Institut National de Recherche et de Sécurité

Acquisition and integration of exoskeletons in establishments

Guide for safety professionals

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Introduction

Many businesses today are tempted to acquire exoskeletons. Their goal in terms of occupational risk prevention is to relieve strain on their employees. While initial experimental studies generally show that exoskeletons can be effective at limiting local muscular constraints, their use in real work situations however raises many questions relating to operators' health and safety (see ED 6311, in French only [1]).

To ensure that the exoskeleton is adapted to the operator and the particularities of the task for which it is intended, it is necessary to follow an approach starting with the definition of the physical support need and ending with the integration of the exoskeleton in the actual work situation. The role of safety professionals is key. They must consider this new context, involving interaction between the operator and the exoskeleton, after exhausting beforehand all of the collective prevention solutions aimed at adapting the work environment to protect employees from occupational risks.

This practical guide proposes a method to help safety professionals to effectively support businesses in their approach for acquiring and integrating exoskeletons.

Objectives of the guide

This guide proposes a three-phase method that has three objectives:

- help safety professionals to support businesses in making the decision to acquire an exoskeleton,
- follow all the evaluation steps necessary for identifying the benefits and limits that may be generated by the integration of an exoskeleton,
- create optimal conditions for successful integration of the exoskeleton.

Implementation method

The implementation method is based on the creation of a working group bringing together stakeholders in the establishments that are concerned by the potential use of the exoskeleton (management, production, staff representatives, occupational health services, safety professionals, operators, etc.). This group, whose composition should be adapted to the context of each establishment, may draw on occupational health services and the occupational risk prevention service of regional occupational health and pension insurance funds.

Its missions are to:

- ensure compliance with the general principles of prevention before considering exoskeletons as a potentially suitable response to the physical load issues identified (in the absence of other solutions),
- draw up specifications integrating the health and safety of users, the technical requirements of the future exoskeleton and the expected uses,
- ensure that the use of an exoskeleton effectively meets the needs identified,
- guarantee the conditions of a successful integration of the exoskeleton in the actual work situation,
- evaluate, beforehand, and then in the actual work situation, the risks related to the use of the exoskeleton,
- repeat, as many times as needed, this evaluation based on feedback and changes in work conditions.

In addition, regularly informing operators and managers is essential for enabling proper understanding and adoption by future users of the integration process. Frequent communication within the establishment (in-house newsletter, posters, short oral communications, etc.) must also be planned.

In the long term, once the integration of these exoskeletons is finalised, evaluations must be conducted within the regular framework of the organisation's risk assessment approach. The working group can then be disbanded.

The three-phase action method

PHASE 1 Decision-making support

Step 1

▶ Analysis of the physical workload and search for prevention avenues

Expected outcomes:
– Identify the work situations where collective and organisational prevention solutions could be beneficial
– Identify the tasks where specific physical support could be beneficial

Step 2

▶ Detailed description of the tasks that may require specific physical support

Expected outcome:
– Identify the specific characteristics of the tasks selected

Step 3

▶ Collective validation of the characteristics of the exoskeleton

Expected outcomes:
– List the objective criteria to be incorporated into the specifications
– Agree on the most suitable exoskeleton

Choice of a potentially suitable exoskeleton

PHASE 2 Evaluation of the human/exoskeleton interaction

Step 1

▶ Introduction of evaluation criteria and tools

Expected outcomes:
– Understand the evaluation criteria
– Select the evaluation tools

Step 2

▶ Elaboration of the evaluation protocol

Expected outcome:
– Engage in a structured protocol

Step 3

▶ Learning outside the actual work situation

Expected outcomes:
– Become familiar with the exoskeleton and learn the task and the environment
– Decide on whether to continue the evaluation in the actual work situation

Step 4

▶ Implementation in the actual work situation

Expected outcomes:
– Thorough learning of the use of the exoskeleton
– Decide on whether or not to definitively integrate the exoskeleton based on the results of the evaluation

Integration of a suitable exoskeleton

PHASE 3 Feedback

Expected outcome:
– Obtain feedback in the short, medium and long term about the effects of the use of the exoskeleton on the health and safety of operators based on developments in the work situations

PHASE 1

Decision-making support

1.1 Step 1 Analysis of the physical workload and search for prevention solutions

Prior to any project to acquire exoskeletons and other new physical support technology, it is necessary to analyse the physical workload in the business.

This analysis is part of a prevention approach aimed at reducing the constraints related to physical activity. In particular, it aims at eliminating both major overall physical constraints, however brief they are, and small, local, long or repetitive physical constraints. The method for analysing physical workload can be used within this framework (see ED 6161, in French only [2]). It is based on different essential steps.

