Investigating the effects of passive exoskeletons and familiarization protocols on arms-elevated tasks

Aurélie Moyon[a,b], Jean-François Petiot[a] , Emilie Poirson[a],*

[a]Ecole Centrale de Nantes, LS2N (UMR CNRS 6004), 1 rue de la Noë, 44321 Nantes Cedex 3, France bEurope Technologies, 2 rue de la fonderie, 44470 Carquefou.

Abstract

Exoskeletons present interesting qualities for high demanding physical tasks, but their integration in companies is still a challenge. This study aims to evaluate the effects of exoskeletons on the completion of arm-elevated tasks. Three categories of dependent variables are studied in a lab experiment: physical measurements (cardiac cost), performance indexes (quality and duration) and perceived benefits (reported by subjects on quantitative scales). The independent variables of the experiment are the presence (or not) of the exoskeleton, and the media used for the familiarization process of the subject before the use of the exoskeleton. Two levels of familiarization are proposed to the subjects: brochure of the exoskeleton manufacturer, and live tutorial demonstration by a skilled experimenter. A laboratory study (n=36 participants) involving two arms elevated tasks was specifically designed to simulate industrial work situations. Results show that the use of the exoskeleton reduces cardiac cost, global and local perceived effort, number of errors, and increases task performance. Concerning the familiarization process, the live tutorial demo provides higher task performances and users acceptance, lower global and local perceived effort and the number of errors. These results confirm that user acceptance and integration of exoskeletons in companies require dedicated training supports.

Introduction

Passive exoskeletons started to enter the market of New Assistive Technologies (NAT) in various industries where handling tasks are still involving human control and know-how. This growing interest forces companies to relate the claimed effectiveness of occupational exoskeletons as a solution that could release muscle activity and task-related strain. Even if functional effects have been established in reducing muscular demand (Huysamen et al., 2018; Theurel & Desbrosses, 2019) these exoskeletons are still facing ergonomics barriers such as discomfort (de Looze et al., 2016), movements limitations, low usability and acceptance of end-users. (Graham et al., 2009).This is why previous studies suggest a more holistic approach (Bosch et al., 2016) to investigate dimensions of usability, moreover on realistic work settings (Baltrusch et al., 2018). Recent studies suggest focusing on the actual use, to better understand expected and potential unexpected effects (Kim et al., 2018). This is why the evaluation of Human Exoskeleton Interaction (HEI) should focus on Usability. Last years, Europe Technologies has been training future users and product managers to the use of exoskeleton, in order to enhance potential adoption. However, no evidence has been found on the effectiveness of a specific familiarization protocol on user's acceptance and on task-related performance. Consequently, the main

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purpose of the current study is to validate the claimed positive effects of the exoskeleton prototype, as well as the effectiveness of a familiarization protocol on objective performance, perceived benefits and user acceptance. A second aim is to highlight specifications of human-exoskeleton interaction to guide further product development and familiarization program. The remainder of the paper is organized as follows. The second section presents the material and method and the description of the experiment. Results are presented in third section. The concluding section provides implications and perspectives for further work.

Materials and methods

Participants and ethics approval

36 healthy participants (50% male, 50% female) with no current injuries / musculoskeletal disorders volunteered and gave written consent before the experiment according to the tenets of the Declaration of Helsinki. Current health status was evaluated using the Nordic questionnaire (Descatha et al., 2007). Their age span from 20 to 65 years old with a range of height between 163 to 175cm. Participants had never been trained to use exoskeleton nor performing tasks.

Occupational exoskeleton

The exoskeleton used is a wearable passive system provided by our partner *SkelEx* (SkelEx, Rotterdam, The Netherlands). It was co-developed with this partner from various field studies and user's feedbacks (Moyon et al., 2018). As shown in figure 1, its design is based on a backpack style with two flat springs in the back that can store kinetic energy when lowering the arms. Reversely, the spring strength is then applied upwards and help reducing upper body strain while performing arm-elevated tasks. This constitutes the first independent variable of our experiment with the two conditions (Exo/No Exo). Two versions of the prototype called Exo A and ExoB have been tested for a secondary design purpose, so differences won't be discussed here. All variables were tested for both versions, results are merged into an Exo condition.

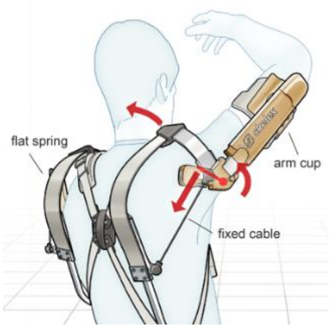

Figure 1. Product architecture and the mechanical principles underlying the of operation of the tested exoskeleton prototype.

