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"Occupational exoskeletons: a new challenge for human factors, ergonomics and safety disciplines in the workplace of the future"

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Introduction to occupational exoskeletons

To prevent work-related musculoskeletal disorders it becomes necessary to consider the use of exoskeletons when other technical and organisational measures to design workplaces can be impractical or infeasible

Exoskeletons can be defined as personal assistance systems that affect the body in a mechanical way and are normally classified as active or passive systems

Examples of lumbar support Active exoskeletons

Commercially available upper-limb passive exoskeleton

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Occupational exoskeletons – Gap of European legislation

In general, an exoskeleton can be defined as a machinery in the field of the regulations of the Machinery Directive of the European Union (directive 2006/42/CE).

To date, only the ISO/DIS 18646-4, which provides performance criteria and related test methods only for medical lower-back support robots.

International safety standards for occupational application of exoskeletons do not yet exist.

Occupational exoskeletons: difficulty of acceptance by workers

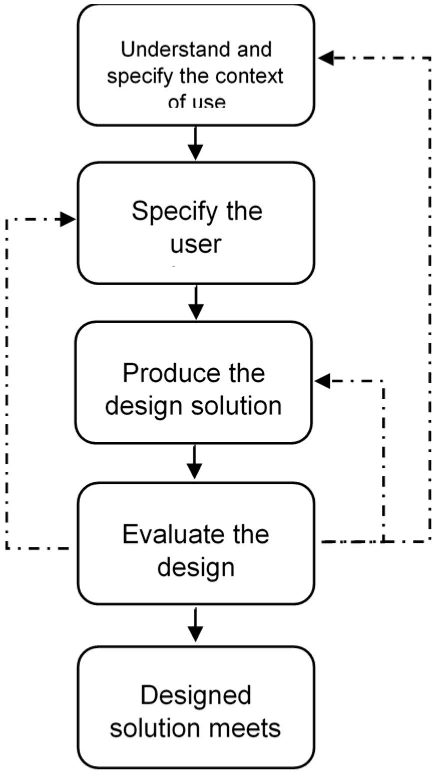
For workers wearing occupational exoskeletons (both active and passive), several risk scenarios can be defined relating to their prolonged use:

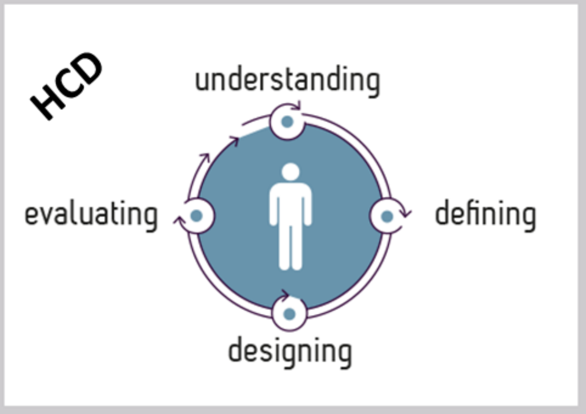
1. new potential health risks could occur for the redistribution of stress to other body regions;
2. the use of exoskeletons affects motor control, joint stability and altered kinematics of the workers body;
3. the passive exoskeletons can potentially increased activity of leg or arm muscles of the workers;
4. the active exoskeletons have a high weight which can affect the health of the workers;
5. ergonomic issues related to the level of discomfort associated with wearing the exoskeleton.

Furthermore the device must not only be safe, comfortable, useful and usable but, just as importantly, must be desirable to the end user. For this reason, it is advisable to resort to a human-centred design approach to involve the users (companies and workers) directly in the exoskeleton design process.