It starts with a risk identification phase. Each work situation is in fact composed of specific tasks that can cause excessive constraints, which must be identified.

For that purpose, the working group can use data available in the establishment, so that it can collect information related to the physical workload:

– the risk assessment,
– employees' complaints,
– the conclusions of a diagnosis conducted in-house or with the support of an external player,
– indicators of occupational health (survey of occupational accidents, occupational diseases, jobs with fitness restrictions, etc.) and of staff management (recurring absenteeism, frequent use of temporary workers, significant turnover, etc.) can also be studied in this first step,
– etc.

This method continues with an in-depth analysis of the physical workload, which is based on a global approach aimed at taking into account all factors that could determine physical constraints, such as:

– physical exertion: loads moved, pushing and pulling mobile equipment, transport distances, ease of handling, etc.,
– the design of the work situation: awkward postures and movements, possibility of making work equipment adjustments, access and circulation, etc.,
– time constraints: task frequency, duration of exposure, recovery periods, etc.,
– environmental factors: temperature, noise, lighting, vibration, toxic products, floor quality, uneven floor heights, personal protective equipment, etc.
– characteristics of work organisation: irregular hours, training of employees in risk factors and in technical and human resources, use of technical aids, possibility of modifying the way of working, etc.

On the basis of this analysis, solutions for prevention are sought, aimed at transforming work situations. These solutions must be in line with the particularities of the establishment and take into account organisational, technical and human dimensions, in compliance with the nine general principles defined by Article L. 4121-2 of the French labour code (see following page).

Once the working group has looked into all of the prevention avenues that could eliminate the risk factors behind excessive physical load, then the tasks requiring more specific physical support can be identified.

The 9 general principles of prevention

1. **Avoid risks; this means eliminating the hazard or exposure to the hazard.**
2. **Evaluate the risks;** this means assessing exposure to the hazard and the magnitude of the risk in order to prioritise the prevention actions to be taken.
3. **Combat the risks at the source;** this means integrating prevention as early as possible, particularly as of when the workplace, equipment and operating modes are designed.
4. **Adapt the work to the individual;** this means taking into account differences between individuals, with a view to reducing the effects of work on health.
5. **Adapt to technical progress;** this means adapting prevention to technical and organisational developments.
6. **Replace the dangerous by the less dangerous;** this means avoiding the use of hazardous processes or products when the same result can be obtained with a method that is less hazardous.
7. **Develop a coherent overall prevention policy** which covers technology, organisation of work, working conditions, social relationships and the working environment.
8. **Give collective protective measures priority** and only use personal protective equipment to supplement collective protection if it is not sufficient.
9. **Give appropriate guidance to employees;** this means training and informing them so that they know the risks and preventive measures.

Therefore, before envisaging the use of an exoskeleton as a prevention solution, it is essential to investigate the collective prevention measures to be implemented based on the following questions:

- Is it possible to eliminate the risk at the source?
- If the risk cannot be eliminated, can it be reduced by collective prevention measures (lightening of the physical load by measures such as re-designing the work situation, organisational changes, technical adjustments, acquisition of new skills, etc.)?
- Can physical support technologies –whether robotic or not– meet the identified need for assistance?
- What is the added value of exoskeletons among the physical support technology available?
- Can exoskeletons be suitable as a personal preventive measure?

At the end of this step, the tasks requiring specific physical support are identified. The working group decides on those for which the use of an exoskeleton could be an option. These tasks must be described in detail in the following step.

1.2 Step 2 Detailed description of the tasks requiring specific physical support

If, ultimately, the choice to acquire a physical support device such as an exoskeleton is made, the establishment's need must be defined specifically beforehand, taking into account the specificities of the task and the local constraints it generates, characteristics of the future users and of the organisational context.

Exoskeletons provide very specific support and cannot be applied generically to the constraints of all workstations and the underlying tasks. This step also serves to identify the risk factors that can potentially be addressed by the use of an exoskeleton.

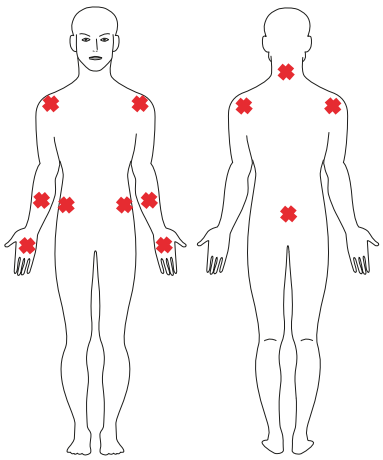
A specific task sheet is used to describe each of the tasks involving a high physical load, for which a primary prevention solution has not been identified. Specific physical support needs are defined precisely so as to select the exoskeleton most suited to the context in which it will be used (physical characteristics, environment, and work organisation).

