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## Field study on the use and acceptance of an arm support exoskeleton in plastering

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### ABSTRACT

Exoskeleton use in day-to-day plastering may face several challenges. Not all plasterer's tasks comprise of movements that will be supported by the exoskeleton and might even be hindered. Furthermore, use in practice might be jeopardised by time pressure, colleagues being negative, discomfort, or any other hindrance of the exoskeleton. We set up a field study, in which 39 plasterers were equipped with an exoskeleton for six weeks, to study exoskeleton usage. Moreover, we studied workload and fatigue, behaviour, productivity and quality, advantages and disadvantages, and acceptance. Exoskeleton use was dependent on the task performed but did not change over the course of the six weeks. For three tasks, higher exoskeleton use was associated with lower perceived loads, although differences were small. Advantages outweighed disadvantages for the majority of our population. This study shows that a majority of plasterers will wear the exoskeleton and is enthusiastic about the load reducing effect.

**Practitioner summary:** For exoskeletons to make an impact on the health and well-being of workers, they need to be applicable in real work situations and accepted by the users. This study shows that 65% of the plasterers in this study want to use the exoskeleton in the future, for specific tasks.

### ARTICLE HISTORY

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### KEYWORDS

Exoskeleton; field study;  
musculoskeletal disorders;  
ergonomics; construction

## Introduction

Exposure to tiring and painful postures is still prevalent in many jobs, despite improvements in workplace design and automation, especially in sectors, such as agriculture, industry, and construction (Eurofound 2017a, 2021). Considering shortage of manual labourers in these sectors, as well as demographic ageing, it is important that exposure to these risk factors are minimised, to ensure sustainable employability and attractiveness of this work in the future (Eurofound 2017a, 2017b). In jobs where traditional workplace design and automation are not feasible or do not sufficiently reduce exposure to tiring and painful positions, exoskeletons might be the right solution.

Exoskeletons may assist workers when exposed to stressful postures, by providing part of the required joint torques, hereby reducing muscle activity and internal loads (de Vries et al. 2019; McFarland and Fischer 2019; Theurel et al. 2018). Arm-support exoskeletons assist workers by providing a torque around the shoulder in elevated arm postures. Previous

studies on arm support exoskeletons show reductions in muscle activation in the shoulder region, but these studies mainly addressed isolated postures, single movements, or quasi-static activities (de Vries et al. 2019; Alabdulkarim and Nussbaum 2019; Kim et al. 2018a, 2018b; Rashedi et al. 2014; Van Engelhoven et al. 2018). However, real working activities often do consist of multiple movements in various directions rather than isolated, single, and small movements.

To analyse the exoskeleton effects in such complex activities, previously we performed a study on plasterers in a controlled environment. When plastering walls and ceilings, workers have their arms elevated over substantial periods of time, while moving their arms in multiple directions. Use of the arm-support exoskeleton resulted in significant reductions of muscle activity in four agonist muscles (up to 30–40% depending on task or muscle), while the activity of two antagonist muscles remained unaffected. Additionally, ratings of perceived exertion dropped

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significantly when using the exoskeleton (de Vries, Krause, and de Looze 2020).

Despite these positive results, it remains questionable whether plasterers would really use the arm-support exoskeletons in their daily work. Obviously, the load reducing effect observed previously may only have impact in terms of fatigue reduction and health risk reduction, if the exoskeleton is used for a sufficient amount of time. However, use in practice might be jeopardised by various factors (Crea et al. 2021; McFarland and Fischer 2019; de Vries, de Looze, and Michiel 2019). Plastering activities are alternated by other activities (without arm elevation and thus no support of the exoskeleton) in which the exoskeleton might cause hindrance. Other jeopardising factors could be time pressure, colleagues being negative, discomfort, decrease in productivity or quality, or any other hindrance of the exoskeleton while using it.

To analyse the use of an exoskeleton and the perceived experiences of plasters, we set-up a field study. Generally, the number of field studies on the use of arm-support exoskeletons in real field settings is limited (Crea et al. 2021). Recently, the results of an 18-months field study (Kim et al. 2021) on effects of an arms-support exoskeleton in automotive industries have been published. This study did not reveal any significant differences in perceived work intensity and musculo-skeletal disorder scores between the exoskeleton and control groups. In this study the proportions of time that the exoskeleton have been actually used during work in the experimental group was unknown. The authors speculate that the lack of exoskeleton effects in this study may be due to the workplaces that are already ergonomically adjusted to minimise shoulder load (Kim et al. 2021).

In the present study, we equipped 39 plasterers with an arm support exoskeleton and analysed the use of it and their experiences over a 6-weeks period. By use of multiple questionnaires, we aimed to answer the following questions:

- How often is the exoskeleton used over six weeks and during which tasks?
- Does the exoskeleton affect the perceived work load and discomfort?
- Does the exoskeleton affect behaviours like 'taking rest breaks' and 'duration of work'?
- Does the exoskeleton affect perceived quality (number of errors) and productivity (working speed)?

- What are the perceived advantages and disadvantages of using the exoskeleton?
- Would the plasterers use the exoskeleton in the near future?

