskeletons in order to reduce the physical strain on employees and improve ergonomic working conditions. By systematically recording the current situation, conducting employee surveys and applying the key feature method, a sound basis is to be created for evaluating the acceptance and effectiveness of exoskeletons. In the long term, the project aims to promote the health and safety of employees and increase productivity within the company.

EXOSKELETONS

Exoskeletons are wearable devices designed to augment, assist, or enhance the physical capabilities of the human body. By mimicking and supporting the movement of the musculoskeletal system, they reduce the strain placed on muscles and joints during physically demanding tasks. These systems typically consist of mechanical frameworks integrated with actuators, sensors, and sometimes advanced control systems, enabling them to provide targeted assistance for specific movements or body parts (Groß et al., 2023, Afolabi et al., 2024).

There are two primary categories of exoskeletons: **active** and **passive**. Active exoskeletons utilize powered actuators, often driven by motors or pneumatics, to provide substantial force assistance. These are commonly used in tasks requiring repetitive lifting or sustained overhead work. Passive exoskeletons, on the other hand, rely on non-powered mechanisms such as springs or elastic materials to redistribute or reduce loads, offering a simpler and cost-effective alternative for less intensive tasks (Groß et al., 2023).

The applications of exoskeletons span various fields. In healthcare, they are used for rehabilitation, aiding patients with mobility impairments or supporting recovery from injuries. Military and defense sectors deploy them to enhance soldier endurance and load-carrying capacity. In industrial settings, exoskeletons are increasingly recognized as tools to reduce the risk of musculoskeletal disorders (MSDs), improve worker productivity, and mitigate the physical demands of labor-intensive jobs (Heinrich et al., 2022).

One of the most promising applications of exoskeletons is in industries characterized by high ergonomic risks, such as manufacturing, construction, and logistics. Workers in these sectors often perform repetitive tasks, heavy lifting, or awkward postures that significantly increase the likelihood of MSDs. By reducing the biomechanical load on the body, exoskeletons can alleviate these risks and create a safer, more sustainable work environment (Lopota et al., 2024).

ANALYSING THE PROBLEMS IN THE COMPANY

The analysis of the internal problem in the aluminum forging plant focuses on identifying and analyzing the physical stresses that employees experience during their work. One key aspect is the high prevalence MSDs, which are responsible for a significant proportion of days of incapacity to work in Germany. Older employees are particularly affected, which underlines the urgency of preventive measures.

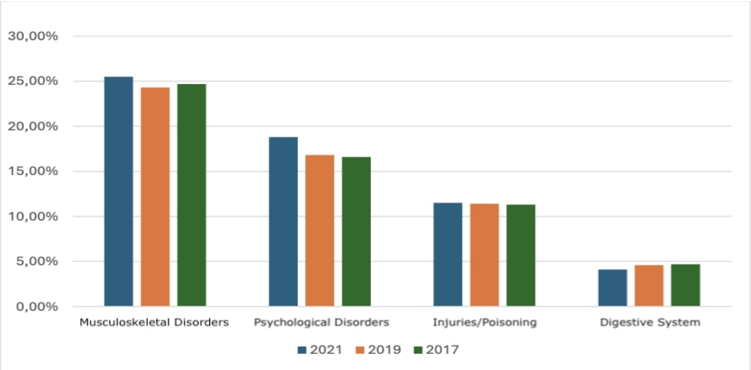

Figure 1: Proportion of disease types in Germany (Statista, 2024).

Various methods were used to record the current situation.

Employee surveys: Specific questions were asked of employees, particularly the foreman, to gather information on the ergonomic design of the workplace, physical strain and preventative measures already implemented. These surveys helped to obtain a comprehensive picture of current working conditions.

Key indicator method: This method was used to record the physical strain in the individual work systems. It serves as a tool for the employer to identify the stresses and strains and, if necessary, to take measures to improve them.

Observations at the workplace: By analyzing the work processes and the physical demands placed on employees in aluminum production, the repetitive and monotonous nature of the work was identified, which indicates a high level of physical strain.

In addition, an investigation by the health insurance company supported the analysis. The investigation included an employee survey in which the physical strain in the various work areas was assessed. Employees were asked to share their experiences and assessments of physical strain during their work. The results were recorded in scores from 0 to 100, with lower scores indicating higher levels of strain. In particular, the focus was placed on repetitive and monotonous work processes that pose an increased risk of musculoskeletal disorders. The employees in the aluminum production area rated their physical strain with only 4 out of a possible 100 points. This was the lowest score in the entire company and indicated significant physical strain. Due to the high physical demands and repetitive tasks, employees were at increased risk of musculoskeletal disorders. This was a key concern that underlined the need for interventions such as the introduction of exoskeletons. The results of the investigation served as the basis for the development of measures to improve working conditions. The introduction of exoskeletons was identified as a promising solution to reduce physical strain and promote employee health.

Due to the findings, the pilot workplace selected for the study was characterized by repetitive and monotonous work processes. The employees frequently performed the same movements, which led to a high level of physical strain, particularly in the arm and shoulder area. As mentioned, this type of work posed a long-term risk of musculoskeletal disorders.

The pilot workplace at an aluminum press in the line includes the following work steps:

1. The aluminum workpiece with a weight of 2.74 kg is positioned in the die by arobot arm is positioned in the die from the right from the employee's perspective.
2. The workpiece is aligned by an employee. This process isrequired by the movement tolerance of the robot arm in order to reduce reduce waste.
3. The first pressing process is triggered by the employee.
4. The employee lifts the workpiece from right to left into the finishing unit using tongs with a length of 53.5 cm from right to left into the finishing die.
5. The second pressing process is triggered by the employee.