An example of a completed task sheet for a ceiling sanding task is presented on the following page (a blank task sheet is provided at the end of this document).

At the end of this step, the specific characteristics of the task selected are taken into account to define the criteria for selecting a suitable exoskeleton.

Example of a task-sheet for identifying specific physical support needs

Task-sheet: Ceiling sanding

Detailed description of the task	The operator sands the ceiling using a sander with arms above the head. This activity is done occasionally depending on the worksite and for limited durations.	
Identification of body regions to be relieved	Location of complaints (pain, discomfort, numbness) ▶ Indicate them on the body maps from the front and the back	
	Presence of occupational accident/disease	Absence of occupational accident/disease
Description of physical characteristics (efforts, postures, etc.)	Manual handling/Load carrying	Carrying with both hands and handling a 3-kg sander that is not suspended
	Postures (dynamic, long and static, etc.)	The operator sands between 20 and 25 m^2 per day depending on the hardness of ceilings. This activity combines long static postures with arms above the shoulders and dynamic postures when the operator moves around on the ground.
	Use of tools or equipment	Electric sander
Description of environmental characteristics	Configuration of the workspace (dimensions, circulation, etc.)	The operator moves about on a height-adjustable platform.
	Physical work environment (temperature, humidity, etc.)	Temperature of 15°C, dust, etc.
	Floor (quality of the floor, uneven floor heights, etc.)	A height-adjustable platform with the ground in good condition
	Protective equipment (personal and collective)	Helmet, personal respiratory protective mask, gloves, etc.
Description of work organisation	Individual work or team work	Individual work
	Possibility of breaks	Need for a 10-minute break every hour

1.3 Step 3 Collective validation of the characteristics of the exoskeleton

The goal of this third step is to provide objective criteria to be integrated in the specifications in order to obtain the best possible match between the physical support technology adopted and the activity done by the future users. The choice can be for a robotic or non-robotic exoskeleton. Depending on the reflection conducted at this step, a "turnkey" device available in the market can be an option, as could adapting an existing device or designing a tailor-made mechanism.

For this purpose, the working group seeks to determine the functions required of the exoskeleton. The group draws on its precise knowledge of the work situation and tasks (see Task sheet – step 2) and seeks to define objective criteria aimed at characterising the exoskeleton. The table below presents a certain number of criteria to characterise the most suitable exoskeleton for the task.

Support for identifying the characteristics of a suitable exoskeleton

What are the original intentions?	▶ Return to work for people under medical restriction. ▶ Eliminate a specific constraint at a workstation. ▶ Provide global assistance to the operator.
What are the contributions and limits?	▶ The exoskeleton addresses the constraints of the activity listed in the sheet (see Task sheet – step 2). ▶ The exoskeleton can give rise to new constraints which must be anticipated (e.g. increase in biomechanical load, change in work organisation, etc.).
Which body parts require assistance?	▶ Upper limbs. ▶ Back. ▶ Lower limbs. ▶ Entire body.
What are the support functions expected of the exoskeleton?	▶ To lift the upper limbs. ▶ To carry heavy loads. ▶ To maintain static postures.

Non-exhaustive list

What are the operating conditions of the task to be performed with the exoskeleton?	▶ Production goals. ▶ Environmental constraints to which the device will be confronted (temperature, humidity, dust, use outdoors and therefore subject to weather conditions, etc.). ▶ Organisational constraints (sequencing of the activity, work pace, relationships with colleagues, etc.).
What are the specific adjustments required of the exoskeleton to take into account the variability of the tasks and inter-individual variability of operators?	▶ Settings easy to use. ▶ Areas on the body where the device should or should not be attached depending on the characteristics of the different users (size, gender, age, etc.) and the use of personal protective equipment (PPE). ▶ Adjustment of the intensity of support depending on the tasks to be performed.

Non-exhaustive list

Moreover, the use of an exoskeleton in actual work situations raises many questions about prevention of occupational risks. Several potential risks emerging from both field observations and acquired knowledge have been identified and can help with evaluating new constraints generated by exoskeletons.

Here are a few examples:

- **Mechanical risks:** as with most work equipment, exoskeletons involve, because of their bulky size and structure, the risk of collision with third parties or elements in the environment. Repeated rubbing or pressure of the exoskeleton against certain parts of the body can cause discomfort and/or skin irritation.