Familiarization protocol

In our observations of the spreading to exoskeletons in industry, we noticed that companies are starting to buy exoskeletons without considering the familiarization phase and potential fail of acceptance for occupational use. In order to protect future users, the French Institute of normalization is working on an agreement and a potential future norm about Human-Exoskeleton Interaction ergonomics. Europe Technologies takes actively part in this project, by sharing field insights. A global acceptance program has been designed to foster better integration of exoskeletons in companies.

A key element of this program is a familiarization protocol (labelled F2), designed to optimize user's performance and acceptance. It is based on our previous expertise to give users the best level of knowledge and practice in the shortest amount of time (to match real-time constraints). To do so, this protocol F2 is composed of the following steps: Demystification, Technics, Potential, Limits, Donning/Adjusting/doffing, Free experience (without industrial constraints) and training scenarios. It aimed at providing certification of a level 4 based on a 1-7 scale of knowledge/practice (Appendix 1). Level 4 means that participants are aware of basic technical, safety and usability principles, and know how to don/doff quickly the exoskeleton. In the following experiment, F2 is performed by a skilled experimenter and materialized by a written script. Another familiarization protocol, F1, corresponds simply to the manufacturer's brochure, materialized by a paper brochure. The two familiarization protocols (F1 or F2) were administered to the participants before the execution of the task. This constitutes the second independent variable of our experiment. Between tasks, participants could adjust the exoskeleton again if needed. They could read the brochure F1 or ask the experimenter to repeat an item in tutorial F2. But the experimenter couldn't take any additional initiative, to not distort the results.

Testing equipment

The heart rate was measured in real-time during the tasks. We used a heart rate computer (RS800CX, Polar Electro, Kimpele, Finland) and its dedicated professional software (Polar Trainer 5, Polar Electro, Kimpele, Finland). This system is composed of an emitter attachable on a thoracic belt. The data transfer was realized from the emitter to the software by an infrared USB adapter. For precision task performance, user lines were obtained by an interactive whiteboard SMART Board 800. This system projects and records automatically produced pixels. 1 pixel = 1mm. All tasks were camera recorded to help further interpretation of results.

Design of experiments

For a secondary product design purpose, all participants tested two versions of the exoskeleton prototype called A and B, so as the NoExo condition. Concerning the familiarization protocol, given that protocol F2 is more informative than F1, it was irrelevant for the same participant to test protocol F1 after F2. For this reason, the only possible orders for the test were F1->F1, F1->F2 or F2->F2. To limit the number of experiments (two tests with two exoskeletons A and B), a balanced incomplete block design was defined, presented in table 1. Six blocks were considered, with six participants in each block.

Table 1. Experimental design for the two variables Exoskeleton and Familiarization protocol with two conditions (NoExo/Exo) and (F1/F2). The rows correspond to the first combination tested by the participants, the column to the second (for example, 6 participants tested first ExoB with protocol F1 (BF1), then ExoA with protocol F1 (AF1).

	AF1	AF2	BF1	BF2
AF1			6	6
AF2				6
BF1	6	6		
BF2		6		

Previous analysis of industrial tasks

Assembling tasks involve arm-elevated postures that could be assisted by an exoskeleton. The manufacturer *SkelEx* (SkelEx, Rotterdam, Netherlands) provided the model that was designed specifically to assist the strain related to this posture. Constraints of the real work situation such as average duration of steps, the weight of the tool, precision standards have been integrated into the lab experiments. Experiments took place between January and May 2019 on the site of LS2N laboratory, Nantes.

Lab tests

From an analysis of the previous industrial tasks, a controlled laboratory experiment was built in order to not disturb the manufacturing process of the industrial. These tasks in a laboratory have furthermore the following advantages:

- To measure more easily the effects of the exoskeleton and the familiarization protocol on user performance, perceived benefits, and acceptance with a reproducible procedure.

- To involve more participants, with a larger diversity of profiles

The idea was to create a simple laboratory protocol that could easily evaluate the potential of exoskeletons for repetitive and precision tasks.

Repetitive task (R):

According to real constraints observed previously, a repetitive task was designed to reproduce arm-elevated posture (Figure 2). A board with eight lines of industrial nuts was placed vertically on the wall. The size and height of the board were adjusted so that any participants could reach at least 7/8 lines with a tool of 6kg. Setting movements were paced at 20 actions/min using a metronome. Participants had to set as many nuts as they can. They stopped when they experienced fatigue or high discomfort or failed pace three times in total. Errors were observed: nuts should be correctly set, we tolerated a space of 5 millimetres corresponding to nut thickness. Data collected were: total time, time per line, number of nuts correctly set, number of errors/line.

