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ARTICLE

The effectivity of a passive arm support exoskeleton in reducing muscle activation and perceived exertion during plastering activities

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ABSTRACT

The supportive effect of arm-support exoskeletons has been mainly studied for single postures or movements. The aim of this study is to analyse the effect of such an exoskeleton on shoulder muscle activity and perceived exertion, in six tasks of plasterers, each including multiple arm movements. The tasks of 'applying gypsum', 'screeding' and 'finishing' were performed at a ceiling and a wall, with exoskeleton (Exo) and without (NoExo). EMG was recorded of six muscles involved in upper arm elevation, four agonists and two antagonists, and plasterers rated their perceived exertion (RPE). In all tasks, the EMG amplitudes of three agonist muscles, Trapezius and Medial Deltoid, and Biceps Brachii, were lower in Exo vs NoExo, while the agonist, Anterior Deltoid, showed lower EMG values in Exo in most tasks. None of the antagonists (Triceps Brachii, Pectoralis Major) showed increased EMG values in the Exo condition. RPE's were lower in Exo condition for all tasks, except for 'applying gypsum to the wall'. Overall, the exoskeleton seems to reduce loads in realistic plastering tasks.

Practitioner summary: Exoskeletons are an emerging technology in the field of ergonomics. Passive arm support exoskeletons have mainly been tested in lab studies using continuous overhead work, involving one posture or movement. However, in reality, working tasks generally involve multiple movements. This study investigates the effectiveness of an arm support exoskeleton in work that requires multiple arm movements, specifically in plastering. Muscle activity, as well as perceived exertion were both reduced when working with an exoskeleton.

Abbreviations: Exo: with exoskeleton; NoExo: without exoskeleton; RPE: rated perceived exertion; EMG: electromyography; Trap: upper trapezius; AD: anterior deltoid; MD: medial deltoid; BB: biceps brachii; TB: triceps brachii; PM: pectoralis major; RPD: rated perceived discomfort; p50: 50th percentile; p90: 90th percentile; MVC: maximum voluntary contraction; GEE: generalised estimated equations

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KEYWORDS
Exoskeleton; construction; muscle activity; MSD; plastering

Introduction

Background

Heavy work is still prevalent in many sectors of industry. Percentages of workers in the EU that are exposed to 'tiring or painful positions', 'carrying or moving heavy loads' or 'repetitive hand or arm movements' for more than a quarter of their working time, are 43%, 32% and 61%, respectively (Eurofound 2017).

A specific type of heavy work in construction, maintenance, assembly, and other sectors, is work that requires the arms to be elevated frequently or for prolonged periods of time. Elevated arm work induces mechanical strain and fatigue in the shoulder region and is associated with the development of musculoskeletal shoulder disorders (Svendsen et al. 2004; Van Rijn et al. 2010).

A relatively new strategy to support workers that are exposed to elevated arm work is the use of arm-support exoskeletons. Several arm-support exoskeletons, mainly spring-based (passive) devices, have been developed and are currently adopted in real-life work settings.

The effect of arm support exoskeletons on parameters like muscle activity, internal forces and moments and subjective measures of load, have been frequently studied in tasks with prolonged upper arm elevation with little changes in shoulder angles, like overhead drilling or assembly (de Vries and de Looze 2019; McFarland and Fischer 2019). Recent reviews show that passive arm-support exoskeletons are effective in

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reducing the activation of the main muscles involved in upper arm elevation (agonists for overhead work): the Upper Trapezius (Trap) and the Anterior Deltoid muscle (AD) or Medial Deltoid muscle (MD) (de Vries and de Looze 2019; McFarland and Fischer 2019). Most studies report reductions in agonist muscle activity: 30–60% for the AD and around 30% for the MD (de Vries and de Looze 2019; McFarland and Fischer 2019). However, for muscles opposing arm elevating movements (antagonists for overhead work), such as the Triceps Brachii (TB), decreases as well as increases in muscle activity have been reported (de Vries and de Looze 2019; de Vries et al. 2019; Theurel et al. 2018). For subjective ratings of perceived exertion (RPE) and discomfort (RPD), a positive trend can be observed as studies report positive or non-significant changes (de Vries and de Looze 2019; McFarland and Fischer 2019). One study showed negative effects on ratings of perceived discomfort when exoskeletons with supernumerary limbs were used (Alabdulkarim and Nussbaum 2019).