- **Risks related to the physical load:** the use of the exoskeleton changes the distribution of load; this can contribute to the appearance of new biomechanical constraints, which are risk factors for musculoskeletal disorders (MSDs). In addition, the weight of exoskeletons or the discomfort associated with performing certain movements can lead to an increase in biomechanical load and more strain on the cardiovascular system.

- **Risks related to the mental workload:** certain activities done with the help of exoskeletons require greater attention because of a change in operators' work practices and strategies which can be accompanied by an increase in stress.

Other potential risks are presented on INRS's website in the information sheet "Exoskeletons at work: 6 critical points".

A preliminary analysis of these risks is essential. These risks will be discussed by the working group and introduced in the specifications in order to eliminate them or prevent them as early as possible when the device is selected or designed. To prepare the specifications, it is possible to refer to guide ED 6231 (in French only) [3].

At the end of phase 1, the characteristics of the exoskeleton adopted are validated. The working group then agrees on the choice of the exoskeleton that could be the most suitable.

Phase 2 consists in evaluating the interaction between the exoskeleton and future users to ensure that the exoskeleton is effectively suited to the operator and the task.

PHASE 2

Evaluation of the human/ exoskeleton interaction

2.1 Step 1 Introduction of evaluation criteria and tools

Evaluation criteria

The criteria proposed below are used to define the objectives aimed at evaluating the relevance of the use of an exoskeleton. These criteria are to be used in the different steps of the evaluation of the use of the exoskeleton.

Five evaluation criteria are proposed:

- **Adoption:** this means evaluating the extent to which the operator has adopted the exoskeleton in their work environment.
  What are the indicators showing that the operator has integrated the exoskeleton in their work activity, among the tools at their disposal?

- **Utility:** this means evaluating whether the task is performed successfully with the physical support.
  Does the exoskeleton provide the service for which it was acquired?

- **Usability:** this means evaluating the ease with which the equipment is used.
  Is the exoskeleton easy to use?

- **Impact:** this means evaluating the changes in the user's operating strategies as well as the effects on the environment and the work community.
  What are the consequences of the use of the exoskeleton on the work practices of the user and the work community?

- **Safety:** this means evaluating the risks to the safety of the operator and their environment.
  What are the effects on safety linked to the use of the exoskeleton?

To better understand the five evaluation criteria, the table below proposes, as an example, items that could be used during the evaluation of the use of exoskeletons.

Presentation of items in connection with the different evaluation criteria

Adoption	Utility	Usability	Impact	Safety
■ Fluidity of movement ■ Control of the exoskeleton ■ Duration of the task ■ Social acceptance ■ Operators' perception	■ Compliance with the cycle time ■ Compliance with the quality of the operation ■ Efficiency of the physical support ■ Duration of active support during the task ■ Operators' perception	■ Ease of implementation: putting it on, taking it off, changing settings, etc. ■ Ease of use ■ Ease of maintenance: cleaning, repairs, etc. ■ The operator has no discomfort when performing the task ■ Adaptability to the different components of the activity ■ Operators' perception	■ Good integration in the work activity ■ Control of the new operating strategies ■ Effects on the operator (physical and cognitive constraints, health effects) ■ Effects on the work community (collaboration among colleagues, time-distribution of tasks, etc.) ■ Operators' perception	■ Assessment of risks to the operator ■ Assessment of risks to colleagues ■ Assessment of risks to the work environment ■ Consideration of the risks of deterioration of the exoskeleton ■ Operators' perception

Non-exhaustive list

The interaction between humans and the exoskeleton makes it essential to take into account operators' perception for each of the five evaluation criteria.

It is important for the members of the working group to agree on the understanding of each evaluation criterion as well as the associated expected outcomes, which will serve to determine whether to continue evaluating the integration of the exoskeleton. The working group chooses the criteria and selects the tools for conducting the evaluation.

Evaluation tools

There can be two types of evaluation tools: "objective" (measuring physiological or physical parameters), or "subjective" (investigating human perception). It is always beneficial to associate the two types of tools because they are complementary.
The tools are selected depending on the evaluation criteria adopted, the dimensions measured by these tools and the resources to be deployed for their implementation (technical resources, human resources, preparation and analysis time, cost and bulk of the equipment, etc.).

The table below presents a few examples of tools to be implemented depending on the dimension studied and the evaluation criteria that may be associated. In Annex 1, the resources to be used for the implementation of evaluation tools are described.