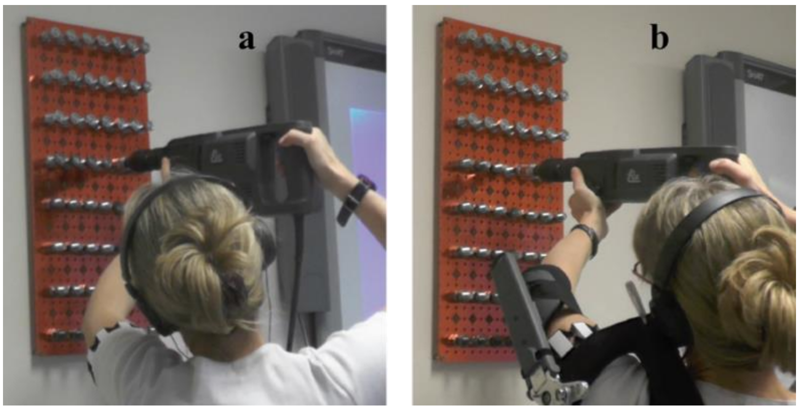

Figure 2. (a) A participant without the exoskeleton performing the repetitive task R and with the exoskeleton (b).

Precision task (P):

This task aimed at testing the potential benefits of wearing the exoskeleton (less perceived effort and fatigue, respect of quality and natural moves) while performing repetitive and accurate movements, as observed in the real work situation. A background of lines was projected on the wall by an interactive whiteboard system (Figure 3). The test consisted of redrawing the same signs with an interactive pen with maximum accuracy. Seven lines of ten signs each are displayed on the background. Participants started by the line at their eye-level and moved progressively upward to an overhead position. They had to stand behind a line placed at 40cm from the wall but could move parallel to the wall. Distance from the wall was visually controlled so that arms elevated posture targeted by assistance would be respected. The test ended when participants experienced fatigue, discomfort or traced all signs. Movements were paced at 4 second/sign using a voice recorded metronome. Data collected were: traced signs, time per line, number of completed signs, and number of errors/line.

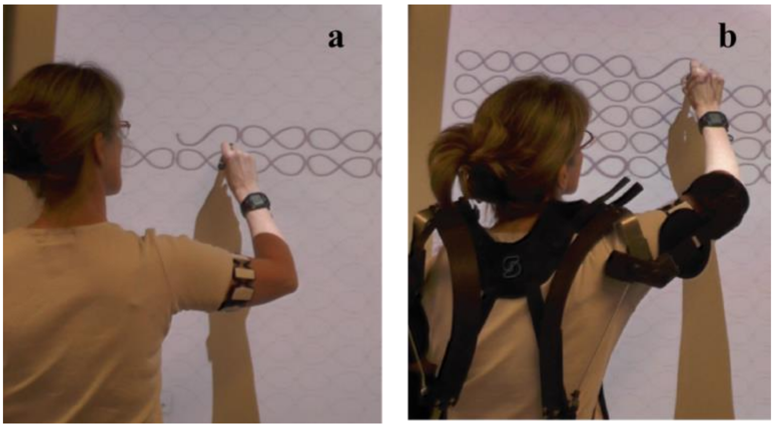

Figure 3. (c) A participant performing the precision task P without exoskeleton (a) and with the exoskeleton (b).

Objective measurements

Familiarization performance of donning/adjusting

Familiarization performance was measured using a chronometer for doffing/donning procedure after the participant had been taught about the exoskeleton using either the brochure or a tutorial (F1, F2). Measurements were organized as follows:

- 5 minutes for the participant to read the manufacturer's brochure or to listen to the tutorial performed by a qualified instructor;
- 3 minutes for the participant to then individually test the exoskeleton;
- 3 minutes for the participant don the exoskeleton and adjust it.

