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Methods, Models, & Theories

Development of an acceptance model for occupational exoskeletons and application for a passive upper limb device

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Conflict of interest Statement

There is no conflict of interest regarding the submitted manuscript.

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Occupational application

Occupational exoskeletons may help reduce the physical demands of work, but several challenges exist in their workplace integration. While there is evidence that wearing an exoskeleton can reduce perceptions of effort and muscle fatigue, exoskeletons can negatively affect user acceptance if they increase local discomfort or don't provide sufficient adjustability. Additionally, most existing evidence is from laboratory settings, which has unknown validity for real work activities. To address these limitations, we completed a field study to identify key acceptance factors in real contexts of use, as well as methods for measurement. From our results, we present acceptance factors in a model centred on four aspects concerning the use of an occupational exoskeleton, a global methodology for factor identification, and propose easy measurement methods for practitioners. These outputs provide new ergonomics specifications for Human-Exoskeleton Interaction (HEI) in the early use stage.

Technical Abstract

Background: To address the high costs of work-related musculoskeletal disorders (WMSDs), several industries have started to experiment with exoskeletons, but have faced technical and psychological barriers. The design of efficient and usable exoskeletons needs to account for both technical constraints and more subtle requirements related to their acceptance by users. Existing models of acceptability, essentially based on predictive methods and information sciences, were not considered relevant for the case of occupational exoskeletons. Purpose: The purpose of this study was to specify an acceptance model adapted to occupational exoskeletons, in order to facilitate their evaluation during the initial phase of use in the field. Methods: We employed an ecological approach. Because of the physical interaction the user experiences with an exoskeleton and within the working situation, acceptance criteria were developed from actual field use. Initially, an action research process was completed to identify key determinants in the field. New factors, missing in existing acceptability models, were added to a proposed new model, together with methods for their measurement. To test the new model, an experiment was completed on manual operations in an industrial context and partly in a laboratory. Results: We organized the identified factors into an acceptance model, which was then validated and completed by exoskeleton experts in ergonomics based on four aspects: physical, occupational, cognitive, and affective. Conclusions: This new model, focused on usability, is based on easy-to-implement methods and could, therefore, be of use to diverse stakeholders (exoskeleton designers, ergonomists, etc.). Based on a real use approach, such a model makes it easier to evaluate the Human-Exoskeleton system, and could thus facilitate more successful adoption by companies.

Keywords: WMSD (work-related musculoskeletal disorders), exoskeleton, acceptance, usability measurements, ergonomics tools and methods, human factors, ecological methods, verbatim transcripts.

1. Introduction

Context

An occupational exoskeleton is an external, wearable structure intended to decrease physical demands during work activities (Perry et al., 2007). There is an increasing demand for exoskeletons in industry, but their integration in companies is quite slow in many cases, due to barriers such as mechanical challenges (Gopura & Kiguchi, 2009); poor usability compared to expectations (Maciejasz et al., 2014); human and organizational challenges (Delaval et al., 2017). Recently, some studies have shown benefits of exoskeleton use, such as a decrease in muscle activity, perceived muscular effort (Huysamen et al., 2018) and perception of fatigue and an increase of worker performance (Spada, et al., 2017). However, research has shown some potential limitations such as the need for better adjustability to reach higher user acceptance (Baltrusch et al., 2018) or a structural counterbalancing toward the ground. If they might help reduce the load on specific parts of the body, they could also increase the load on other regions of the wearer's body (Rashedi et al., 2014). They also could increase perceived difficulty in specific tasks (Baltrusch et al., 2018) which could lead to important limitations in the industrial environment. Such evidence suggests that exoskeletons are not yet widely adopted for occupational use.

Focus on acceptability

The acceptability (judgement before use) of exoskeletons, as a new technology, could involve multiple, diverse factors. The most commonly used model in industry is Nielsen's (1993) model, which is mainly structured around practical acceptability and usefulness. Usefulness is the degree in which a person trusts the technology to perform the desired goal, and in Nielsen's model is broken down in two further notions: Utility and Usability (Figure 1).

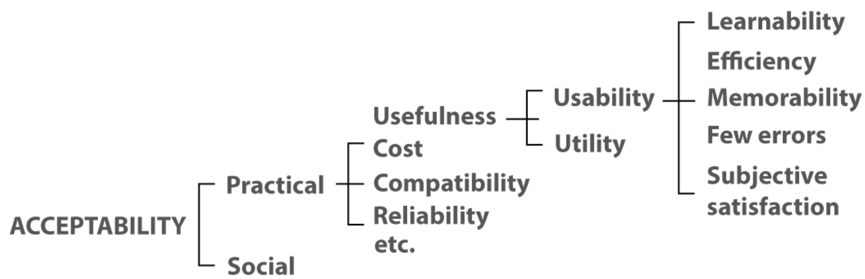

Fig. 1. Nielsen’s (1993) model of system acceptability (M1).