Example of evaluation criteria, associated tools and dimensions studied

Evaluation criteria	Associated tools	Dimension studied
Safety	Business risk assessment	Analysis of risks
Impact	Borg scale	Quantifies effort perceived
Adoption, utility, impact	Nordic questionnaire	Quantifies perceived pain and discomfort
Utility, usability, impact	Heart rate monitor	Measures the heart rate to estimate energy expenditure, heart, mental and thermal strain
Adoption, utility, usability, impact	Timekeeping	Time analysis of work

At this stage in the method, evaluation criteria and tools are adopted, enabling the evaluation of the use of the exoskeleton chosen by the working group. The evaluation continues with the elaboration of a protocol.

2.2 Step 2 Elaboration of the evaluation protocol

Defining sampling

In order to take into account differences between individuals, it is necessary to repeat the evaluation with several volunteers. At a minimum, all operators concerned by the integration of an exoskeleton must be involved. When an organisation has a high number of staff members, ideally, ten operators should participate. It is also possible to test several similar workstations.

Establishing the measurement protocol

To evaluate the benefit of the exoskeleton, it is necessary to compare how the task is performed with and without the exoskeleton. Each volunteer employee shall have to perform the task both ways, with and without the exoskeleton. The comparison can only be done for the same task (pace, load, work situation, etc.), according to the same measurement protocol as presented below:

1. Selection of evaluation tools
2. Performance of the task with/without the exoskeleton
3. Evaluation of the human/exoskeleton interaction
4. Determination of a recovery time based on the intensity and duration of the task performed

Establishing the schedule

In order to inform the different players, it is necessary to establish a test schedule.

Recruiting volunteers

Team meetings can be used to present the exoskeleton project and evaluation test goals as well as the protocol proceedings. The aim is to present the key features so that some operators volunteer.
Preference should be given to the teams concerned by the work situations targeted by the evaluation, since those operators have a good knowledge and experience of the mission and associated tasks.

Informing players

The different players are informed of the investment required, the time commitment, and of the evaluation protocol. The occupational health service is also informed and associated with the entire protocol.

It must be specified to all participants that data will be processed anonymously. Staff representatives are informed regularly of the progress of the programme and the results. Frequent communication within the organisation (in-house newsletter, posters, etc.) must also be planned.

After the protocol is finalised, the next step is to perform the evaluation of the human/exoskeleton interaction in concrete terms. Here, learning how to use the exoskeleton is particularly important. It is necessary to proceed in two stages. The first occurs outside of the actual work situation to enable the operator to adopt the exoskeleton. The second stage involves the use of the exoskeleton in an actual work situation to ensure that it is compatible with production establishment (appearance of other risks, deterioration in the performance expected, etc.).

2.3 Step 3 Learning outside the actual work situation

A progressive learning phase is necessary for the operator and members of the working group to ensure that the exoskeleton is well suited to the task and its environment. Ideally, to facilitate this learning, it is recommended to reproduce a task as close as possible to the actual work situation so as to relieve the operator of production requirements. If this is not possible, the learning phase can be done directly in the actual work situation (see *Phase 2 – step 4*).
This learning phase is a two-stage approach: operator's familiarisation with the exoskeleton, followed by learning strictly speaking.
The evaluation criteria and tools (see *Phase 2 – step 1*) serve to ensure that learning is effective.

Familiarisation

Familiarisation corresponds to the progressive discovery of the use of the exoskeleton. It is about giving the operator the means to become accustomed to the unit (fluidity of movement, ability to adjust the system if possible, operator's perception, etc.) in accordance with their interaction with the exoskeleton. For that purpose, it is essential, beforehand, to inform the operator of the specific risks related to the use of the exoskeleton (see *Phase 1 – step 3*).

This aims to:
– ensure that the technical specifications and the system adjustment possibilities adapt to the the operator's morphology,
– identify moments during which the device's physical support is active or not,
– pinpoint the contributions and constraints of the exoskeleton,
– etc.