Global physical workload

This work situation has been previously targeted by an internal ergonomic study. Laboratory tasks were designed to approach real perceived effort with similar postures and duration constraints. The condition Exo/NoExo was measured on both tasks R and P, always in the same order and separated by a break while they seated. A reference heartbeat (HR) was recorded while seating 5min before performing the task. Activity blocks were analyzed with the conditions Exo/NoExo. The measurements were separated by a 10 minutes break while operators remained seated. According to

Meunier protocol (Meunier, 2014), in order to compare two different conditions of the activity (NoExo, Exo), we calculated the Absolute Cardiac Cost (ACC) according to the duration of the activity. ACC is the difference between the average heart rate (Ha) and the Reference Heart rate (Hr) and it is expressed in beat per minute (bpm). ACC*duration is expressed as the heart rate (h) according to the duration of the task (in minutes), which means: ACC*d = (Ha-Hr)*d. It represents the number of pulses 'consumed' during the task. The definition of the Absolute Cardiac Cost is represented inFigure. 4.

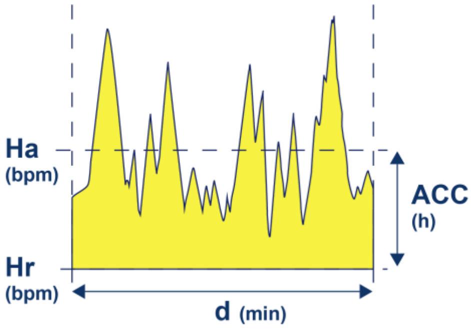

*Figure 4. ACC*d is the difference between Reference Heart rate (Hr) and Average Heart rate (Ha) expressed in beat/min multiplied by task duration (min).*

Tasks performance

We measured the task performance based on two factors: the number of errors made by the participant and the duration of the task. On the repetitive task R, the number of completed settings was observed and the duration of task recorded using a chronometer. Errors were observed for uncompleted settings with a tolerance of 5mm. taken into account A speaker connected to a digital metronome indicated the rhythm to respect. The performance of precision task P was measured using a chronometer and counting the numbers of completed symbols. Errors were observed for uncompleted signs with a tolerance of 5mm.

Subjective measurements

A four dimensions questionnaire (Cognitive, Occupational, Physical and Affective) built from a previous study (Moyon et al.) recorded user's subjective effects of exoskeleton on tasks. The perceived musculoskeletal strain was evaluated with Borg Scale (CR-10) (Hill et al., 1992). We recorded on Likert scales (0-10) factors such as Easiness of learning, Evolution of perceived musculoskeletal effort, Perceived Usability for industrial constraints, Physical Comfort, Intention to use daily and Acceptance after use.

Data Analysis

The study investigates the significant differences in user performance, perceived benefits and acceptance between Exoskeleton. To do so, differences in means were analyzed by comparisons of NoExo (without exoskeleton)/Exo (with exoskeleton) using an ANOVA (mixed linear model, that considers the subject as a random effect and the factor "Exoskeleton" as a fixed effect) and a one-tail one-sample T-test was applied to determine a significative threshold for Exo condition subjective results according to the variables. Also, the effectiveness of the familiarization protocol (F1/F2 conditions), was analyzed for the same variables and for Exo condition only, by a two-samples two-sided T-test, which calculate the difference of means between the six groups. The statistical significance was set to $p<0.05$ (*) and $p<0.001$ (**).

Statistical analyses were performed using XLSTAT 2019 (Addinsoft, Paris, France). For each dependent variable, the results for the different conditions are reported as means (with their standard errors) in original units.

Results

Study of exoskeleton effects on Global physical workload

The evolution of Absolute Cardiac Cost (ACC) with task duration (ACC*d) is expressed in number of heart rate (h). The results are shown in figure 5.

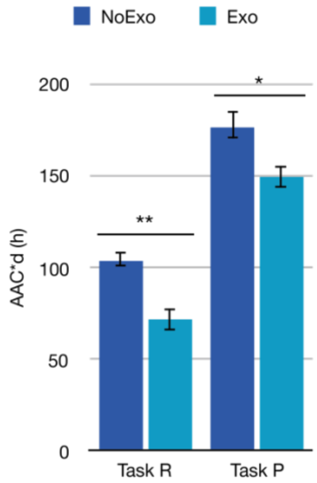

*Figure 5. Evaluation of ACC*d (h) for Task R and task P with (Exo) and without (NoExo) exoskeleton. Errors bars indicate standard deviation and brackets indicate significant results. Asterisks indicate significant difference (*$p < .05$, **$p<0.001$).*

For both tasks, the lowest values of ACC*d are found while wearing the exoskeleton (Exo). Without the exoskeleton (NoExo), ACC*d is increased by 32 h ± 2.9 for the task R and by 27.1 h ± 5.9 for the task P. Despite the weight and physical constraints produced by springs, the exoskeleton seems to reduce the cardiac cost for all tasks.