The reduction in muscle activity of the agonist muscles can be explained by the passive exoskeleton's mechanism, where spring-like materials are stretched and loaded. The loaded springs generate a supportive force, which contributes to the shoulder moment that is required to keep the arms elevated. The force required to load the springs is provided when the arms are lowered with the help of gravitational forces. This may require additional antagonistic muscle activation depending on task characteristics (mass of the load or tool handled, shoulder angle and posture) and the exoskeleton's supporting forces.

Many tasks do not comprise of single working postures or movements but involve many different movements and postures. Multiple arm movements are required, in different planes, various arm postures, with different movement speed, pressure in different directions and various tools. Here, some of the tasks may benefit from the spring-based support, while other tasks would require more effort, as they require movements against the force of the springs. For these tasks, it can be questioned what effects on the activation of shoulder muscles will be and how this will affect the perceived exertion.

Aim

In the present study, we aim to show the effect of a passive arm-support exoskeleton in realistic working tasks, comprising of many movements (in different directions) and postures, notably the tasks of plasterers. We are interested in shoulder muscle activity over total task duration. Specifically, 50th percentile (p50) and 90th percentile (p90) of the muscle activity over the recording period of each task. The hypothesis is that exoskeleton use would lead to a reduction in the activity of the agonist muscles, while the activity of antagonists might increase due to the loading of the springs. Furthermore, we aim to show the effects of the exoskeleton on the subjective rating of perceived exertion.

Methods

Participants

Eleven male participants were recruited via internet, social media and word of mouth. They were active plasterers, without musculoskeletal disorders that would prevent them from carrying out their normal plastering activities, at the moment of testing. For one subject, the EMG measurements could not be used, due to technical issues during the maximum voluntary contractions (MVCs). Participants signed an informed consent document, approved by the ethics committee of TNO, after being informed about the procedures of the experiment (Table 1).

Table 1. Subject characteristics.

Variable	Mean ($n = 11$)	SD
Age (y)	36.2	8.4
Length (cm)	183.1	8.3
Weight (kg)	88.8	12.1
Preferred hand	4L, 7 R	

Setting

Before setting up this experiment, several building sites were visited to observe plastering activities. Roughly, the work of a plasterer consists of three activities. Figure 1.

The first task is applying the gypsum. After the gypsum is mixed it is applied to either wall, by an upward movement, or ceiling, by a backwards backhand movement: for both wall and ceiling, this is done with the dominant arm, in the direction of the hand back, by external rotation and flexion of the shoulder while holding a trowel with a pronated wrist.

The second task is screeding. During screeding, the gypsum is spread and evened out over the surface with a straight edge (150 cm). This task is mainly performed in an upward direction (wall), or backward direction (ceiling), with supinated wrists.

The final task is finishing with a spatula: After a drying period, the wall is finished with a squeegee knife,

Figure 1. Overview of the set-up and activities on the ceiling. (A) applying the gypsum to the ceiling, (B) screeding and (C) finishing with a plastering spatula.

to create a smooth final surface. Movements in this task are more variable, depending on the area that needs to be smoothed. Plasterers indicate that more force is exerted on the surface while performing this task.

Between tasks, (sub)movements and tool usage can differ and therefore have their biomechanical consequences. In this study, we are interested mainly in the overall exoskeleton effect within each of the tasks and therefore do not elaborate on the differences between tasks.

In practice, the surface is generally screeded a second time, and a final sanding can be performed depending on the required level of finishing. This would have elongated the experiment's duration substantially due to drying times, without significantly adding to the movement diversity. We, therefore, chose to limit the experiment to single execution of each of the above-mentioned tasks.

Based on our observations, we defined the tasks and order of tasks to be performed as indicated in Figure 2.

After task 4 was completed, a professional plasterer determined when the surface was ready for the finishing procedure with the aim to let the surface dry to the same level for each participant (±20–25 min between task 4 and 5), during which the participant could rest. Participants had a 10 min break between Exo - NoExo conditions, in addition to the drying time between task 4 and 5.

The duration of each task for the Exo and NoExo conditions is presented in Table 2. Repeated measures ANOVA showed that the exoskeleton condition had no significant effects on the duration of the tasks.

The experiment took place in a facility for education and examination of plasterers, where booths are present with standardised dimensions and working surfaces (NOA, Veenendaal, The Netherlands). The plasterers had to complete a wall of 4 m^2 and a ceiling of 2 m^2. Quick dry gypsum was used to allow for less dry time between plastering activities.