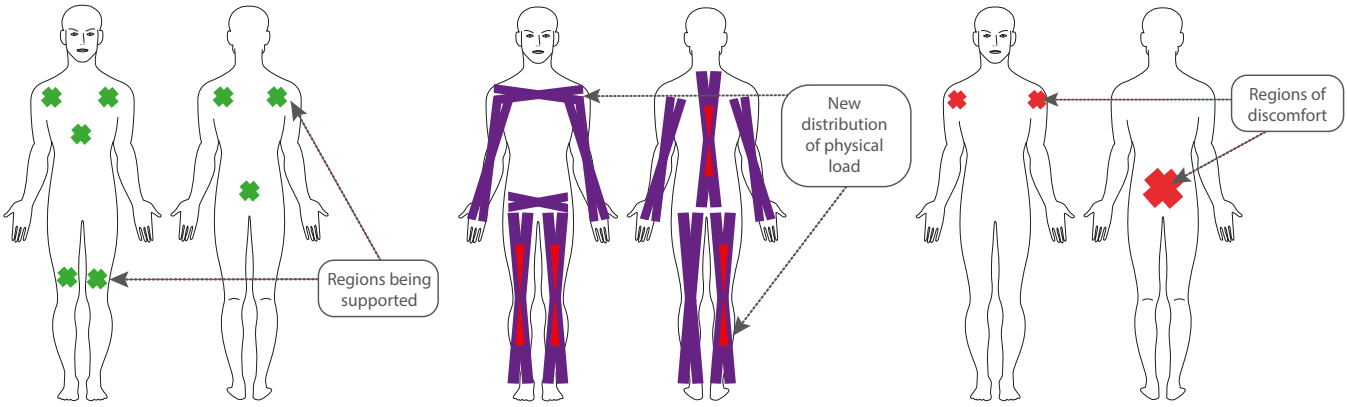
When the operator has become familiar with the exoskeleton, they may then use it to perform the task reproduced to deepen their learning. The adjustments of the exoskeleton to the operator's morphology are discussed when the operator is becoming familiar with the device outside the actual work situation, but can be fine-tuned in the work situation reproduced and in the actual work situation. Learning is a dynamic process that evolves as time passes.

Learning the task reproduced and its environment

This has three objectives:
- Reproduce a task as close as possible to the actual work situation so that the exoskeleton can be tested for a task, and in the environment in which it will actually be used. The task sheet (see *Phase 1 – step 2*) can be used to build this reproduced task.
- Re-configure, if required, the work situation reproduced (material elements, work environment, etc.) for the operator to discover and use as best as possible the exoskeleton's potential for physical support.
- Identify the moments during which the device's physical support is active or not.

During this learning, body maps devoted to the evaluation of the human/exoskeleton interaction can be used to help the operator to locate the regions:
– where support is provided,
– where physical load is newly distributed,
– where there is discomfort.
These three areas must be investigated separately (blank guidance sheets are proposed at the end of this document).

Example of body maps identifying regions where support is provided, where physical load is distributed and where there is discomfort



It is essential to perform this learning phase with several operators in order to have different evaluations and give operators the possibility to compare opinions at this stage.

In order to characterise the human/exoskeleton interaction, specific indicators can be identified and reported in a summary sheet (see *Phase 2 – step 4*), for example, the percentage of physical support duration compared to the duration of the entire task (see below).

Item	Indicator	Evaluation criterion
Duration of physical support	Specify the % of time during which physical support is active during the task	Duration of the support considerable or not

This learning phase outside of the actual work situation is finalised once the data have been analysed and validated by the working group. Then, the exoskeleton can be implemented in actual work situations.

2.4 Step 4 Implementation in actual work situations

In-depth learning in actual situations

The working group shall take into account summary elements from the learning phase outside the actual work situation (previous step) to adapt the actual work situation to the use of the exoskeleton before it is integrated (cycle time, reconfiguration of material elements, possibility of working differently, etc.). The operator shall have time to adopt this new situation. This adoption time varies depending on factors related to the operator, the exoskeleton, the task to be performed and the work environment.

Validation of the integration of the exoskeleton

The five evaluation criteria proposed in *Phase 2 – step 1* must again be used to decide on whether to validate the definitive integration of the exoskeleton.

A summary sheet can be useful to combine relevant characteristics from the evaluation data in order to come to a conclusion on whether the exoskeleton will be integrated in the actual work situation. An example of a summary sheet is presented below (a blank sheet is proposed at the end of this document).

Summary sheet

Items	Indicators	Evaluation criteria
Adoption duration	Duration	Long or short
Adjustments	Describe the difficulties	Number of difficulties
Physical support duration	Specify the % of time during which support is active during the task	Duration of the support considerable or not
Regions receiving physical support	Show on a body map	List of regions being supported: match between these regions and the constraints of the activity
Regions where physical load is distributed	Show on a body map	Identification by the operator of any new physical strain
Regions of discomfort	Show on a body map	Number of regions of discomfort
Adaptation of the environment for the task reproduced	Type of environmental adaptations	List of adaptations: feasible or not
Adaptation of the environment for the actual task	Type of environmental adaptations	List of adaptations: feasible or not

This summary is used to decide on whether to validate the initial goals concerning the benefit of using the exoskeleton.

Following this phase, the working group must make practical recommendations concerning the conditions of use of the exoskeleton in actual work situations: operating instructions, conditions in which the exoskeleton is attached and removed, maximum duration of use of the device, etc.