## Methods

### Participants

Forty-five male participants were recruited *via* internet, social media, and word of mouth. We experienced a few drop outs before starting the study, partly due to the covid pandemic, which caused us to start the study with 39 participants. They were active professional plasterers (plastering was their main or single job), without musculoskeletal disorders that would prevent them from carrying out their normal plastering activities, at the moment of testing. Nine of the plasterers currently experienced physical complaints caused by their work and only three had never experienced physical complaints caused by their work. All plasterers indicated to have an interest in new technologies and four had worn an exoskeleton before. Participants signed an informed consent document, approved by the ethics committee of TNO, after being informed about the procedures of the experiment.

### Procedure

The plasterers were divided into three groups of 15. Each group started with a kick-off meeting, which encompassed explanation of the study, a fitting session in which each received a custom fitted exoskeleton, user instructions, and room for discussions on the exoskeleton and the experiment. The first group started in April, the second in June and the third in September. Each group was followed for seven weeks. The first week they worked without an exoskeleton (Base monitoring), the following six weeks with the exoskeleton (monitoring weeks). Participants were monitored by means of questionnaires. Links to the questionnaires were sent on a daily basis *via* SMS. Additionally, there were two phone calls to discuss the experience with the exoskeleton so far and to address any issues with the exoskeleton or questionnaires (Figure 1). Participants were encouraged to, at least, try the exoskeleton once with all different tasks, but for the entire 6-weeks period, they were free to choose whether they actually used the exoskeleton or not. The most important tasks are applying the gypsum, smoothing the gypsum, and finishing the surface with a spatula. A description of the tasks can be found in de Vries, Krause, and de Looze (2020).

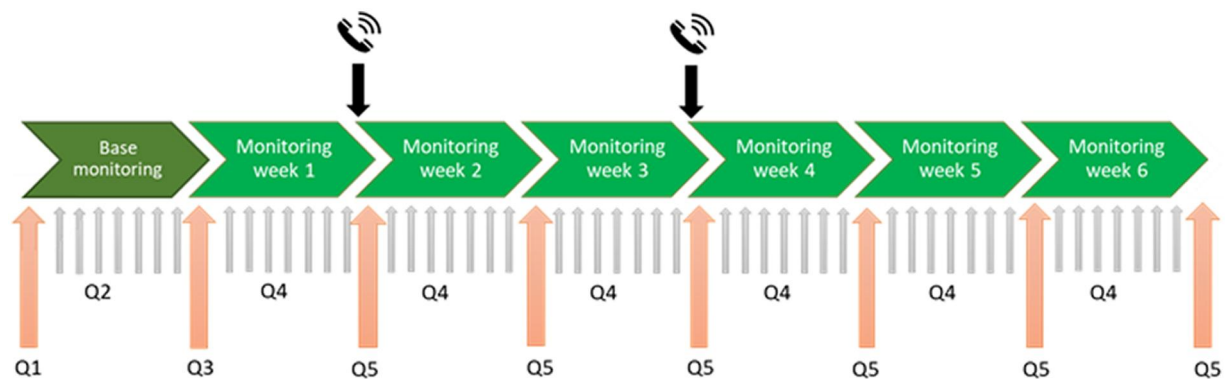


Figure 1. Overview of the questionnaires and set up of the field study.

11:19 23° 51%

Wat heb je gedaan en hoe lang?

**Werk voorbereiden**

☐ niet gedaan

☐ minder dan 1 uur

☒ 1 tot 2 uur

☐ meer dan 2 uur

11:21 23° 51%

**Afreien (muur)**

☐ niet gebruikt

☐ soms gebruikt

☐ evenveel wel als niet gebruikt

☒ vaak gebruikt

☐ altijd gebruikt

11:21 23° 51%

Door het dragen van het exoskelet heb ik vandaag...

1= korter gewerkt  
2= een beetje korter gewerkt  
3= even lang gewerkt  
4= een beetje langer gewerkt  
5= langer gewerkt

3

1 5

Figure 2. Screen capture of the questionnaire on a mobile phone. Three different screens are shown, with questions and answers in the plasterers native language (Dutch). From left to right we asked whether they performed these tasks and for how long, whether they used the exoskeleton for these tasks and whether their shift duration was shorter or longer.

### Questionnaires

Five questionnaire were created in an online software environment (Survalyzer, Survalyzer Nederland BV) (Figure 2).

These questionnaires were filled in on a daily or weekly basis and at different points in time as shown in Figure 1. They addressed six items corresponding with the six research questions:

#### 1. usage

Per task, the plasterers were asked to indicate to what extent they used the exoskeleton, on a scale of one to five (not used, sometimes used, as much used as not used, often used, always used).

#### 2. work load an fatigue

For each task that was performed that day, we asked how heavy it was, on a scale of one to five (light, a little light, average, a little heavy, heavy). And much discomfort did you experience in neck, shoulders, chest, upper back, upper arms, forearms, lower back, or abdomen.

#### 3. behaviour

Each day the plasterers were asked whether usage of the exoskeleton changed their behaviour by means of breaks and work duration.

#### 4. productivity and quality

In the daily questionnaire plasterers were asked whether exo use affected work pace and in the weekly questionnaire they were asked whether they made more or less mistakes due to exo use.

#### 5. advantages and disadvantages

In the weekly questionnaire plasters reported which advantages and disadvantages of working with the exo, they experienced.