More recent predictive theories of technology, such as the Technology Acceptance Model (TAM; Davis, 1989) or the Unified Theory of Acceptance and Use of Technology (UTAUT; Venkatesh et al., 2003), are also based on *a priori* studies. Some more recent research in Informative Sciences, based on acceptance, focus progressively on real use and adoption (Venkatesh et al., 2012). The emerging theory of “situated” acceptance proposes to consider four dimensions (individual, organizational, relational, professional/identity) of the occupational activity in the field of social psychology (Bobillier Chaumon, 2016), and explains how acceptance factors should be engineered by confronting a real context. Unfortunately, little research has been reported on acceptance – the judgment towards a product after use – where both functional and perceptive factors are studied during first use (familiarization phase).

These existing models are used to study mature and similar informative technologies, whereas innovative devices, such as exoskeletons, change the framework of acceptance through a new user-product relationship (Akrich, 1989). Moreover, some appropriation theories in activity ergonomics explain that it is the actual experience of the product that will influence future behavior and future adoption (Rabardel, 1995). In addition, the acceptance of non-digital systems needs to consider physical and environmental aspects. The exoskeleton is designed to assist a particular posture. Consequently, we are studying a ‘Human-Exoskeleton’ System (HES) in a particular environment, and for a particular task. This consideration of ‘interfacing’ is why we believe that existing models of acceptability/acceptance are not sufficiently adapted to physical user-product experience in the occupational environment.

Consequently, there is a need to involve real work situations to identify important determinants of exoskeleton acceptance (Graham et al., 2009), and a more holistic and usability focused approach is needed to identify obstacles to worker acceptance that are not evident in a laboratory environment (Bosch et al., 2016; Spada et al., 2017). Supporting these needs is recent research showing that user acceptance of an exoskeleton was strongly influenced by perceived usability (Hensel & Keil, 2019). When assessing the "expected" effects of a passive exoskeletal vest, recent authors suggest focusing on the actual use, which will also include "unexpected" effects (Kim et al., 2018). This is why we argue that the evaluation of acceptance factors should focus on Usability (the experience of use).

To improve usability implies determining which factors are the most important for users (Mayhew & Mayhew, 1999), and is why we have recommended a user-centered approach to study various aspects of an acceptable human-exoskeleton interaction at the early stage of use. Some research on Usability assessment proposed to reorganize factors for a more holistic approach. (Bengts, M.K., 2004) proposed a classification of usability factors (learnable, error preventing, efficient, memorable), together with several principal concepts from the Human-Computer Interaction (HCI) literature, to structure the scope of usability with three aspects: affective aspects, utility aspects, and cognitive aspects. We will rely partly on this hierarchy to help classify factors after interviews during focus groups with the project team.

The purpose of the current study was to identify the key factors of acceptance in the early phase of exoskeleton use (familiarization phase) and to enrich existing models presented within a real use situation and a non-digital interaction centered on usefulness/usability, and to generate a classification of factors created from both user's subjective satisfaction and experts. For these reasons, we choose the original Nielsen's model as a starting point. It is mainly developed around practical acceptability and usefulness/usability, includes user's satisfaction, considers the early phase of use, and is commonly used among our partners.

2. Method and Results

Overview of Model Development and Context for Case Study

The objective of the current study was to identify acceptance factors and organize them to adapt Nielsen's model in the early stage of exoskeleton use, along with easy measurement methods for practitioners. In order to define relevant acceptance criteria regarding our context, we developed a general methodology composed of several Stages (Figure 2). Each Stage involved gathering information, from either a field approach, laboratory study, or a literature analysis. To start, in Stage 0, an initial model (M1) was used, based on the literature and stemming from the Usability component of Nielsen's Model (Figure 2). Determinants of acceptance emerged initially, in Stages 1 & 2, and subsequent Stages developed and tested related assessment methods. After testing in Stage 4, a few new factors emerged, as they were rephrased in a model (Stage 5) and discussed with experts (Stage 6). This work was completed within a case study (boat manufacturing task), involving both field and laboratory-based testing.