Each participant completed the plastering activities, in two separate booths. In one booth the activities were performed without and in the other booth with an exoskeleton (Skelex 360, Rotterdam, The Netherlands). The gypsum was prepared for the plasterers, using a water dosing unit to control the consistency of the gypsum.

Procedures

Before the experimental procedure, surface electromyography (EMG) electrodes were applied and maximal voluntary contraction (MVC) measurements were performed on four main agonists (involved in raising the arm) and two antagonists (involved in lowering the arm). The activity of four agonist muscles: Anterior Deltoid (AD), Medial Deltoid (MD), Trapezius pars descendens (Trap) and Biceps Brachii (BB) as well as antagonist muscles: Triceps Brachii (TB), and Pectoralis Major (PM) were measured using bipolar Ag/AgCl (AMBU Blue Sensor N) electrodes, which were recorded using a Porti 7 system (TMS, Enschede, The Netherlands). The locations of the electrodes and procedures for obtaining MVCs were chosen according to guidelines by Hermens et al., n.d.; Konrad 2005. EMG signals were sampled at a rate of 2048HZ. EMG signals were further processed in MATLAB R2019b, where they were bandpass filtered at 25–500 Hz (De Luca et al. 2010), rectified, smoothed using MOVAG with a window size of 200 ms and normalised to MVC values (Konrad 2005). MVC measurements were performed against manual resistance (Hermens et al. 1999; Konrad 2005). The MVC value for each muscle was obtained by taking the maximal obtained smoothed EMG signal over three trials. Even though we encouraged participants to reach maximal contractions, they might not be able to reach their full MVC's in the experiment. Therefore, MVC values reported in this paper should be considered as the maximum obtained in this experiment.

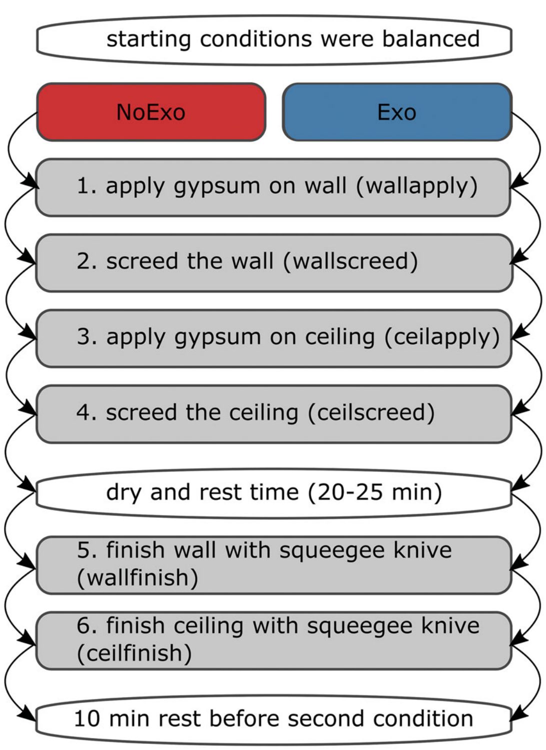

Figure 2. Experimental design and order of tasks to be performed in Exo and NoExo conditions.

Half of the participants started with the exoskeleton condition. An ergonomics expert helped with instructions and fitting of the exoskeleton. The support setting was set at about half way and was not adjusted between subjects or tasks. The first tasks were applying and screeding of the wall and then the ceiling. After each task was finished, participants were asked to rate their perceived exertion (RPE). The RPE and 6–20 point Borg scale with descriptions, was shown to the participants before the experiment and each time when they were asked to score a task.

Statistics

Muscle activity

Our aim was to assess the effect of the exoskeleton on muscle activity over the whole duration of each working task. Therefore, we chose to calculate the 50th percentile and 90th percentile over the whole EMG signal of each task, for each muscle. Generalised Estimated Equations (GEE) were used to test for main and interaction effects of exoskeleton condition (Exo

Table 2. Duration of tasks in minutes shown as: mean (sd).