#### 6. acceptance

In the weekly questionnaire, plasterers reported whether they would want to use the exo in the future (1: definitely not—5: very much).

The first questionnaire (Q1) was conducted at the kick off before baseline measurements (Figure 1), it addresses the personal characteristics of the participants. Q2 and Q4 were filled out at the end of each work day. Q2 was used during the phase of base monitoring (without exo) and Q4 was used during the experimental phase (with exo). Q2 and Q4 both addressed which tasks were performed that day, as well as items 2, 3, and 4 (as numbered above). Q4 also included whether the exo was worn for each task

that was performed (item 1). Q3 and Q5 were weekly questionnaires for base monitoring (without exo) and the experimental phase (with exo), respectively (addressing items 4, 5, and 6). A final interview was conducted at the end of the experiment, in which participants were asked about their experiences, and will to use the exo in the future.

## Materials

Plasterers were fitted with a Skelex 360 (Figure 3), arm support exoskeleton. This is a passive arm support exoskeleton that provides the most support when the arms are elevated (de Vries et al. 2019). The exoskeleton was fitted to each plasterer by one of the exoskeleton's designers. Anthropometric settings were noted and provided to the participants. We asked the participants to make only minimal adjustments to the anthropometric fitting whenever the fit does not feel right.

Besides the anthropometric settings, the level of support can be adjusted using the force adjuster (Figure 3) to provide the support that the user desires. We encouraged the plasterers to alter the support settings for the various tasks, in case they felt they needed more or less support and made sure they knew how to do so during the kick off.

## Statistics

### Exoskeleton usage

We tested whether the exoskeleton usage was task-dependent and whether usage changed over time with Generalised estimating equations (GEE). Per task, plasterers also indicated how heavy the task was.

### Perceived load and discomfort

The effect of exoskeleton use on the experienced load and whether this effect changed over time was tested with GEE, using day as a covariate.

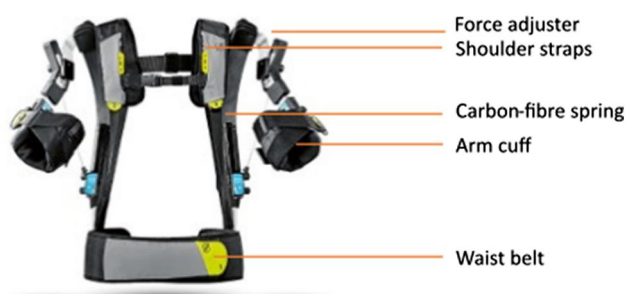


Figure 3. Skelex 360 (Rotterdam, The Netherlands).

We cannot directly test the effect of exo use on discomfort, because exo use was reported per task daily, whereas discomfort was reported on a weekly basis. Therefore, we clustered the subjects into two groups: frequent or non-frequent users. Classification of frequent/non-frequent users was done based on exo usage during the tasks with highest exo use (apply man ceil, smooth ceil, finish w. spatula ceil, apply mach. ceil). Frequent users were those participants that scored 4 or 5 on exo use for all selected tasks, remaining participants were considered non frequent users. This resulted in 34.5% of the participants being classified as frequent users.

We tested whether discomfort was different for frequent exo users and whether the week number had an effect on discomfort, including the first week, in which participants did not use the exoskeleton yet. The effects were tested using GEE.

GEE's were used because they can cope with missing data and the responses are measured on an ordinal scale. Inferential statistics were performed in IBM SPSS 25.

### Quality, productivity, behaviour, advantages and disadvantages, and will to use the exo

Other outcomes, such as Quality, productivity, behaviour, advantages and disadvantages, shift duration/breaks, and will to use the exo, will be reported, but were not statistically tested, because no comparisons between exo or no-exo conditions were made.

## Results

### General overview

In total 39 plasterers started the study. Regarding adherence to the questionnaires, 21 participants did not miss more than one questionnaire over the whole study. In total 82 and 75% of all daily and weekly questionnaires, respectively, were filled in. An overview of the tasks that were performed by the participants during the 6-weeks period and their frequency of occurrence are presented in Table 1.

### Exoskeleton usage

Exoskeleton use differed significantly between tasks. In Table 2, the parameter estimates of the GEE are shown. The  $\text{Exp}(B)$  value for each task helps to classify the task in one of the five exo use categories. For example: Exo use 5 = always used with threshold  $\text{Exp}(B) < .236$ ; Exo use 1 = not used with threshold  $\text{Exp}(B) > .978$ . The upper part of the table shows the

**Table 1.** An overview of the reported tasks that the plasterers performed over the six weeks.

| Task                     | Number of times task was performed | Percentage of all tasks |
|--------------------------|------------------------------------|-------------------------|
| Prepare                  | 404                                | 14.5%                   |
| Primer ceil              | 53                                 | 1.9%                    |
| Primer wall              | 177                                | 6.4%                    |
| Apply machine ceil       | 37                                 | 1.3%                    |
| Sand wall                | 295                                | 10.6%                   |
| Finish with spatula ceil | 164                                | 5.9%                    |
| Sand ceil                | 94                                 | 3.4%                    |
| Finish with spatula wall | 444                                | 16.0%                   |
| Smooth ceil              | 132                                | 4.7%                    |
| Apply man. wall          | 316                                | 11.4%                   |
| Smooth wall              | 398                                | 14.3%                   |
| Apply mach. wall         | 144                                | 5.2%                    |
| Apply man. ceil.         | 121                                | 4.4%                    |
| Total                    | 2779                               |                         |

ceil: ceiling; man: manual; mach: with gypsum spraying machine.