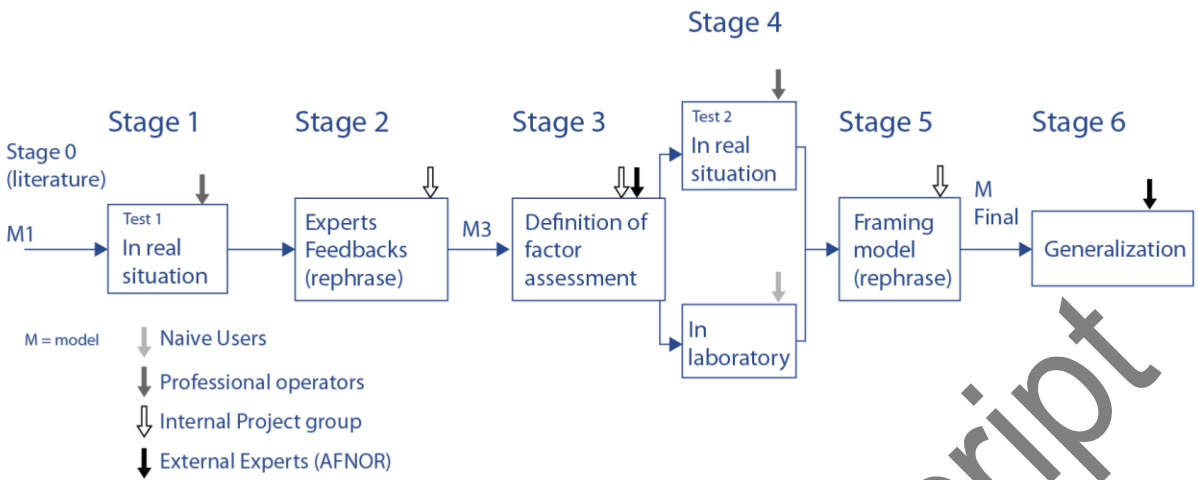

Fig. 2. Overview of the methodology used to develop the new exoskeleton acceptance model.

BJ Technologies, a boat manufacturer, allowed us to conduct experiments in the finishing workshop of its catamaran *Lagoon*. Roofs and hulls were done separately, and we focused our observations at a workstation dedicated to hulls (Figure 3). Finishing tasks include iterative phases of sanding and polishing, followed by painting using a spray gun. The work zones are along the sealing edge of the two boat parts. This particular workstation required overhead work postures that could be assisted by an exoskeleton. We chose a passive exoskeleton for the upper extremity, designed to assist during tasks with raised arms, which was provided by *Skel-Ex* (Skelex, s. d.). Both the field and lab experiments described below were approved by the project group, composed of two members of the Health, Safety and working conditions committee, an ergonomist, two workshop managers, a safety manager, and a project manager. All participants volunteered, and informed consent was obtained by Health and Safety executive members of the project group. We had a panel of 11 operators in a real situation.

A controlled laboratory experiment was used to measure some factors more easily and without disturbing the manufacturing process. A boat mock-up was created, with appropriate surface shapes and density. To require similar postures to those observed in the field experiment, the structure was adjustable in height. We had a panel of 6 operators in the laboratory.

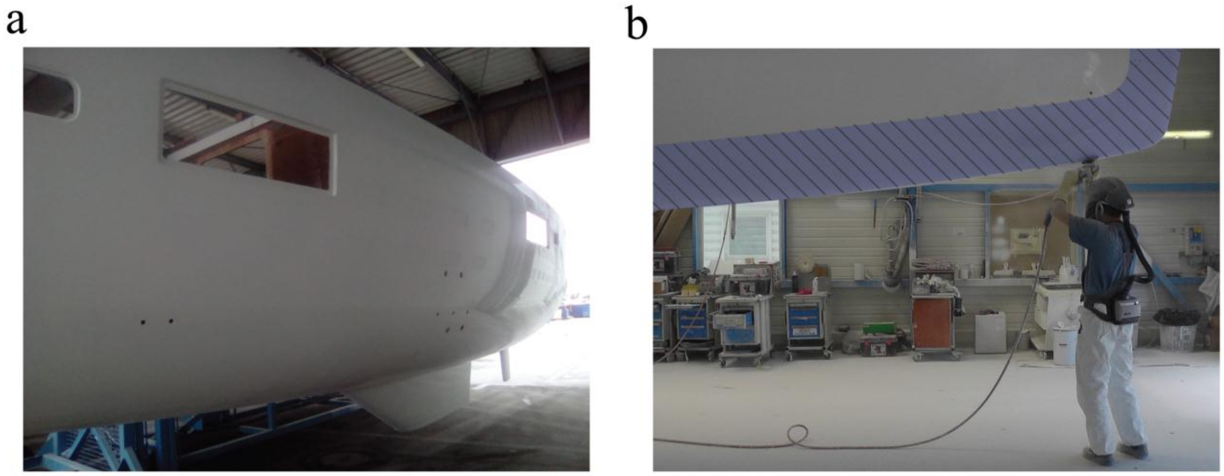

Fig. 3. (a) Side view of the catamaran hull. (b) An operator is sanding the sealing edge. Hatches show the work zone for manual sanding.