	Wall			Ceiling		
	Apply	Screed	Finish	Apply	Screed	Finish
Exo	7.06 (1.94)	2.26 (0.96)	4.14 (1.29)	4.99 (1.65)	1.88 (0.49)	3.47 (1.67)
NoExo	6.79 (1.76)	2.28 (1.58)	4.53 (1.14)	5.12 (1.58)	2.01 (0.97)	3.50 (1.37)

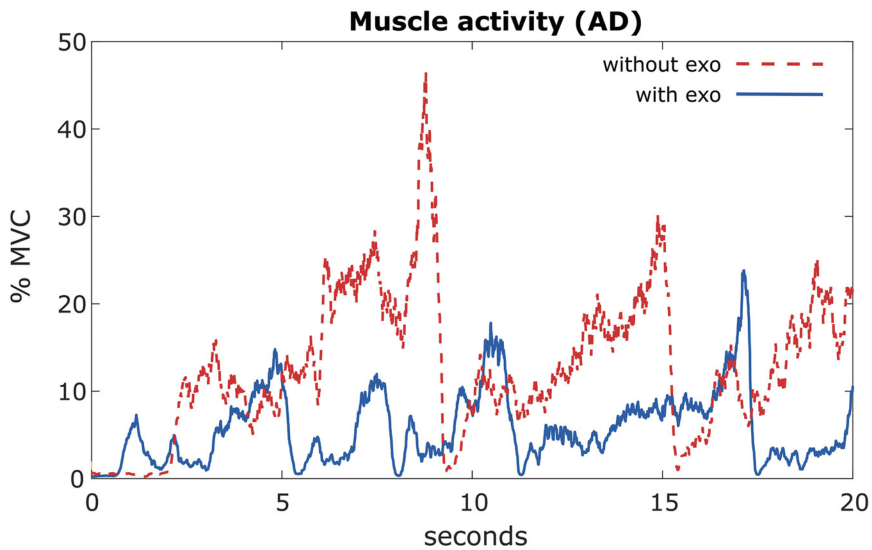

Figure 3. Typical example of muscle activity of the Anterior Deltoid muscle (AD), Exo (solid blue) and NoExo (dashed red) during the task: finishing of the ceiling.

or NoExo) and task (apply, screed, finish, on wall and ceiling) on p50 and p90 for each muscle. When interaction effects were found, differences between Exo and NoExo conditions were analysed per task. Post hoc pairwise comparisons were done after Bonferroni corrections were applied.

Perceived exertion

Generalised Estimated Equations were used to analyse the main and interaction effects of exoskeleton condition and task on the ordinal response variable RPE. When interaction effects were found, we followed up with nonparametric Wilcoxon signed rank tests, to evaluate the differences between Exo and NoExo conditions. Statistics were performed in IBM SPSS 25.

Results

Muscle activity

A typical example of muscle activity recorded during a selected period of finishing of the ceiling is shown in Figure 3. This paper further elaborates on the p50 and p90 values of the signals as obtained over the whole duration of each task (duration of tasks is shown in Table 2).

All main effects of exoskeleton condition and interaction of exoskeleton * task on muscle activity are reported in Table 3. All significant effects indicate a reduction in muscle activity in the exoskeleton condition. No significant increase in muscle activity was observed, in the Exo versus NoExo condition, for any of the studied muscles or tasks.

The slope of the lines in Figure 4 indicates the differences in muscle activity between Exo vs NoExo conditions. Almost all slopes are negative (statistical significance is discussed below), however, during some tasks, muscle activation of antagonist muscles (TB and PM) only slightly increased, but never reached significance (Table 4; Figure 4). The MD and Trap showed significant reductions in muscle activity when wearing an exoskeleton, for all plastering activities, both for p50 and p90 values (Figure 4; Table 4).

Table 3. GEE results on the effects of exoskeleton and exoskeleton × task on muscle activity.

Muscle	Var	Exo	Exo * Task
AD	p50	χ^2 **= 12.28, *p* < .01**	χ^2 **= 60.70, *p* < .01**
	p90	χ^2 **= 8.38, *p* < .01**	χ^2 **= 63.13, *p* < .01**
MD	p50	χ^2 **= 18.66, *p* < .01**	χ^2 **= 18.66, *p* < .01**
	p90	χ^2 **= 6.87, *p* < .01**	$\chi^2 = 8.56, p = .125$
Trap	p50	χ^2 **= 26.27, *p* < .01**	χ^2 **= 29.07, *p* < .01**
	p90	χ^2 **= 6.61, *p* = .01**	$\chi^2 = 4.06, p = .540$
PM	p50	χ^2 **= 4.13, *p* = .04**	χ^2 **= 25.68, *p* < .01**
	p90	$\chi^2 = 2.56, p = .11$	$\chi^2 = 8.35, p = .14$
BB	p50	χ^2 **= 9.48, *p* < .01**	$\chi^2 = 8.80, p = .117$
	p90	$\chi^2 = 2.60, p = .11$	$\chi^2 = 9.58, p = .09$
TB	p50	$\chi^2 = 3.83, p = .50$	χ^2 **= 17.59, *p* < .01**
	p90	$\chi^2 = 0.81, p = .37$	χ^2 **= 136.24, *p* < .01**

Statistically significant values ($p < .05$) are shown in bold.