PHASE 3

Feedback

Short-, medium, and long-term evaluation is essential: it questions the benefits of the system depending on changes in the work situation. For a long-term evaluation of any effects on operators' health, the establishment can use external expertise, particularly in connection with the occupational health service.
The evaluation is based on the comparison between the original situation and the short-, medium- and long-term situations.

In order to be implemented, the evaluation must draw on good knowledge of the original situation and define the precise goals that should be shared by all players. The evaluation must investigate different dimensions related to the employees (health, complaints, satisfaction, etc.), the structure (occupational accidents, absenteeism, turnover, etc.), the activity (technical, human and organisational changes). Phase 2 of the method remains a basis for collecting feedback over time.

The critical analysis of the objectives set, resources used, results obtained and the impact on the establishment serves to build arguments to maintain, modify or abandon the use of the exoskeleton.

The evaluation must promote a culture of occupational health by demonstrating the impact of the exoskeleton's integration on the health and safety of employees and on the work quality. This evaluation provides content for the occupational risk assessment. Updating it ensures that the action put in place is always relevant, regardless of the changes in the work situation.

At this stage, the working group can be disbanded. The evaluation will then be incorporated into the establishment's usual occupational risk assessment approach.

Conclusion

The three-phase method proposed in this guide enables safety professionals and establishments to grasp many issues raised by the integration of an exoskeleton. The participatory nature of the approach and the evaluation at different steps can be included in a continuous improvement process, guaranteeing consideration of occupational risk prevention in compliance with the general principles of prevention.

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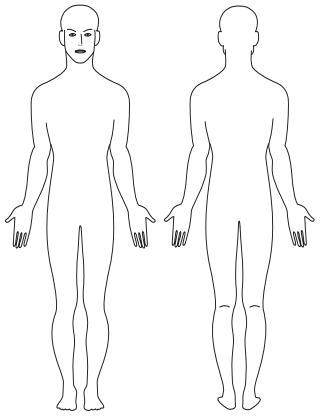
Evaluation aids