2.1. Stage 1: Observe and analyze the occupational context

Initial testing (Test 1) was completed, which included two parts. In the first part, we first identified the most physically demanding aspects of the work situation based on occupational ergonomic analyses. In the second part, we completed interviews with field operators, who were asked to identify and classify their own acceptance factors after a familiarization phase. Ecological observations of two operators were completed while they worked during a whole day, during which an observation grid (number of arm releases, postures) was completed. Then, we confirmed the most demanding tasks observed using an interview. The OSHA Checklist (*OSHA,* 2017), and the RULA method (McAtamney & Nigel Corlett, 1993) were used to estimate the physical demands related to the risks of musculoskeletal disorders (MSD). Posture analysis yielded a score of 7 (using the RULA method), which indicates the necessity of an ergonomic intervention and justifies the need for assistance. This step allowed us to focus on the "finishing task, under the boat" as the most demanding task (figure 3b).

We introduced the exoskeleton and its functionalities through a familiarization phase of about 15 minutes to all 11 operators, wherein we demonstrated and commented the don/adjust/doff process. Operators verbalized individually a target duration they would consider satisfying. This reference value was called the ‘target time’. Then, we recorded the process and compared it to their target time. Records ended when participants considered the exoskeleton was adjusted and they were ready to work. Then they familiarized themselves with it by completed some simple gestures for about 5 minutes. This step provided a reference duration for ‘ease of learning’ measurements (see C1 in Table 1).

All 11 operators then completed an open interview, during which acceptance factors were verbalized, based on a description of the finishing task (actions, duration, etc.) and the type of physical demands each operator encountered. Factors verbalized by operators during these interviews were centered on the utility, usability, comfort, and suitability of the exoskeleton in the industrial environment. They then completed additional interviews, using a self-confrontation method (Argyris & Schön, 1991). The following four categories were redefined with the operators in the self-confrontation interviews: 1) Utility (practical ability of the system to function); 2) Comfort (perceived fitting on body); 3) Usability (easy to don adjust, use, doff, and store); and 4) Impact on activity (effects that can occur in the work environment, such as process disturbances, tools accessibility and compatibility, and safety for the environment). Lastly, the operators were asked to distribute 100 total points to indicate the relative importance of the revised acceptance factors.

To conclude Stage 1, we interviewed project group members to rephrase and cluster the acceptance factors identified from the field. Measured durations converged to 50 and 31 seconds for don/adjust and doff, respectively. Results from the distribution of the 100 points among the four acceptance categories indicated that Utility (50%) was the most important, followed by Comfort (24%), Usability (15%), and Impact on activity (11%). Each of these factors was thus considered necessary to integrate into the new acceptability model.

2.2. Stage 2: Obtain expert feedback & rephrase factors

An internal group was formed, composed of six individuals with varying expertise (nurse, ergonomist, workshop, health and safety managers, and project director). A discussion was conducted among this group, to rephrase factors from the literature: as the starting acceptability model (M1) was focused on Usability, we used this Stage to translate Usability factors from the information science literature to our occupational exoskeleton context. We based this rephrasing on literature analysis and field expertise. We confronted usability factors from Bengts (2004) to our occupational exoskeleton context, to integrate the diverse aspects of usability: affective, utility, and cognitive, as well as the specific aspects of occupational use. These factors were discussed with the project group to validate their integration into a new model M2 (figure 4).