An overview of post hoc results, comparing both conditions, ordered per task, is provided in Table 4. During finishing of the wall, applying on the ceiling and finishing of the ceiling, muscle activity of muscles (AD and MD and Trap) was reduced in the Exo condition, both for p50 as well as p90 values. BB showed small but significant reductions for all tasks, but only in p50 values. For some activities, antagonist muscles (TB, PM), showed significant decreases in muscle activity (Table 4). However, these reductions were always small (Figure 4). Further details on the statistical analysis can be found in the supplemental appendix.

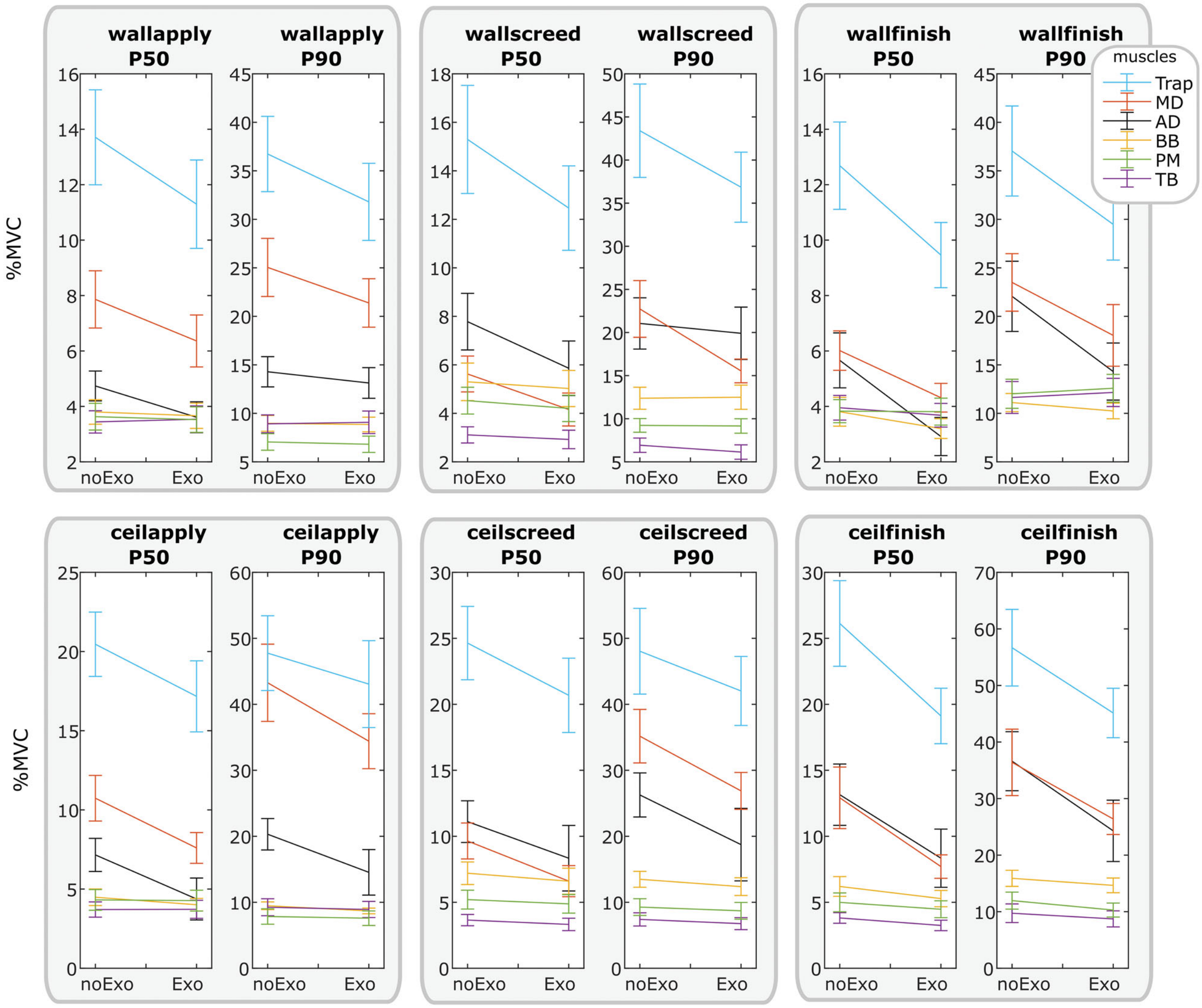

Figure 4. Muscle activation in Exo and NoExo conditions for different plastering tasks. Each panel represents one plastering task, upper row shows working on the wall, lower row shows working on the ceiling. Graphs show the mean and standard error of the mean for each muscle. The slope of the lines indicate the change in muscle activity. Note that the scaling of the figures differs across tasks to optimise the visualisation of the changes within each task.

Table 4. Significant ($p < 0.05$) reductions of muscle activity in Exo conditions are marked per task (✓) (Post Hoc results).

	Trap		MD		AD		BB		TB		PM	
Task	p50	p90	p50	p90	p50	p90	p50	p90	p50	p90	p50	p90
Wall apply	✓	✓	✓	✓	✓		✓[a]					
Wall screed	✓	✓	✓	✓	✓		✓[a]		✓[a]			
Wall finish	✓	✓	✓	✓	✓	✓	✓[a]		✓[a]			
Ceil apply	✓	✓	✓	✓	✓	✓	✓[a]					
Ceil screed	✓	✓	✓	✓			✓[a]		✓[a]		✓[a]	
Ceil finish	✓	✓	✓	✓	✓	✓	✓[a]		✓[a]		✓[a]	

[a]For some activities the muscles TB, BB and PM, showed significant but small decreases in muscle activity. These are indicated ✓.