**Table 2.** Parameter estimates for exo usage per task exponentiated beta coefficients predicting exoskeleton use.

|                       |             | Hypothesis test |    |      | 95% Wald confidence interval for Exp(B) |       |       |
|-----------------------|-------------|-----------------|----|------|-----------------------------------------|-------|-------|
|                       |             | Wald chi-square | df | Sig. | Exp(B)                                  | Lower | Upper |
| Threshold             | Exo use = 5 | 22.662          | 1  | .000 | .236                                    | .130  | .428  |
|                       | Exo use = 4 | 11.534          | 1  | .001 | .403                                    | .239  | .681  |
|                       | Exo use = 3 | 4.178           | 1  | .041 | .628                                    | .402  | .981  |
|                       | Exo use = 2 | .009            | 1  | .925 | .978                                    | .619  | 1.546 |
| Apply man ceil        |             | 19.917          | 1  | .000 | .129                                    | .052  | .317  |
| Apply mach wall       |             | 8.245           | 1  | .004 | .230                                    | .085  | .628  |
| Smooth wall           |             | 6.676           | 1  | .010 | .511                                    | .307  | .850  |
| Apply man wall        |             | 2.552           | 1  | .110 | .621                                    | .346  | 1.114 |
| Smooth ceil           |             | 23.172          | 1  | .000 | .132                                    | .058  | .300  |
| Finish w spatula wall |             | 4.194           | 1  | .041 | .592                                    | .359  | .978  |
| Sand ceil             |             | 10.147          | 1  | .001 | .208                                    | .079  | .547  |
| Finish w spatula ceil |             | 13.071          | 1  | .000 | .190                                    | .077  | .467  |
| Sanding wall          |             | 2.717           | 1  | .099 | .643                                    | .381  | 1.087 |
| Apply mach ceil       |             | 11.296          | 1  | .001 | .099                                    | .026  | .381  |
| Primer wall           |             | .003            | 1  | .954 | 1.014                                   | .639  | 1.609 |
| Primer ceil           |             | .090            | 1  | .764 | .846                                    | .285  | 2.515 |
| Prepare               |             | .               | .  | .    | 1                                       | .     | .     |

Exp(B) thresholds for each category of exoskeleton usage, the lowest parts show the corresponding Exp(B) values for each task (Table 2). The highest usage (low Exp(B) value) was found, for tasks performed at the ceiling, but also for one task at the wall, namely apply mach. wall. These tasks have Beta coefficients representing 'often used' and 'always used' (marked in green, Table 2). Tasks with Beta coefficients indicating 'as much used as not used' are marked in yellow and tasks representing 'not used' or 'sometimes used' are marked in red (Table 2). Per colour coded category, exo usage of the two most executed tasks are visually represented in Figure 4. No significant effect of time nor an interaction effect of time and task was found on exoskeleton usage.

### Effect of exo use on perceived load and discomfort

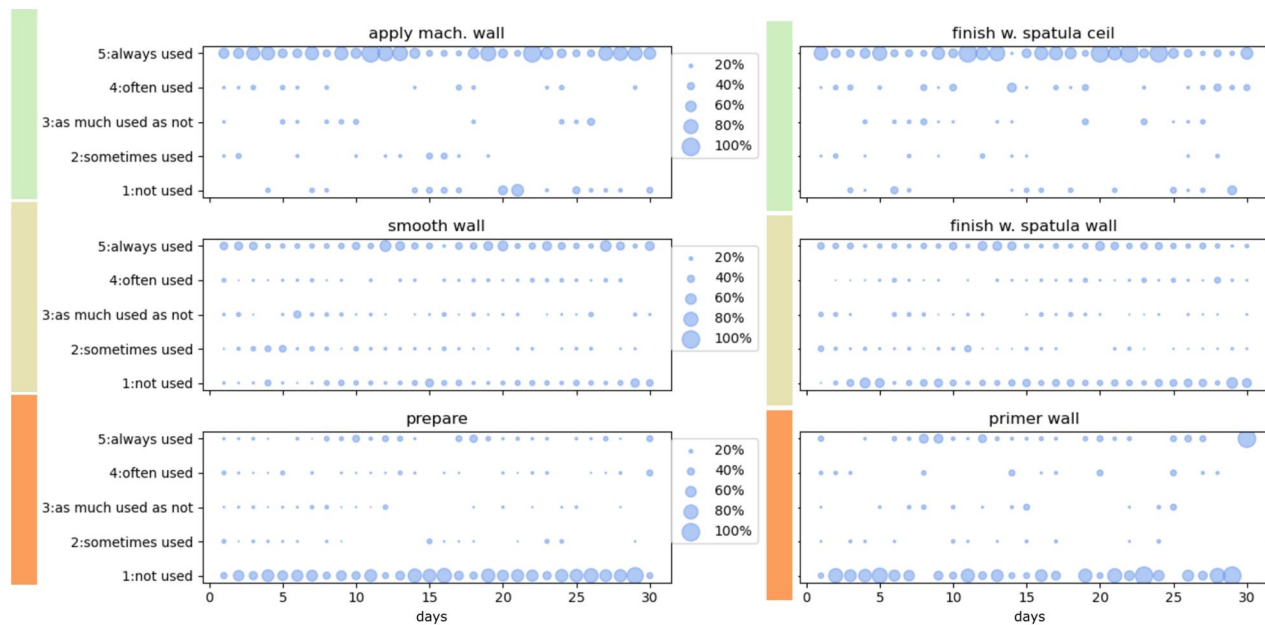
For three tasks, an increase in exoskeleton use resulted in a decline in experienced load, although these effects were small. For **apply mach. wall**, all exo