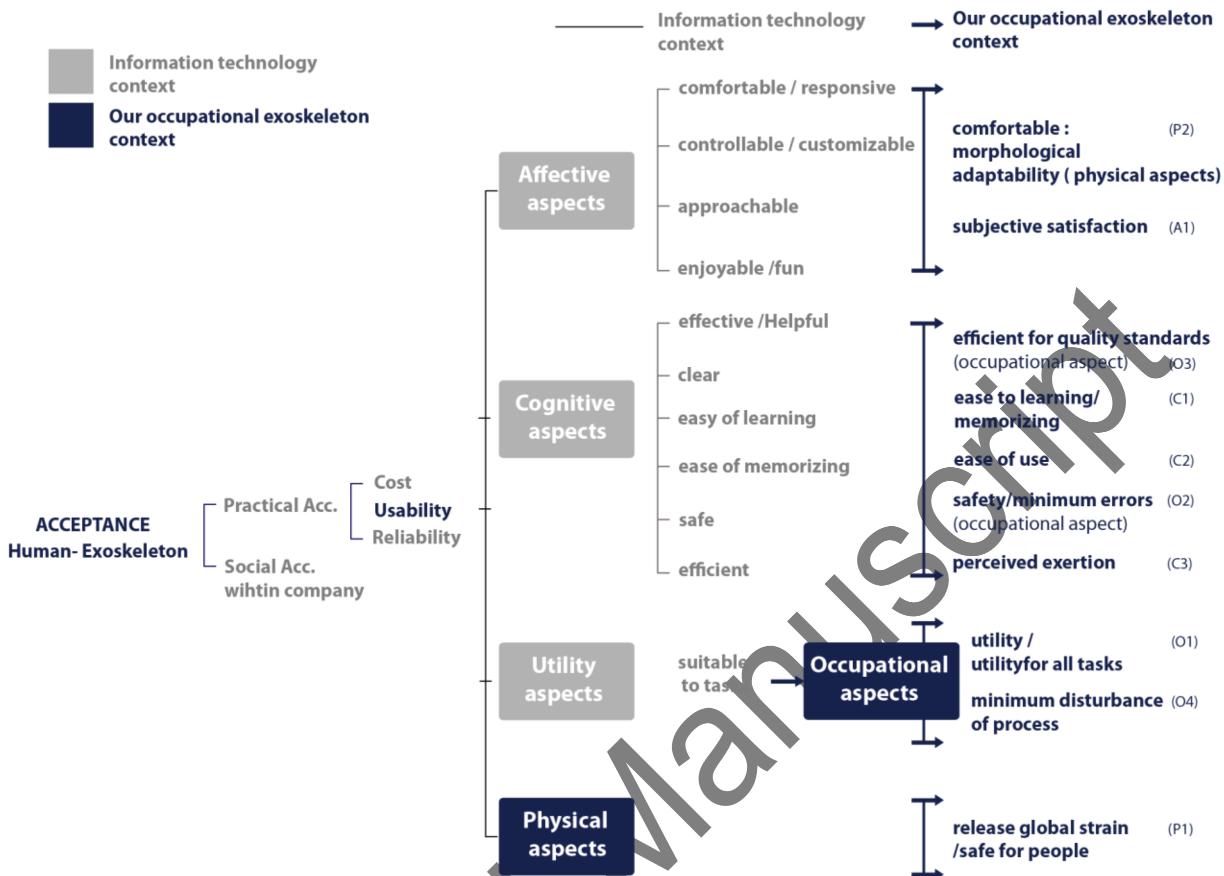

Fig. 4. Model M2 generated from literature application to case study and field study.

Most of the factors from the information sciences context were directly transferable. For example: ‘easy to remember' could be the decreasing of installation/uninstallation durations. ‘Comfortable' (responsive) could be translated as ‘Comfortable' (a physical aspect). The physical aspect could integrate all factors related to wearable aspects of an exoskeleton (comfort, physical safety, etc.). Utility aspects were directly translated to Occupational aspects (utility for tasks…). Utility aspects were translated as Utility for occupational context, rephrased in Occupational aspects. This category could contain the efficiency for high-quality standards, minimum errors due to the exoskeleton, Utility for the task and other tasks (flexibility), and minimum process disturbance. However, we would not be able to consider all the ‘enjoyable factors’, such as ‘fun’ and ‘entertaining’, because we are working in an occupational context. In this first approach, we did not consider any hierarchy between factors.

2.3 Stage 3: Define measurement methods

Methods for measuring each acceptability factor were obtained from the literature on usability measurement and expert recommendations. When no suitable method existed, we proposed relevant indicators related to field observation and self-confrontations. For each, we suggested an objective and/or subjective method. A questionnaire was created, derived both from potential acceptability obtained from open interview results (comfort, impact on occupational activity, etc.) and existing instruments (TAM questionnaire for perceived ease of use, perceived usefulness, etc.); this questionnaire is available in online supplemental material.

The experts involved in this Stage and the next were members of a project group on-site or of the AFNOR workgroup for the future Norm NFX35 on ‘Human – exoskeleton Interaction evaluation'. This workgroup is composed of about 20 exoskeleton and occupational experts. In order to generate a relevant list of factors and associated measurement methods, we recommended existing methods that were suggested in a draft guide shared in the workgroup between 2016 and 2018. The workgroup suggested a range of qualitative and subjective measurements from the Human Factors literature. When no method existed, we suggested a method to the project group. This new research iteration was organized as follows: 1) we gathered observational data on activities; 2) we proposed a factor and measurement method from what we observed, and 3) we validated or modified the factor and related measurement method by a confrontation between operators and experts group project. From these iterations, a list of 10 factors was defined with associated measurements methods (objective or subjective).