6. The employee lifts the workpiece again from the right to the left using the tongs from the finishing die into the trimming die.
7. The employee triggers the third pressing process and the workpiece is separated from the burr. The burr is removed while the workpiece is conveyed on a conveyor belt.
8. The workpiece is conveyed through a water bath to cool down.
9. Another employee removes the workpiece, punches a hole in it and then hangs it up.

The following movement sequences are given for the use of the exoskeleton in the area of the working leg:

1. With the arm extended at an angle of approx. 40°, the employee positions the workpiece. The employee usually positions the workpiece with one hand using pliers and triggers the automated pressing process.
2. The employee usually places the workpiece into the subsequent die with both hands, holding the workpiece with the pliers over the die for a brief moment for more precise positioning and repeating the pressing process.

METHODOLOGY

One month was planned for the test phase in which the exoskeleton from exoIQ (Figure 2) was to be used at the selected workplace. The aim was to reduce the physical strain on the employee due to the use of the exoskeleton.

Figure 2: Exoskeleton exoIQ.

Before the exoskeletons were introduced, training courses were held for all employees. The aim of this training was to familiarize employees with how the exoskeletons work and how to use them correctly. One responsible person per shift was appointed to provide support in the event of questions or problems.

The employees were divided into the following categories for the study: Small/Slim, Average and Tall/Muscular.

The work area was also divided into different zones (refer to Figure 3), as the force required differs for each zone.

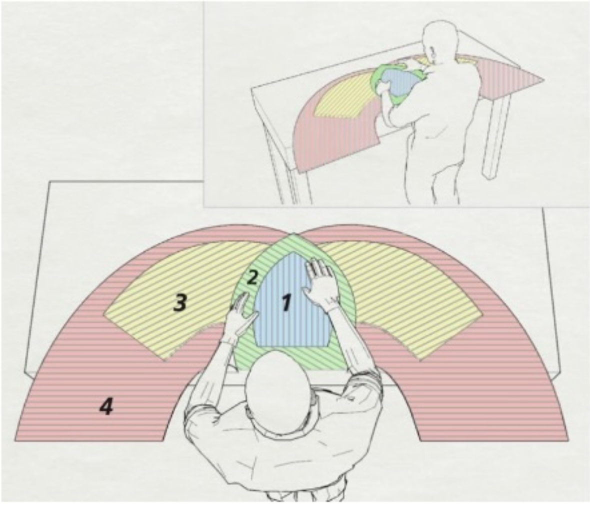

Figure 3: Working zones.

Zone 1: work center/ assembly site, both hands work close together and are in the are in the center of the field of vision.

Zone 2: Extended work center, both hands reach all points of this zone.

Zone 3: One-handed zone, zone for placing objects that are gripped/operated with one hand.

Zone 4: Extended one-handed zone, outermost usable zone, e.g. for placing small parts in gripping containers. With a heavy load, the strain has a negative effect on the musculoskeletal system after a short time (Daub et al., 2018).

As can be seen from the colors, zone 1 is ergonomically safe according to the guiding characteristics method, while zones 4 and 3 are very bad for posture and effort.

RESULTS

The key indicator method was first carried out before the deployment and then during the deployment. The improvements in posture and effort are shown as a percentage in Table 1.

Table 1: Improvement of key indicators in percentage.

	Zone 1	Zone 2	Zone 3	Zone 4
Small/Slim	5,11 %	3,20 %	30,42 %	50,36 %
Average	8,43 %	1,32 %	18,98 %	41,67 %
Tall/Muscular	0,44 %	0,21 %	10,42 %	22,25 %

The insights gained from the evaluation correspond with the individual feedback from the employees. The employee from the small/slim category emphasized the personal evaluation particularly emphasized the positive support and was generally very satisfied with the exoskeleton. The only negative aspect he mentioned was that the support for the arms cannot be adjusted independently. The assessment of the employee in the average category also emphasized the positive support and was also satisfied overall, although this employee negatively employee negatively mentioned the heat development at the contact points of the straps. Overall, the employees in the small/slim and average categories would recommend the exoskeleton in their day-to-day work. The employees in the tall/muscular category mentioned the heat generated by the belts at the contact points in their assessment. The support was mentioned as positive, but the negative aspects outweigh the positive ones in this category. Negative aspects, which is why the employees in this group would rather not use the exoskeleton in their everyday work.

CONCLUSION

The results of the study on the implementation of exoskeletons in the aluminum forging plant are based on comprehensive data collection and analysis of the physical strain on employees. The survey regarding the ergonomic strains showed that employees are exposed to significant ergonomic stress, particularly during repetitive movements and heavy lifting activities. The analysis of work processes revealed that many activities are carried out in forced postures, which increases the risk of musculoskeletal disorders. In the interviews, employees gave predominantly positive feedback on the support provided by the exoskeletons. Employees in the "small/slim" and "average" categories in particular reported noticeable relief at work. They emphasized that the exoskeletons reduce physical strain and increase efficiency. The evaluation of the test results also showed that the exoskeletons are able to significantly increase the physical performance of employees. The support of the joints and muscles led to a reduced risk of injury, particularly during heavy physical work.

Overall, employees showed a high level of acceptance for the use of exoskeletons in their day-to-day work. It can therefore be concluded that exoskeletons are a promising tool for improving working conditions and supporting employees in physically demanding occupations.

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