Human-centred design and occupational exoskeletons

- Human-centred design is an approach to interactive development that aims to make systems usable and useful by focusing on the users, their needs and their requirements, and by applying human factors/ergonomics, and usability knowledge and techniques.
- This approach enhances effectiveness and efficiency, improves human well-being, user satisfaction, accessibility, and sustainability, and counteracts possible adverse effects of use on human health, safety and performance.
- The EN ISO 9241-210:2019 aims to make this information available to help to develop systems following an interactive process, where appropriate. This standard is specifically for managing hardware and software design and redesign processes, but the approach can also be useful for other complex systems such as the design of an occupational exoskeleton.
- Another useful standard for the scope of HCD is EN 614-2:2000+A1:2008 - Safety of machinery. Ergonomic design principles. Interactions between the design of machinery and work tasks





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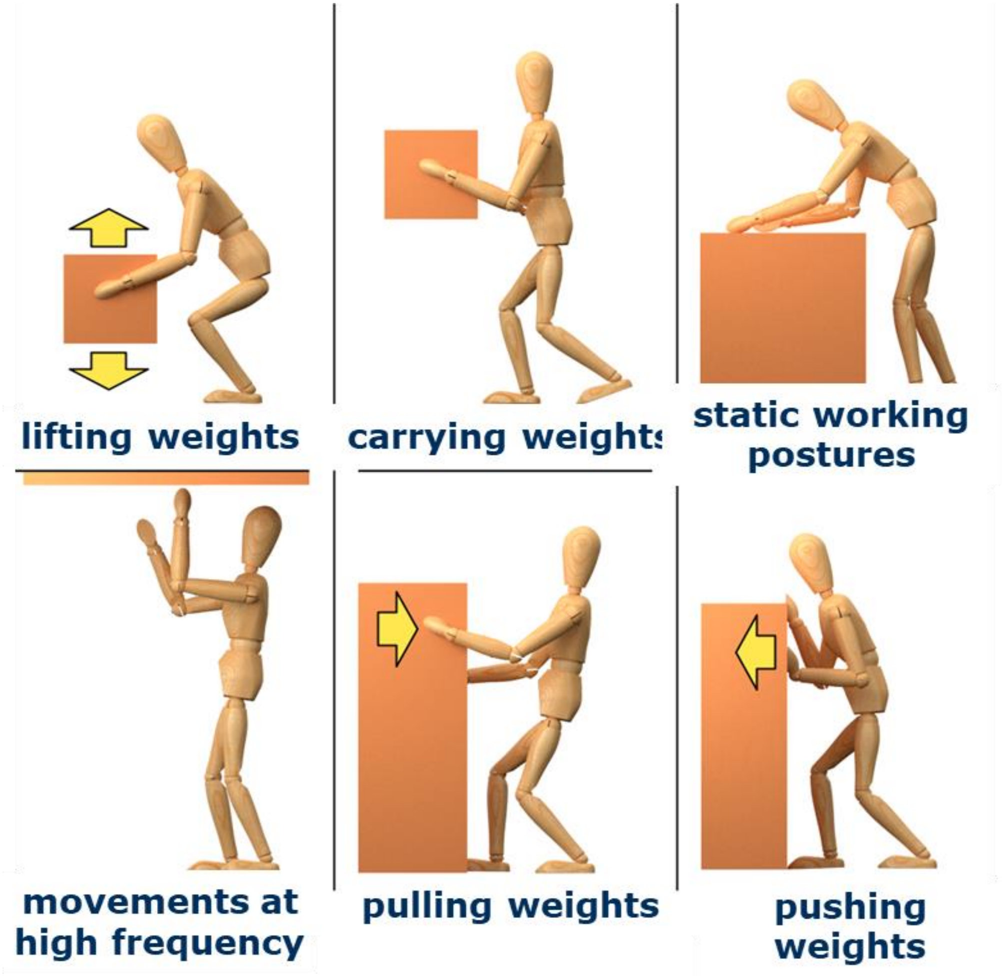
Design characteristics of a safe occupational exoskeleton with HCD process

When adopting the HCD process, understanding and describing the user context is the first step to take. Therefore, for occupational exoskeletons it is of great importance to define the characteristics of the workplace and the MMH activities to be carried out by the worker. In this case it is useful to refer to the ISO/TR 12295:2014 technical report on the manual handling of loads and the evaluation of static working postures. Based on this procedure have to be define the tasks per-formed by the worker, such as:

- lifting and carrying weights,
- pushing and pulling weights,
- movements at high frequency,
- static working postures.



Design characteristics of a safe occupational exoskeleton with HCD process

Other aspects to consider at this stage relate to:

1. the handling load (e.g. mass, size/dimension, grip/handles),
2. work environmental aspects (e.g. temperature, outdoor/indoor activity, restricted spaces, work space features),
3. production conditions (e.g. times and working methods, price of the device),
4. workers’ characteristics (e.g. gender, age, qualifications, skill).