Study of exoskeleton effects on tasks performance

Hypothesis: performance is better when the participant is wearing the exoskeleton. For task R, we observed the highest number of valid actions (45.5±1, $p<0.0001$) and the lowest number of errors (4.4±0.3, $p<0.0001$) is found when wearing the exoskeleton. A similar effect is found for task P: the highest number of valid signs (49.6±0.9, $p<0.0001$) and the lowest number of errors (5.1±0.3, $p<0.0001$) were found when wearing the exoskeleton. We conclude that for all tasks, Human-Exoskeleton performance is better than NoExo condition with a higher number of actions and a lower number of errors.

Subjective measures

Physical aspects: evolution of perceived musculoskeletal strain

Questions:

'With the exoskeleton, my perceived global strain is' (non-existent-unbearable) 'With the exoskeleton, my perceived local strain (for various body parts) is' (non-existent-unbearable).

Hypothesis: perceived exertion could be reduced while wearing the exoskeleton. Global exertion for tasks R and P has been evaluated respectively with a mean of 6.99/10 ± 0.21 and 6.45/10 ± 0.25 for NoExo condition and 4.22/10 ± 0,14 and 3.61/10 ± 1.16 for Exo condition. Dotted lines in Figure 6 represent these values. Results indicate that globally the strain is lower when wearing the exoskeleton, with a significant ($p<0.0001$) reduction of global strain respectively of 3.06/10 and 3.12/10 for task R and task P.

Perceived local strain shows lower scores when wearing the exoskeleton and an effect of transfer towards other parts of the body has shown in figure 8 (both tasks merged). Indeed, participants perceived a mean reduction of strain on upper parts of the body, on Shoulders (2.32/10; ± 0.15, $p<0.0001$), on Arms (2.93/10 ± 0.12, $p<0.0001$), Elbow/forearms (0.06/10 ± 0.16, $p<0.0001$), Neck (1.41/10 ± 0.14, $p<0.0001$), in the Upper and lower back (0.79/10 ±0.09, $p<0.0001$ and 0.46/10 ±0.1, $p<0.0001$) and on Legs (0.17 ±0.06, $p<0.0001$). Also, the perceived strain has been transferred to other parts of the body, with a small mean increased of 0.4± 0.16, $p= 0.002$ in the Elbow/Forearm part.

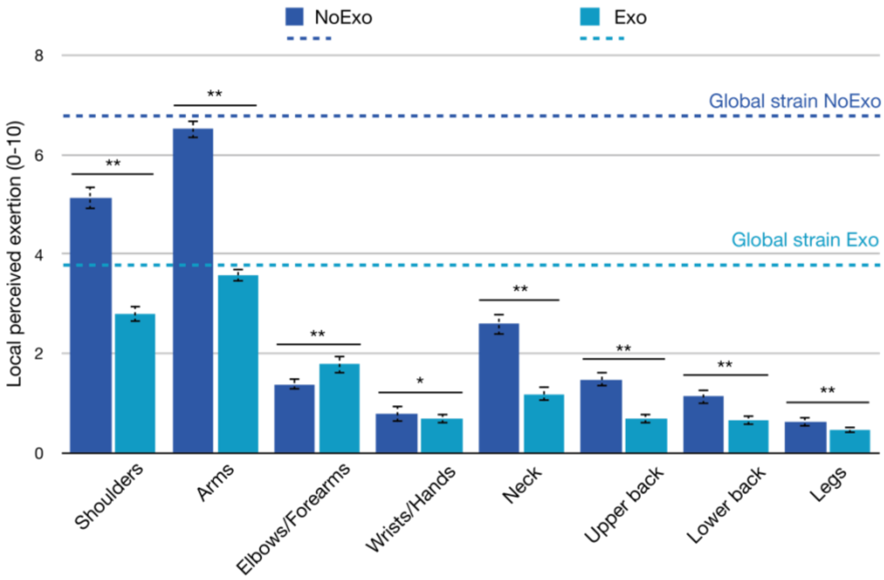

Figure 6. Evaluation of global and local perceived effort for specific parts of the body without (NoExo) and with Exoskeleton (Exo) for all tasks. Dotted lines indicate global strain means.

We can conclude than the evolution of perceived strain could be reduced globally while wearing the exoskeleton (Exo). However, we observed a transfer effect of local strains with a very small local decrease on Wrist/Hand and and a non-expected increase on Elbow/Forearm.