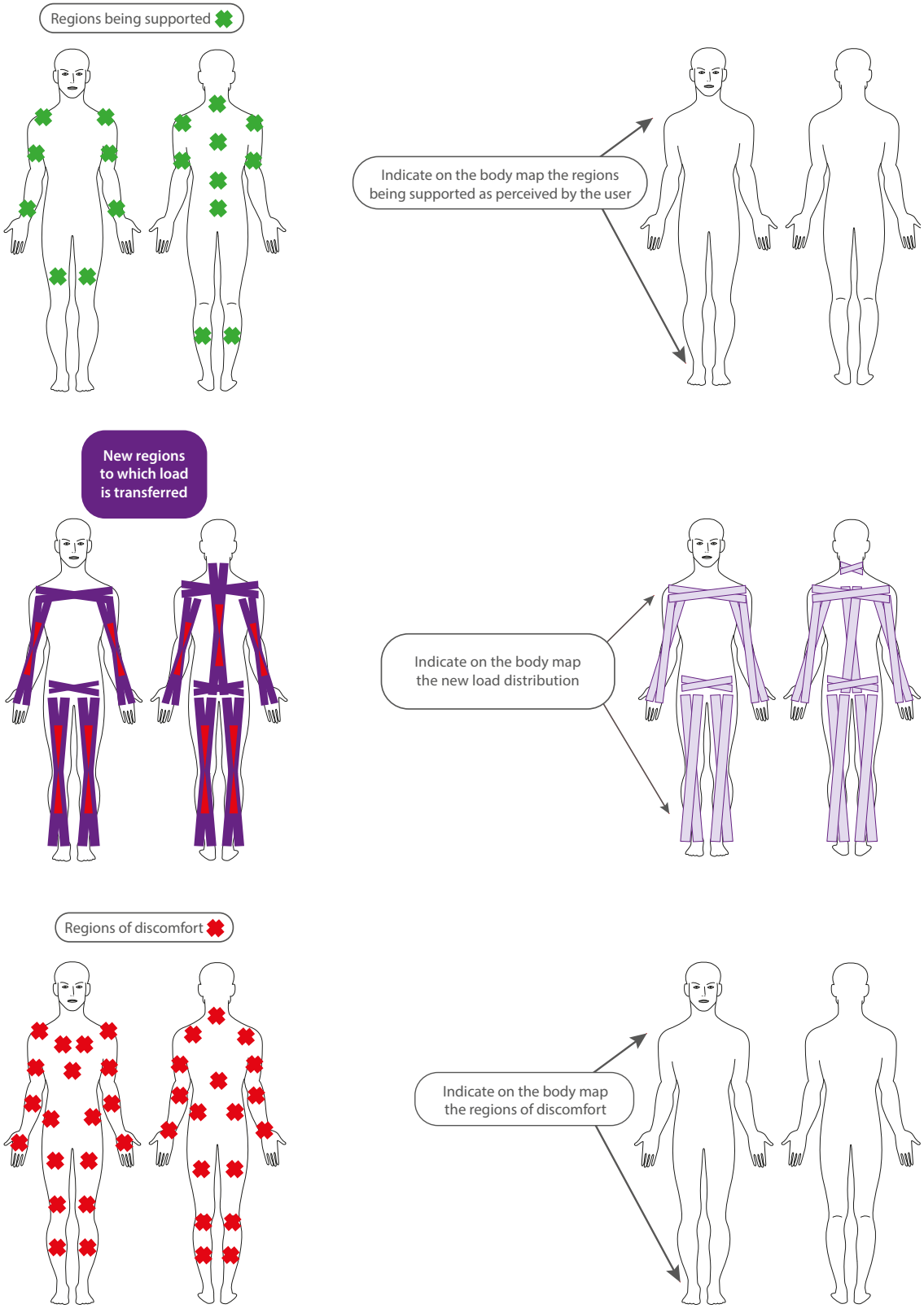
A – Task sheet

Task			
Detailed description of the task			*Comments*
Identification of regions to be relieved	Location of complaints (pain, discomfort, numbness) ▶ Indicate them on the diagrams		
	Presence of occupational accidents/diseases		
Description of physical characteristics (efforts, postures, etc.)	Manual handling/ Load carrying		
	Postures : – dynamic postures – long, static postures		
	Use of tools or equipment		
Description of environmental characteristics	Configuration of the work space (dimensions, circulation, etc.)		
	Physical work environment (temperature, humidity, etc.)		
	Floor (quality of the floor, uneven floor heights, etc.)		
	Protective equipment (personal and collective)		
Description of work organisation	Individual work or team work		
	Possibility of breaks		
...	...	...	...

B – Summary sheet

Items	Indicators	Evaluation criteria	Results and comments
Adoption duration	Duration		
Adjustments	Describe the difficulties		
Physical support duration	Specify the % of time during which support is active during the task		
Regions receiving physical support	Show on a body map		
Regions where physical load is distributed	Show on a body map		
Regions of discomfort	Show on a body map		
Adaptation of the environment for the reproduced task	Type of environmental adaptations		
Adaptation of the environment for the actual task	Type of environmental adaptations		
...	...	...	...

C – Identification of regions being supported, to which load is transferred, and regions of discomfort



Annex 1 – Support for choosing evaluation tools based on their characteristics

	Description	Evaluated by	Training necessary	Technical resources	Human resources	Preparation time	Administration time	Analysis time
Self-confrontation	Expression by the subject of their work activity	Operator and expert	yes	Video, audio recordings	2 or 3 people	Long (collect data that will be used for self-confrontation)	2x1 hour or 3 or 4x ½ hour	Long (because the content has to be analysed)
Borg scale	Quantifies an effort perceived	Operator	no	Form to fill out	1 person	None	5 minutes	Short
Interview	Collection of information	Expert	no	Recording possible, interview guide	1 person	Duration variable depending on the complexity of the task	1h30 or more	Can be long
Logbook	Collection of data on each of the activities done during a work day	Operator	no	Paper, pencil	1 person	Depends on what is being investigated	Can be long depending on the data collection duration	Long (because the content has to be analysed)
Nordic questionnaire	Quantifies pain and discomfort perceived	Operator	no	Form to fill out	1 person	None	5 to 10 minutes	Short
Questionnaire	Collection of data on employees' perception at their workstations	User/ operator or expert	no	Recording possible, interview guide	1 person	More or less long depending on whether or not the questionnaire exists	1 hour	Relatively long
NASA-TLX	Evaluation of mental workload	Operator	no	Paper, pencil	1 person	5 minutes	5 minutes	Short
Heart rate monitor	Measurement of heart rate to estimate energy expenditure, heart, mental and thermal strain	Expert	yes	Heart rate monitors and analysis software	1 person	5 minutes	According to the duration of the task	Relatively short with software
Timekeeping	Time analysis of work	Expert	yes	Stopwatch or video (video processing software)	1 person	Variable depending on the activity	Between 20 and 30 cycles	Relatively short
Method for analysing physical workload	In-depth analysis of the physical workload	User	yes	Paper, pencil	Working group	None	Based on the duration of the task	15 minutes