Table 5. GEE results on the effects of exoskeleton and exoskeleton x task on ratings of perceived exertion.

Independent variable	Wald Chi-square	df	Sig.
EXO	91.215	1	**< .001**
Task	6.611	5	.251
Task * EXO	32.672	5	**< .001**

Dependent Variable: RPE.
EXO (Exo or NoExo), Task (apply, screed, finish on wall and ceiling). Statistically significant values (p< .05) are shown in bold.

Perceived exertion

The main effects of exoskeleton condition and interaction of exoskeleton * task are reported in Table 5. A significant Exo * tasks interaction was found ($\chi^2(5) = 32.672$; $p < .001$). Wilcoxon tests were used to follow up this finding (Table 6) which showed that for all activities, except for applying on the wall, RPE was significantly reduced. All effect sizes are above Cohen's benchmark for non-parametric statistics of .5 indicating a large effect size. Differences in RPE between Exo conditions per task are shown in Figure 5.

Table 6. Post hoc Wilcoxon signed rank tests for ratings of perceived exertion.

Task	Test statistic	Effect size (*r*)	*p*-Value
Wallapply	5	−0.56	.066
Wallscreed	1.5	−0.81	**.007**
Wallfinish	6	−0.73	**.015**
Ceilapply	0	−0.89	**.003**
Ceilscreed	0	−0.89	**.003**
Ceilfinish	0	−0.89	**.003**

Statistically significant values ($p < .05$) are shown in bold.

of the tasks. Moreover, the perceived exertion as obtained after completion of the tasks was also generally reduced.

Muscle activation

We analysed muscles that generally share the function of lifting the arms with the exoskeleton, namely the agonist muscles AD, MD, Trap and to a lesser degree