The final list of factors and measurement methods is provided below (Table 1). For example, our case study observations showed that operators were relaxing their arms by lowering them. So, we suggested we could measure the number of such "arm releases". Self-confrontation confirmed that it was an indicator for Utility. We thus supported the measurement method 'number of arm releases' as an evaluation criterion for 'Utility'. Perceived ease of use is recorded by counting the number of verbal complaints during a test. Likert scales are used to assess Ease of learning, Cognitive impact, Utility/Utility for all tasks, Safety, Efficiency, Impact on activity, Comfort and Perceived exertion. Overall exertion is measured by asking operators to describe all the tasks and to identify which tasks were the most difficult before the experiments.

Table 1: Classification of measurement methods for each acceptance factor.

Factor	Objective measurement	Method	Subjective measurement	Method
Affective aspects				
A1. Individual Satisfaction			Evaluate satisfaction and social image after 15 - 30 min of work with the exoskeleton	Open interview, survey (scoring on Likert scale). Scoring factors with 100 points.
Cognitive aspects				
C1. Ease of learning /memorizing	Don/adjust/ doff duration	Measure the duration of the Don/adjust/ Doff duration	Evaluate scoring after familiarization stage	Scoring on Likert scale
C2. Perceived Ease of Use	Number of complaints during the task	Counting the number of complaints	Evaluation after test of 15 to 30 min of work with the exoskeleton	Scoring on Likert scale
C3. Cognitive Impacts	Perceived exertion	Scoring of Global perceived	Self-confrontation after 15 - 30	Scoring on Likert scale

(perceived exertion)		scale Borg CR10 with/without exoskeleton	min of work with exoskeleton	
Occupational aspects				
O1. Utility/utility for all tasks	number of arm releases	Observation and counting the number of arm releases	Evaluate after a minimum 15 - 30 min of work with exoskeleton	Scoring on Likert scale
O2. Safety/ minimum errors	errors due to exoskeleton	Counting errors due to exoskeleton	Evaluate after a minimum of 15 - 30 min of work with exoskeleton	Scoring on Likert scale
O3. Efficiency for quality standards	Control quality from workshop managers	Counting number of returns in workshop	Evaluate after a minimum of 15 - 30 min of work with exoskeleton	Scoring on Likert scale
O4. Minimum disturbance (habits, process)	Task duration	Measure task duration with/without system	Self-confrontation after working with exoskeleton for 15 min to 2 h.	Scoring on Likert scale
Physical aspects				
P1. Physical strain /Safe for people	Cardiac cost	Cardiac cost protocol (e.g., using heart-rate monitor)	Evaluate global and local perceived exertion Self-confrontation	Scoring on CR10 Borg scale
P2. Comfort/ Morphological adaptability	Number of adjustments	Counting number of adjustments	Evaluate perceived comfort after working with exoskeleton for 15 min to 2 h.	Scoring on Likert scale

2.4 Stage 4: Measure factors in field and laboratory tests

A second sets of tests (Test 2) were complete, which involved an application of the measurement methods from Stage 3. Two types of testing were completed, one in the field and one in the laboratory, the latter included to minimize disturbances to the working environment and to increase the number of subjects. Testing was similar in both cases, though the duration was limited in the lab but corresponded to the natural working schedule in the field. Also, questions about occupational aspects were only asked in the field.

<u>Field testing</u>

Eleven operators participated in the study, whose ages varied from 20 to 46 years, and each had a minimum of three months of experience. There were four females and seven males, from among the daily crew working on the same operations. Testing took place between March 2017 and April 2018, at the site of *BJ Technologies* in Dompierre, France. The health status of each operator was evaluated using the Nordic questionnaire (Descatha et al., 2007). Some of the participants had already sustained injuries related to their work but were in a good state of health on the day of the test.

Donning and doffing durations were measured over four trials using a chronometer. These real timings were then compared to the reference values obtained earlier (Stage 1). We obtained a mean installation duration of about 1.8 min and uninstallation duration of about 0.5 min. Subsequent tests were organized as follows. First, Safe installation was checked visually by an experimenter, and satisfying comfort was determined by the participant while doing simple gestures. This step was mandatory to continue testing. Second, operators were allowed to move freely with the exoskeleton while reproducing simple moves then task gestures. Third, all objective measurements were made with/without exoskeleton, always starting with the exoskeleton on, during the finishing tasks on the sealing edge (figure 3b). Operators were asked to follow their usual working process without any change, for 15 to 30 min, according to their natural operations schedule. Observations were made by visual control and notes on an observation grid, while subjective measurements were recorded before (global perceived effort) and after the task by an individual survey. Fourth, the 11 field operators were interviewed to assess how they perceived the exoskeleton and what they considered as key factors for daily use. A comparative measurement of global strain was also made, using the CR10 Borg scale (Hill et al., 1992), which was recorded before and after the task. Tasks were recorded with cameras to be analyzed later. We conducted observations with an observation grid specially designed for the activity and a chronometer. All observations were written on the grid. The self-confrontations and interviews were conducted with an open interview file and questionnaires.