use categories (2: sometimes used up to 5: always used) showed a significant decline in perceived load compared to no exo use (Figure 5). For **smooth wall** only exo use categories 5 (always used) showed a significant decline in perceived load compared to no exo use (Figure 5). For **apply man wall**, exo use 2, 3, and 5 showed a decline in load compared to no exo use (Figure 5). For the other tasks no significant effects of exoskeleton use on experienced load were found. For none of the tasks an effect of time was found on perceived load or discomfort nor an interaction effect with exo use was found.

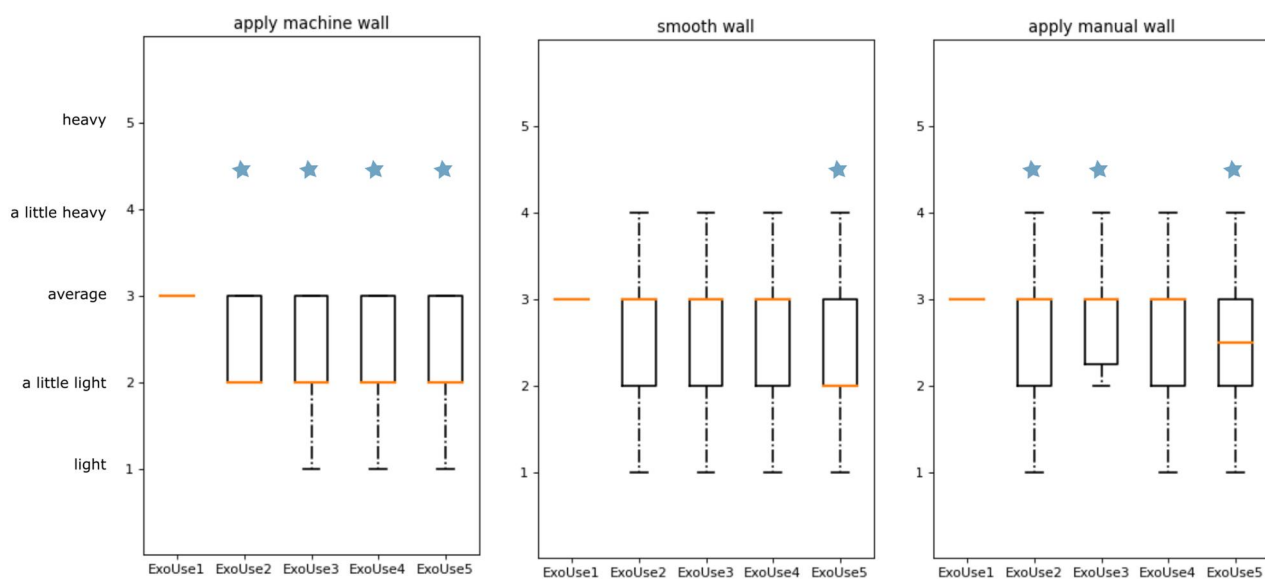
For six body regions, we tested whether being a 'frequent exo user' had an effect on experienced discomfort. For none of the body regions: shoulders, neck, chest, upper back, lower back, and stomach an effect of time or group (frequent user or not) was found.

### Behavior

Daily, plasterers indicated whether exoskeleton usage affected their behaviour regarding breaks and working



**Figure 4.** Exoskeleton use per task. The size of the circle represents the percentage of respondents per day for each ordinal response). Tasks with Beta coefficients representing 'often used' and 'always used' are marked green, tasks with Beta coefficients indicating 'as much used as not used' are marked in yellow, and tasks representing 'not used' or 'sometimes used' are marked in red. Per colour coded category, the two most executed tasks are visually shown.



**Figure 5.** Experienced load per exo use category. Significant differences compared to exo use 1 (not used) are presented with a star. Boxes range from the 25th to the 75th percentile, whiskers represent the data range, and median is indicated with a solid orange line.