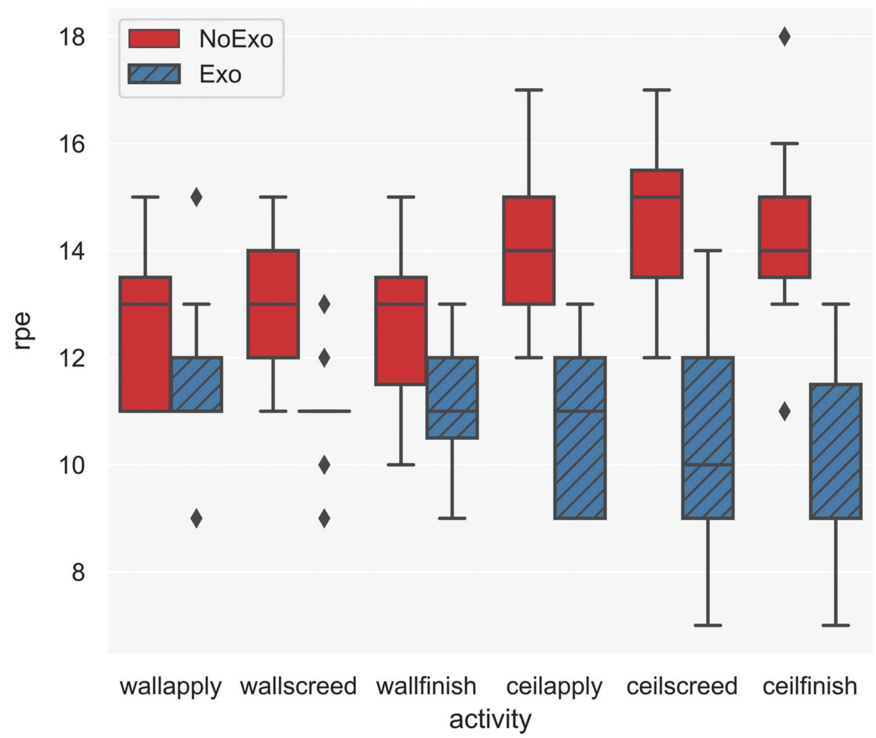

Figure 5. Ratings of perceived exertion in Exo and NoExo conditions Striped blue and plain red boxes represent Exo and NoExo conditions respectively. Boxes range from the 25th to the 75th percentile, whiskers represent the data range and median is indicated with a solid line, diamonds show outliers.

Discussion

The effects of arm-support exoskeletons are mostly defined in tasks involving limited postures and movements, in which arm positions remain relatively stable, such as overhead assembly and drilling. Many tasks do not comprise of single working postures or movements but involve many different movements and postures. In the current study, we investigated the effects in plastering tasks, involving a large variety of arm movements in multiple directions, with varying speed and amplitude, some of which oppose movements supported by the exoskeleton. Therefore, only part of these tasks could be expected to be supported by the exoskeleton. Nonetheless, significant reductions in muscle activity due to the exoskeleton were found for some shoulder muscles, while none of the muscles studied showed a significant increase in activity in any BB. We also analysed muscles that act in opposing direction, in lowering the arms, namely the antagonists TB and PM. Based on the working mechanism of the exoskeleton, a reduction in agonist muscle activity was expected, while for the antagonists an increase in activity could be expected.

However, we did not find a significant increase in muscle activity for the antagonist muscles (nor for the other muscles). Actually, we found significant reductions in p50 values for TB and PM, but not necessarily relevant, considering the small size of the effect. However, for the antagonists TB and PM, it is already remarkable that no significant increases in muscle activity were found. The absence of an increase in antagonist muscle activity in our study could be explained by our data analysis. We defined p50 and p90 values over the whole duration of each task. It is possible that in these measures, any increased activity during short time periods is smoothed out when considering the total task time. However, even for p90 values, in which short durations of increased activity have a more pronounced effect, no negative effects of wearing an exoskeleton were found.

Other explanations could be found in the limited support the exoskeleton provides, namely lower than arm's weight. Therefore, relaxing the arm is enough to move the arm against the direction of the supportive force, when the body is upright. Lowering the arm, is in most activities shorter in duration than raising the arm, or keeping it raised. Combined with slow movements and slow changes in joint angle, counteractive effects from the exoskeleton on antagonists can be expected to be small to absent. During work on the ceiling there are limited to no movements made that the exoskeleton counteracts.

As expected, the agonist muscles showed the largest reductions when wearing an exoskeleton. For the MD and Trap, the exoskeleton was effective in reducing median (p50) and extreme (p90) values of muscle activation in all tasks. For AD, the p50 and p90 values were reduced for finishing of the wall and applying and finishing on the ceiling. Furthermore, p50 (median), but not p90 (extreme) values were reduced during applying and screeding of the wall. Although kinematics are lacking to support the following speculation, it might be because applying and screeding on the wall, involve the largest variation in movements. For these tasks, the work is performed at different heights (at the bottom as well as the top of the wall). When applying, the plasterer has to move away from the wall to put the gypsum on his hawk and when screeding the wall, the screed was rotated to accommodate for the relatively narrow working space. The variation in these activities can explain the absence of a significant effect on the p90 values for the AD during applying and screeding of the wall. A reduction in agonist muscle activation during real working activities was previously shown in automotive industry. Anterior Deltoid and Biceps Brachii activity was reduced during tasks at the end of a workday when wearing the exoskeleton (Gillette and Stephenson 2019).