Cognitive and Occupational aspects

Regarding Affective aspects, no participant found that wearing the device was devalorizing. To check if the exoskeleton is suitable to perform simulated tasks constraints, we observe the evolution of extra focus demand, perceived quality and performance while wearing the exoskeleton. Between task R and P, differences in means were not significant ($p>.05$), means for both tasks are merged.

Questions (Likert scale 0-10):

'I can perform my work at the same quality when using the exoskeleton' (strongly disagree–strongly agree)

With the exoskeleton, I feel (much less effective-much more effective)

Two reverse questions:

‘Using the exoskeleton requires extra focus demand’ (strongly disagree–strongly agree)

‘Mastering the use of the exoskeleton involves effort’ (not important at all–extremely important)

For all results except the two last inverse sentences (Effort to master and Extra focus demand), results <5 are interpreted as a negative effect and results >6 are interpreted as a positive effect. A score between 5 and 6 corresponds to indecision or average effect. The effort to master and Extra focus demand, results <5 are interpreted as a positive average effect and results >4 are interpreted as a positive effect of the exoskeleton. A one-tail one-sample T-test was applied to determine a significative threshold according to the variable. For both tasks in average regarding cognitive aspects, perceived effectiveness was positively significant with the exoskeleton (mean = 7.19, lower mark interval: 6.88, p<0.0001), participants reported that wearing the exoskeleton didn’t require important extra focus demand (mean = 4.21, upper mark interval: 4.64, p=0.001) or require an important effort to master (mean=4.07, upper mark interval: 4.39,p= p<0.0001). Also, they could perform the same quality standards (mean=7.17, lower mark interval: 6.84, p<0.0001). We can conclude than the use of exoskeleton on the simulated industrial tasks does not disturb the respect of quality standards, perceived performance and doesn’t imply extra mental load concerning focus demand.

Effects of familiarization protocol (F1/F2)

Objective results

Donning performance

Hypothesis: shortest donning duration performed with F2 protocol. Figure 46 displays participants’ exoskeleton donning performance, based on the familiarization protocol (F1 and F2). Depending on the maximum duration allowed by the industrial partner, records might have been limited to 180 seconds. We observed a significant decrease of donning performance (adjustments included) with the shortest duration of 93.97±26.47s for F2 vs 171.97 ±26.36s for F1 as shown in the Figure 46. Donning performance is expressed in seconds, the dotted line represents the maximum duration users have to reach to pass level 4 of familiarization on our internal scale (HEFL: Human Exoskeleton Familiarization levels). Otherwise, user certification is not delivered.

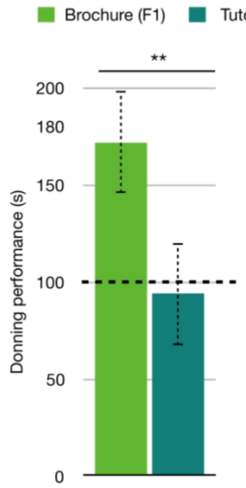

Figure 7. Evaluation of donning/adjusting performance (seconds) according to familiarization protocol (F1 or F2).

The results show that the F2 protocol has a positive effect on donning/adjusting performance with an average duration close to the target level of 100 seconds. Familiarization using the manufacturer's brochure (F1) is much less efficient and not enough to reach the certification level (100 seconds). All the participants excepted tree reached the maximum limit of 180 seconds.

Global physical workload

Hypothesis: F2 allows to have a lower physical strain by optimizing installation, adjustment, and use. If experiencing F2, ACC*d is reduced by 64.28 h ±80.3 for the task P with p=0.008. The decrease for task R is not significant, as shown in figure 8.

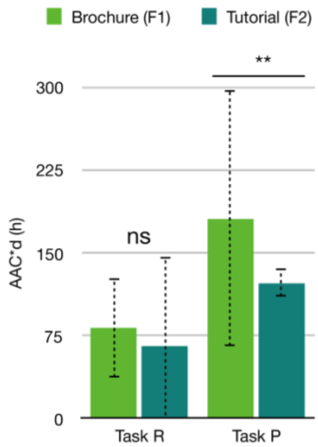

*Figure 8. Evaluation of mean CCA*d (h) for Task R and task P according to familiarization protocol F1 or F2.*

Concerning the task P, we found the lowest ACC*d values for the participants who learned how to use the exoskeleton with the F2 protocol. We can conclude that F2 had a positive effect on users' global physical workload for the task P.