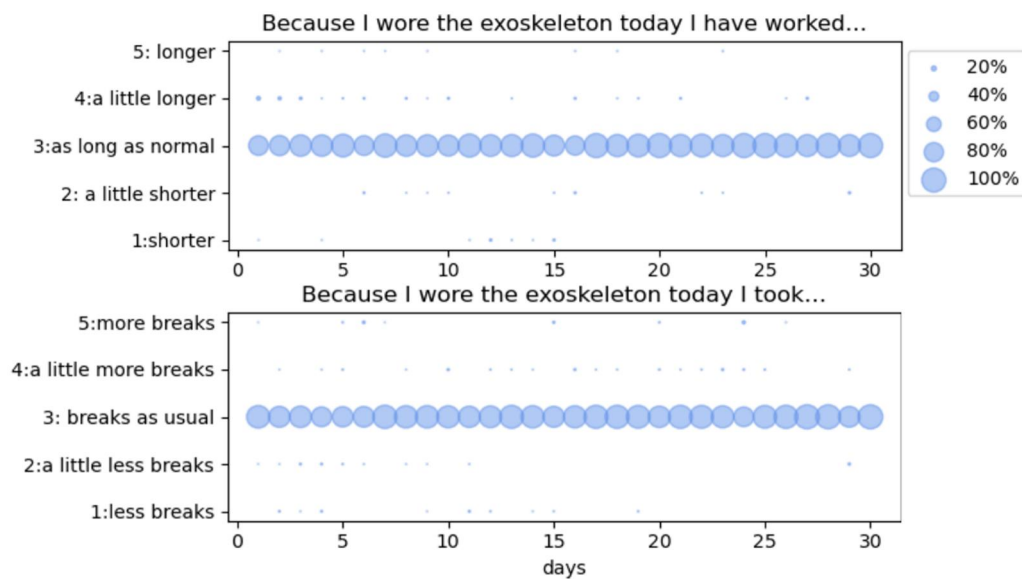
hours. From Figure 6, it can be seen that the exoskeleton had minimal effect on both aspects, neither did this change over time.

### Productivity and quality

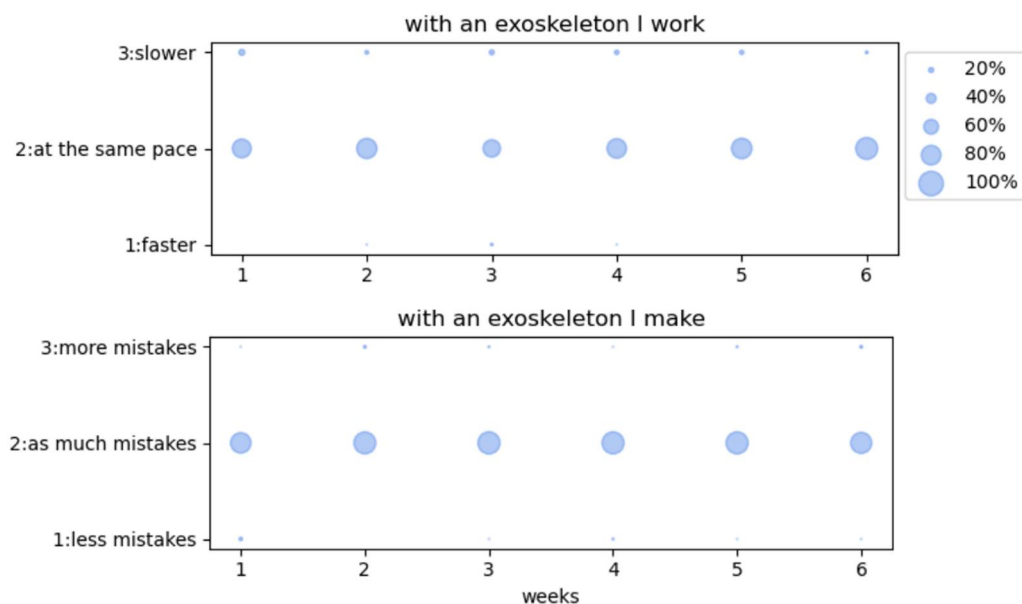
Additionally, their perceived work pace and the quality of work were not affected by the use of an exoskeleton (Figure 7).

### Experienced advantages and disadvantages

In the weekly questionnaire, plasterers indicated the experienced advantages and disadvantages of using the exoskeleton (Figure 8). The three mostly mentioned advantages are: 'I have less pain' (36%), 'I am less tired' (45%), and 'it supports me' (93%), whereas the three mostly mentioned disadvantages are: 'doesn't fit well' (25%), 'obstructs my movements' (36%)



**Figure 6.** The effect of exo use on breaks and working hours. Percentage of respondents is represented by the size of the dots (see legend for reference).



**Figure 7.** Perceived productivity and quality. Percentage of respondents is represented by the size of the dots (see legend for reference).

and 'hinders me' (60%) (Numbers in the text are from the final week).