Subjective measures

The perceived exertion was in general positively affected using an exoskeleton. For all tasks, but one, namely applying on the wall, the perceived exertion was reduced when the exoskeleton was worn. As discussed above, applying on the wall, is a task, which involves working at different heights and involves subtasks, such as collecting the gypsum. During tasks involving various movements, passive exoskeletons typically are not as effective as during less varied tasks (de Looze et al. 2016; de Vries and de Looze 2019). Therefore, the movement variation during applying on the wall, might explain the absence of significant reduction in RPE for this task. Reductions in RPE, were mostly larger for the tasks at the ceiling. This is in line with our results regarding muscle activation: reductions in muscle activation were larger when working on the ceiling, therefore perceived exertion seems to coincide with measured exertion levels.

In previous studies, generally positive subjective experiences with exoskeletons were reported, although some issues regarding thermal comfort and concerns about hindrance during working tasks were raised as well (McFarland and Fischer 2019; Smets 2019). Subjective experiences in exoskeleton use were mainly evaluated by means of the ratings of perceived discomfort (RPD). The RPD was found to be reduced when using an exoskeleton in overhead drilling in the upper arm, shoulder and lower back area (Rashedi et al. 2014), in the forearm when a heavy tool was used (Kim et al. 2018) and in neck and shoulders in automotive industry (Smets 2019). Whereas RPD is a subjective measure of local discomfort, and RPE of global effort, our positive findings on RPE are in line with the trend of positive subjective feedback. Moreover, our study adds to this research by showing that these results translate to realistic working tasks that involve more varied movements.

The adoption of exoskeletons will only be successful if the experienced benefits of using the exoskeleton outweigh the limitations of an exoskeleton (Davis 1989; de Looze et al. 2001; Marangunić and Granić 2015). Subjective measures such as the perceived exertion, give insight into the user experience. However, these measurements are generally performed during the working tasks, whereas the adoption of exoskeletons is likely also to be influenced by factors outside of the primary tasks, such as donning and doffing, ease of use, appearance and costs (Baltrusch et al. 2020). The plasterers generally reported that they were willing to use the device in their work, but there were also some points of improvement considering wearing comfort, such as issues with the arm cuffs and size of the device, which could cause hindrance during specific working tasks (de Vries, de Looze, and Krause 2020). How this will affect the adoption of exoskeletons on a larger scale will have to be tested in longitudinal monitoring studies, where the behaviour and use of an exoskeleton is monitored and workers report their experience in working with an exoskeleton in everyday use.

Limitations

In our testing protocol, participants were not subjected to a familiarisation period. Neither did we adjust the support level of the exoskeleton to the physique of each individual. It is not clear how these aspects of our set-up have affected our findings.

In this study, the effect of an exoskeleton on muscle activation was evaluated. A reduction in agonist muscle activity indicates that part of the required moment is provided by the exoskeleton, which alleviates the muscles involved in raising the arms. A reduction in muscle activity is likely to reduce or delay muscle exhaustion and is related to reduced strain in the muscles, on tendons and ligaments. These effects may result in a reduction of prevalence of work-related MSDs (Jaffar et al. 2011), but the eventual effects of exoskeletons on MSDs will need to be studied on a larger scale.

The tasks that were evaluated in this experiment are very similar to the actual work of plasterers, which was part of the aims of this study. However, compared to a realistic working day or week, the tasks are still relatively controlled. This controlled environment is inherent in a within-subjects study evaluating muscle activity. However, to gain insight into the user experience and bottlenecks of implementing exoskeletons in everyday use, pilots are needed that follow a larger group of workers over a longer duration. Despite these uncertainties, the findings in this study as well as the reported will to use the exoskeleton are promising and encourage the implementation in larger scale studies.

Conclusion

Through an experimental study with a strong focus on realistic working activities for plasterers, this study evaluated the effectivity of an arm support exoskeleton to reduce muscle activation as well as perceived exertion. Muscle activation was reduced in all tasks for most agonist muscles, especially for tasks that require less varied movements and which involve overhead work. Similar results were found for the perceived exertion, with stronger reductions in RPE for working above the head. For all tasks but one, a reduction was found in RPE. For applying gypsum on the wall, which involves more varied movements, no reduction in RPE was found. Results are promising for exoskeleton application by plasterers, nevertheless, also require more research.

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Disclosure statement

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