Effectiveness on task performance

Hypothesis: Performance is better when a participant has been familiarized with expert tutorial (F2). The evolution of the number of actions and error for the repetitive task R with familiarization protocol (F1 or F2) is shown in figure 9. The highest number of valid actions (49.22±7.62, p<0.0001) and the lowest number of errors (3.52±1.61, p<0.0001) were found when experiencing the expert tutorial F2.

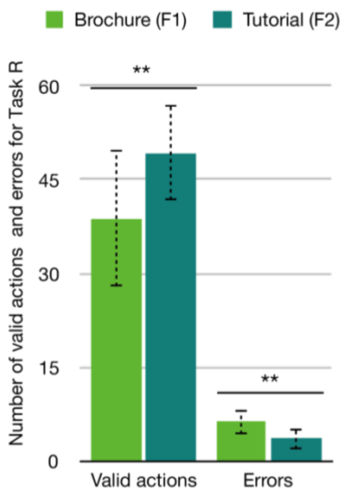

Figure 9. Number of valid actions and errors committed for repetitive task R according to familiarization protocol (F1 or F2). Brackets indicate significant differences between F1 (manufacturer's brochure) and F2 (expert tutorial) condition.

Results for the precision task P with familiarization protocol (F1 or F2) are shown in figure 10. The highest number of valid signs (52.92±7.93, p<0.0001) and the lowest average number of errors (3.81±2.55, p<0.0001) were found when wearing the exoskeleton.

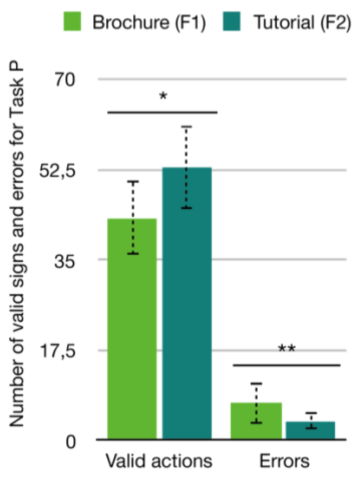

Figure 10. Number of valid signs and errors committed for precision task P according to familiarization protocol (F1 or F2).

We conclude that for all tasks, F2 has given a better Human-Exoskeleton performance than manufacturer's brochure F1with a higher number of actions and a lower number of errors.

Perceptive results

Physical, Cognitive and Occupational aspects

Hypothesis: F1 protocol produces lower perceived benefits, usability and acceptance score than F2 protocol. The effectiveness of familiarization protocol (F1/F2) on user's perception is verified by two-samples two-sided T-test to compare the means of these two groups. The results are presented in Table 5. Higher scores given on Likert scale (0-10) have been found when participants experienced F2 familiarization protocol. The most significant differences were found in this order for easiness of learning (donning and adjusting) with an increased score of +4.15/10, comfort (+3.36/10), easiness to move with (+2.95/10), focus demand (+2.63/10). They are shown in bold in Table 2 with all variables.

Questions (Likert scale 0-10):

'To learn how to don and adjust the exoskeleton is easy' (strongly agree–strongly disagree)

'To master the exoskeleton is easy' (strongly agree–strongly disagree)

'The support the exoskeleton provides when performing the tasks is' (not important at all–extremely important)

'Learning to move with the exoskeleton is easy (strongly agree–strongly disagree)

'The exoskeleton is comfortable' (extremely uncomfortable- extremely comfortable)

'Using the exoskeleton requires extra focus demand' (strongly agree–strongly disagree)

'When using the exoskeleton, I feel' (much less effective-much more effective)

'I can perform my task at the same quality when using the exoskeleton' (strongly agree–strongly disagree)

User acceptance

Hypothesis: the user's acceptance score is higher when experiencing F2. Acceptance is scored through a three-dimensional question:

Q1: 'My global satisfaction for the exoskeleton is (extremely low- extremely high),

Q2: 'If needed, I would use the exoskeleton (Never-Everyday),

Q3: I would recommend the exoskeleton to a colleague (Not at all- absolutely). The validity of three questions toward a global Acceptance dimension is verified by alpha's Cronbach >0.80.