### Acceptance

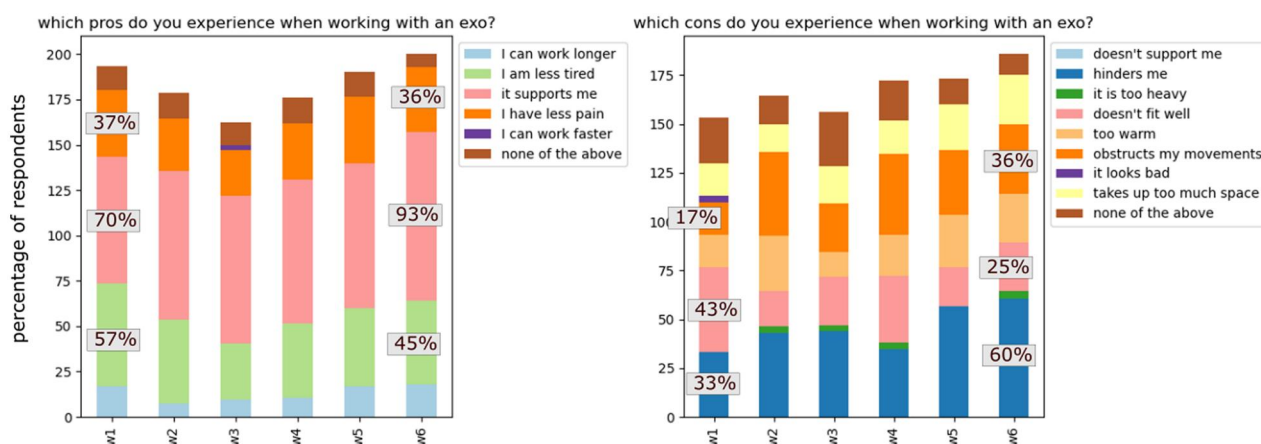
Each week participants indicated whether they would want to use the exo in the future. In the final week, 29% of the respondents would probably use it, and 36% would definitely use it [Figure 9](#). This adds up to

65% that are positive towards using the exoskeleton in the future.

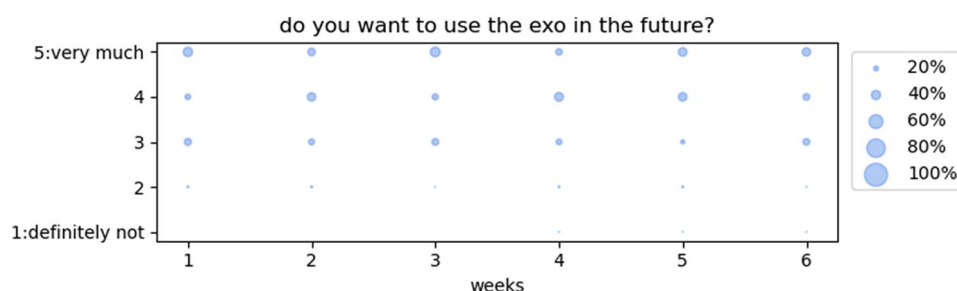
### Discussion

#### Overview

The aim of this field study was to gain insight into usage, work load and fatigue, behaviour, productivity and quality, advantages and disadvantages, and



**Figure 8.** Experienced advantages (pros) and disadvantages (cons) when working with the exoskeleton, as reported on a weekly (w1–w6) basis. The percentages of the number of respondents are shown. Multiple answers were allowed, adding up to totals exceeding 100%.



**Figure 9.** Will to use the exoskeleton. Percentage of respondents is represented by the size of the dots (see legend for reference).

acceptance of an arm support exoskeleton in plastering. This field study is to our knowledge the first study that provides exoskeletons to a target group and monitors the exo use as well as the afore mentioned aspects over a longer period of time.

### Exo usage per task

We studied the exoskeleton usage per task, and found that the usage for tasks that involve work at the ceiling are mostly associated with using the exoskeleton 'always' or 'often'. This is in line with previous findings, that showed the highest reduction in muscle activity and perceived exertion for tasks performed at the ceiling (de Vries, Krause, and de Looze 2020), and also showed the highest will to use the exoskeleton for tasks at the ceiling (de Vries, de Looze, and Krause 2020). Exo usage is dependent on the balance between advantages and disadvantages of using an exoskeleton. For example, the exoskeleton causes more hindrance and obstruction of movements in tasks that involve varied movements. The tasks with higher exo usage are likely to have characteristics that cause the advantages of exo use to outweigh the disadvantages. For example, applying gypsum on the

wall with a machine was also linked to high exoskeleton usage, in contrast to applying gypsum to the wall manually. When working with the machine, the plasterer holds a lance that puts out the gypsum instead of manually scooping the gypsum from the bucket. Therefore, the task characteristics change and becomes less dynamic, compared to manually applying the gypsum. The difference in exo usage between tasks, emphasises that preferably an exo is not used the entire day, but should be quickly donned and doffed for the appropriate tasks.

Other monitoring studies have also intended to measure exo use, by means of a built-in movement counter as well as pen and paper. However, these methods were found to be unreliable by the authors of this study, as the compliance was too low (Kim et al. 2021), which is in contrast to our study in which digital surveys were used.

### Load and discomfort

An effect of exoskeleton use on perceived load was found for three tasks (apply mach. wall, smooth wall, and apply manual wall), but was small. No effect of 'fanatically' using an exoskeleton on experienced

discomfort was found. The lack of (large) effects on discomfort and load can be explained by two opposing mechanisms. We could hypothesise that the experienced load and discomfort will be reduced when exo use is increased, but on the other hand, we could hypothesise that exoskeleton use will be higher for tasks that have a high experienced load. In this study, we wanted the plasterers to be free in the decision to use the exoskeleton in their work or not. Therefore, the design of this study is not optimal for studying the effect on load. Actually, we observed a clear load reducing effect (muscle activity and experienced load), in a previous study where we compared with exo vs. without exo conditions in a more controlled environment (de Vries, Krause, and de Looze 2020).