From the open interviews, we obtained several definitions of factors: the notion of physical aspects (body pain, morphological adaptation, etc.), cognitive aspects (perception of workload, ease of appropriation/learning, etc.), and occupational aspects (access to tools, process, and safety for the work environment).

Laboratory testing

Six male participants were included, who had no previous professional experience of sanding or polishing tasks. Their ages ranged from 29 to 56 years, and all were in good health on the day of testing, as determined using the Nordic questionnaire (Descatha et al., 2007). Laboratory testing took place between March and May 2018 in an experimental room at l'Ecole Centrale, LS2N laboratory, Nantes. An experiment manager was trained to the real task by operators, and a technical document was transmitted to the lab so that the task could be reproduced as close as possible to the real situation.

Laboratory procedures and tests material (including questionnaire) were the same as described for the field, with some exceptions. First, a portion of the questionnaire, addressing O4 "Impact on activity" (habits, process), was not included. Second, lab participants were shown how to do the specific movements and the actions required for the task. Participants practice until they could reproduce these correctly in term of gestures and timings, visually controlled by the experimenter. Third, comparative measurements with/without the exoskeleton, were done during 15 minutes. From this stage, we had measured all of the proposed methods, and new factors appeared from the results of objective and subjective measurements as presented in Stage 5.

2.5 Stage 5: Final organization of factors

From previous stages, several factors needed to be updated into a final model. Indeed, the results of the field and laboratory measurements revealed some new factors or organization. The project group (involved in stage 2) evaluated the moderation of each acceptance factors in a focus group format. During this, verbatim transcripts from interviews and self-confrontation were rephrased into factors, leading to a final model (Mfinal; Fig. 5). For example, the following reformulations were recommended:

- 'Comfortable' is also described as: 'morphological adaptability' and 'safe for people'. Indeed, from the interviews, comfort is considered as something that fits the body as well as possible.
- The risk of supplementary stress has been rephrased as 'light cognitive workload'.
- The potential evolution of perception (focusing demand…) rephrased as 'minimum changes in perception'.
- The ability of the device to not disturb other tasks was rephrased a 'flexible with other tasks'.

- Regarding safety and organizational concerns, the project group added ‘efficient for quality standards’ and ‘minimum disturbance of process’.

Social aspects were also mentioned, and the project group suggested a need for more evidence of social acceptability in further research. Finally, based on the expertise of the project group, the measurement tools and protocols were optimized.