*Table 2. Descriptive statistics (mean, standard deviation, difference, p-value) and comparison of familiarization protocol (F1 or F2) on perceived benefits and acceptance dimensions (*p < .05).*

Dimension	Brochure (F1)	Tutorial (F2)	Difference, p value
Easiness of learning (donning and adjust)	4.38 (2.49)	8.18 (1.29)	4.15, <0.0001
Perceived support	6.06 (2.22)	7.29 (2.02)	1.24, 0.001

Master demand	5.11 (2.33)	3.03 (1.92)	2.09, <0.0001
Perceived global strain	5.29 (1.57)	3.81 (1.37)	1.48, <0.0001
Easiness to use	5.81(2.28)	7.86(2.15)	2.04, <0.0001
Easiness of movement	4.91 (2.62)	7.86 (1.92)	2.95, <0.0001
Comfort	4.53 (2.10)	7.88 (2.23)	3.36, <0.0001
Focus demand	5.52 (3.03)	2.88 (2.67)	2.63, <0.0001
Effectiveness	6.28 (2.31)	8.11 (1.77)	1.83, <0.0001
Respect of quality	6.34 (2.52)	8 (1.86)	1.65, <0.0001
Acceptance score	6.42 (1.99)	8.25 (1.70)	1.82, <0.0001

We conclude that for all aspects presented (Cognitive, Occupational and Physical), operators reported with F2 protocol a better perceived effectiveness, benefits and user acceptance than with F1 protocol (manufacturer's brochure). Human-Exoskeleton performance could be significative influenced by the familiarization experience that includes different type of knowledge and practice.

Discussion and Conclusion

Firstly, some interesting contributions to Human-Exoskeleton Interaction on simulated industrial tasks have been found. Significant positive effects have shown a reduction in Global physical workload and perceived strain, an increase in task performance, in relation to positive effects on subjective benefits as perceived performance, the respect of quality standards and the lack of extra focus demand. These positive effects on physical, cognitive and occupational aspects are strategic to ensure occupational exoskeleton adoption in industries. Also, if the expected reduction of perceived strain is significant in targeted muscles (shoulder, arms), some muscular strain increased while wearing exoskeleton and highlights the possible influence of load transfer that should be investigated. A further study could aim at simulating muscle activation of the Human-Exoskeleton system to better understand this effect. Secondly, a key finding of this study is a significant positive effect of an expert familiarization protocol on perceived benefits, usability and user acceptance. These results suggest that the use of exoskeleton is not intuitive. A familiarization experience that includes specific knowledge and practice could help optimize Human-Exoskeleton performance and user acceptance, that could eventually lead to a quicker adoption in companies. It is not easy to study the familiarization process as it is related to time. And long experiments would not be appropriated as they would involve participants to endure high strains. The suggested laboratory protocol is easily repeatable and allows the test of familiarization dimensions using a short duration of physio pathogenic activity. Further work could deal with the influence of panel diversity that has not been taking into account in this study. Also, differences of effects on all variables could be investigated, to bring manufacturer interesting feedbacks on the effect of claimed design improvements from Exo A to B prototypes.

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ANNEXES

Annexe 1: Human-Exoskeleton Familiarization Levels. According to our field expertise, a certified user should reach at least level 4.

HEFL	Human-Exoskeleton Familiarization levels	Description
0	No previous experience with the exoskleleton. It is an unkown system.	The worker has no previous experience with the exoskeleton neither knowledge of the system. His perception can be biased by 'science fiction effect' (movies, advertising...).
1	First visual contact. Basic knowledge.	The worker has no experience with the exoskeleton but a basic knowledge of general principles. His perception can be biased by' science fiction effect' (movies, advertising...)
2	Knowledge of technological basics and utility (case studies).	The worker has basic knowledge of general and technical principles. Limits and application have been explained. A test of donning/adjusting may have been tried.
3	Knowledge of technological basics and applications. Donning/adjusting/doffing are mastered.	The worker knows basic, mechnical and adjustment principles. He knows how to donn/adjust/doff the exoskeleton within 100 seconds with safety checks, including experience of limitations.
4	Knowledge of risks. Subjective validation of the exoskeleton on simulated tasks.	The worker has all previous knowledge and experience and he has felt potential assistance and limitations with a tailored protocol (simulation of case study tasks) in the range of assistance.
5	Subjective validation of the assistive device with an intermediate test in work situation.	The worker has all previous knowledge and experience. He used the exoskeelton for at least 48h (2h/day). He has positively evaluated the device after short tests (acceptance score >7/10).
6	Subjective validation of the assistive device with an long test in real situation.Experimented practice.	The worker has all previous knowledge and experience and used the exoskeleton at least for 48h (2h/day). He has positively evaluated the device (acceptance score >7/10).
7	Adoption of the exoskeleton. It is frequently used and evaluated after long tests in real work situation.	The worker has a good knowledge on use principle and a minimum experience of 3 weeks (4h/day max). His subjective evaluation is globally positive and effects on eventual changes in organisation/process/habits have been adopted.