A limited amount of field studies already exist (Crea et al. 2021). For example, arm support exoskeletons were found to reduce experienced strain in neck, shoulder and spine in automotive (Hefferle, Snell, and Kluth 2021), and the effect of back support exos has been studied in farmers (Omoniyi et al. 2020). However, none of these field studies studied exo use over longer durations. The duration of these field studies were all in the range of hours, as opposed to several weeks, or even longer. The duration of six weeks seems reasonable for answering our research questions. However, much longer monitoring studies would be required in case we want to gain insight into the influence of exo use on the development of MSD's and long term health benefits. A relatively long monitoring study (18 months) at an automotive facility, reported no significant effects on perceived intensity and MSD scores (Kim et al. 2021). However, it was not clear to what extent the exo was used, which could have affected the impact on intensity and MSD figures.

### Behaviour

The use of the exoskeleton did not seem to change the plasterers behaviour in terms of taking breaks or changing working hours. It is worth noting that the planning of a plasterer's work day is largely dictated by drying times of the gypsum between the different tasks, and characteristics of the assignment, which leaves little room for changes in time planning.

### Performance and quality

It could be hypothesised that a device that is worn on the body, such as an exoskeleton, negatively affects the quality and performance of the work. On the other

hand, it could also be hypothesised that an exoskeleton increases performance. However, the plasterers reported no change in the performance or quality of their work. It is important for plasterers who are often self-employed or work for small businesses, that the exo does not negatively influence performance or quality. They are looking for solutions that reduce the physical load of their work, but it should have a minimal detrimental impact on the performance and quality of their work. From anecdotal evidence, back support exoskeletons were reported to have positive effects on productivity in farming activities, however for activities involving walking it was experienced as limiting their productivity (Omoniyi et al. 2020). Other studies showed negative effects on quality and performance in precise tasks (Alabdulkarim and Nussbaum 2019; Kim et al. 2018a). This emphasises that the results regarding productivity and quality are limited to plastering and might be extrapolated to similar tasks, but on work that differs and has different requirements, characteristics, and environments, might be differently affected by exo use.

### *What are the perceived advantages and disadvantages of using the exoskeleton?*

Regarding the mentioned advantages it is noteworthy that 36% mentioned they experience less pain when working with an exoskeleton. First of all, this indicates that the exoskeleton is experienced as effectively reducing pain in about a third of the participants, but secondly, it also indicates how many plasterers experience work related pain, and thus emphasises the importance of studies addressing work load in occupations like plastering. Forty-five percent indicates that they are *less tired* at the end of the day due to exo use. This causes plasterers to be less tired in their free time, which could affect quality of life. Finally, 93% experienced that the exo supported them, indicating that the exoskeleton does indeed provide support during this type of work. On the other side, the disadvantages that were experienced, such as '*doesn't fit well*' (25%), '*obstructs my movements*' (36%), and '*hinders me*' (60%), indicate that the exoskeleton is not experienced yet as a seamless human-machine interaction. From the interviews, we derived that hindrance is especially prevalent in smaller spaces, such as toilets and staircases. Future exoskeleton developments should focus on being less obtrusive and more adaptable to the work and the situation at hand.

Regarding the fit of the exoskeleton, in the first week, 43% of the respondents mentioned this as a

disadvantage, whereas after six weeks this was down to 25%, indicating that the exoskeleton requires some getting used to, and also reflects our effort to resolve issues regarding the fit in the first phone call at the end of week 1.

### *Would the plasterers use the exoskeleton in the near future?*

Plasterers will have to weigh their own advantages and disadvantages to decide whether they want to use the exoskeleton in the future. In our final week, 65% of the plasterers were positive towards using the exoskeleton in the future.

Since plastering is often performed in dusty and moist environments, it can be tough on the wear and tear of the exoskeleton. Whereas certain adjustments can be made to make the exo more rugged, such as additional dustcovers, but also cleaning and maintenance instructions, the plasterers kept the exoskeleton in their own possession for six weeks, without major technological challenges. The exoskeletons were used three times, so in total 18 weeks.

### *Limitations*

From (de Vries, Krause, and de Looze 2020) and the present study, we know that the exoskeleton is effective in reducing the load while a large number of plasterers are willing to use it in practice. However, scientific evidence that an arm support exoskeleton would really reduce the prevalence of musculoskeletal disorders (MSD) among plasterers is not yet provided. A much larger and longer study is needed to be able to monitor the development of MSD's over time.

The plasterers in this study volunteered to participate in this study, which results in a selection bias towards plasterers that have an interest in innovative solutions. However, it is still an interesting finding that in this group a large percentage was still enthusiastic about using the exoskeleton in the future. Furthermore, it is worth to mention that it was easy to find participants, indicating that a lot of plasterers are open to innovations that might help to reduce the load of their work.

### *Conclusions*

The use of the exoskeletons by the plasterers was quite high in tasks where the arms are continuously elevated, such as all plastering work at the ceiling, but also applying gypsum to the wall using a machine.

93% of the plasterers experienced a load-reducing effect of the exoskeletons, while 45% of the plasterers indicated less fatigue due to the exoskeleton. The plasterers did not experience any loss in performance because of exoskeleton use. After 6 weeks the majority of participants were still enthusiastic and willing to use the exo in their daily practice. The results of this monitoring study, together with previous work that found load reducing effects for plastering tasks encourage to make exo's accessible for plasterers, and labourers with comparable tasks, who want to use such a device.

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