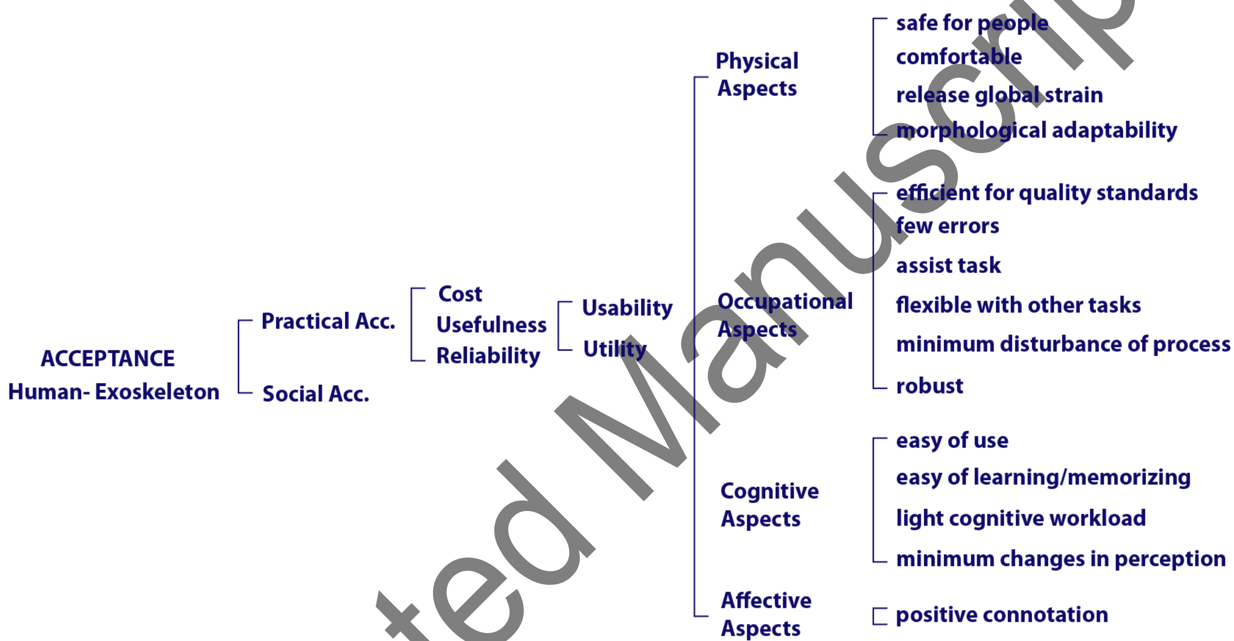

Fig. 5. Final model (Mfinal) including new acceptance factors.

2.6. Stage 6: Generalization

This study considered only one case study and one model of exoskeleton. A generalization of this work is only possible by comparison with other contexts. Indeed, the exoskeleton is designed for all sort of arm-elevated postures. Mfinal was presented to a network of occupational experts on ergonomics and on exoskeletons for validation and generalization concerning different devices. The model and associated methods were discussed through interviews with seven occupational exoskeleton experts and a focus group with project group members. They also engaged in some discussion related to acceptance factors. Proposed factors were supported, however exchanges highlighted that some factors were missing in relation to different contexts of use and various models of exoskeleton, such as ‘minimal changes of natural movement’, ‘hygienic’, and ‘compatible with equipment’.

3. Discussion

In summary, exoskeletons have a great potential to relieve pain and work-related muscle workload but they are facing physical and psychological barriers. To facilitate their integration in industries, they need to be evaluated in a real context. We have modified an existing model from the field of information technology, using an exploratory field approach, in order to identify global acceptance (judgement after use) and usability factors for exoskeleton. Then we have measured them and validated factors relevance with experts to better understand human-exoskeleton interaction (HES). From this method, we recommended a new model which includes physical aspects, occupational aspects, cognitive aspects, and affective aspects. Each aspect is related to a factor (easy to learn, comfortable etc.) that is easily measurable.

Through this study, we have identified that an exoskeleton, as physical assistive technology, might require some attention to usability and specific acceptance factors. We found that the main acceptance factor from the user perspective is related to physical comfort. This finding highlights the need to evaluate physical aspects and the importance of subjective perceptions in the evaluation of this new technology, intended to decrease occupational physical demands. Several studies, including ours, have measured some dimensions of usability and suggest that a more holistic approach should be developed. A recent field study (Hensel & Keil, 2019) confirmed that acceptance ratings decreased at the end of the study, which could be related to the learning experience. This explains why predictive methods are not relevant in the case of exoskeletons, as there is no experience of use. Some research focused on usability suggest that the introduction of innovative systems should be studied from a user perspective (Redström, 2006; Vardouli, 2015). Subjective satisfaction and acceptance factors should actually be studied during use (Bobillier Chaumon, 2016).

The added value of this study is to explore, through real situations, several unanswered questions related to exoskeleton acceptance, such as: What are the satisfaction factors from the user perspective? What is meant by 'easy to learn', and how should this be measured? What does 'Utility' mean for an exoskeleton, and how can we measure it? We give insights and examples of how we can better understand acceptance factors and measure them. However, our initial explorations have highlighted the possibility of encountering more acceptance factors, which should be identified and adapted for occupational exoskeletons in future work. We suggest there is a need to watch for more complex aspects of interactions between operators, for example regarding how to evaluate any social aspects of exoskeleton use. Addition work remains, such as determining factor accuracy, the choice of acceptance indexes and their validity, the reliability and validity of questionnaires, the hierarchy of factors, and how to verify model generalization. In addition, the evolution of exoskeleton acceptance factors could be evaluated in future studies through a longer period of use.

Despite these limitations, we believe that our study has raised human factor awareness among our partners, to whom we have recommended developing an integration protocol based on our model of acceptance. This work will be discussed collectively for further completion and might evolve regarding use cases and measurement results in the future. We note that even if the final model presented here might not be complete, we suggest using it as a first guide to facilitate the evaluation of these assistive systems since it requires only simple measurements methods, tested in real situations. Based on a real-use approach, this user experience approach could enhance the evaluation of the Human-Exoskeleton System, thus supporting a successful adoption by final users.

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