Design characteristics of a safe occupational exoskeleton with HCD process

The second stage of the HCD process is specifying user requirements. In general, in the literature, the following main requirements have been identified:

1. freedom of movement (e.g. body postures, dimensions of the device),
2. comfort (e.g. postural and physiological comfortable angle),
3. environmental conditions (e.g. interaction between operators, caloric/metabolic expenditure),
4. wearability (e.g. material, shape of the device, adaptability),
5. intuitiveness of use (e.g. cognitive resources required),
6. biomechanical aspects (e.g. force/pressure in the different parts of the body, vibrations, noise, distribution of the weight on the operator's body),
7. physiological aspects and effects (e.g. right balance between activity and in-activity).

Furthermore, other secondary aspects can encourage the acceptance of the system, such as the aesthetics of the occupational exoskeleton.

Design characteristics of a safe occupational exoskeleton with HCD process

Operator's variability	
Strength	Physical dimension
EN 614-1:2006+A1:2009 EN 1005-1:2001+A1:2008 EN 1005-2:2003+A1:2008 – Safety of machinery – Human physical performance – Part 2: Manual handling of machinery and component parts of machinery EN 1005-3:2002+A1:2008 – Safety of machinery – Human physical performance – Part 3: Recommended force limits for machinery operation EN ISO 15536-1:2008	EN 547-3:1996+A1:2008 – Safety of machinery – Human body measurements – Part 3: Anthropometric data EN 614-1:2006+A1:2009 – Safety of machinery – Ergonomic design principles – Part 1: Terminology and general principles EN 894-1:1997+A1:2008 – Safety of machinery – Ergonomics requirements for the design of displays and control actuators – Part 1: General principles for human interactions with displays and control actuators EN 1005-1:2001+A1:2008 – Safety of machinery – Human physical performance – Part 1: Terms and definitions EN 1005-4:2005+A1:2008 – Safety of machinery – Human physical performance – Part 4: Evaluation of working postures and movements in relation to machinery access into machinery EN ISO 14738:2008 – Safety of machinery – Anthropometric requirements for the design of workstations at machinery EN ISO 15536-1:2008 – Ergonomics – Computer manikins and body templates – Part 1: General requirements EN ISO 7250-1:2017 – Basic human body measurements for technological design – Part 1: Body measurement definitions CEN ISO/TR 7250-2:2011+A1:2013 – Basic human body measurements for technological design: Statistical summaries of body measurements from national populations

Human/machinery interface				Concentration	
Sensitivity	Auditory	Visual	Interaction	Cognitive performance	Mental operation
EN ISO 7730:2005 – Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria ISO 7933: 2004 – Ergonomics of the thermal environment – Analytical determination and interpretation of heat stress using calculation of the predicted heat strain EN ISO 8996:2004 – Ergonomics of the thermal environment – Determination of metabolic rate	EN 614-1:2006+A1:2009	EN 614-1:2006+A1:2009 EN ISO 14738:2008	ISO 6385:2004 – Ergonomic principles in the design of work systems EN ISO 9241-910:2011 – Ergonomics of human–system interaction – Part 910: Framework for tactile and haptic interaction	EN 614-1:2006+A1:2009 EN ISO 10075-1:2017 EN ISO 10075-2:2000 EN ISO 10075-3:2004	EN 614-1:2006+A1:2009 EN ISO 10075-1:2017 – Ergonomic principles related to mental work-load – Part 1: General terms and definitions EN ISO 10075-2:2000 – Ergonomic principles related to mental workload – Part 2: Design principles EN ISO 10075-3:2004- Ergonomic principles related to mental workload – Part 3: Principles and requirements concerning methods for measuring and assessing mental workload

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Conclusion

As shown the exoskeletons can support workers in performing specific tasks in some working environments, and therefore can help prevent WRMSDs.

Nevertheless, for several reasons the use of occupational exoskeletons in the workplace is still rather limited.

On the one hand, there is little knowledge about these devices and their real preventive effects on WRMSDs.

On the other, some "significant" technical challenges and user acceptability issues explain the current state of diffusion of these wearable service robot devices in the workplace.

The HCD approach can be a tool to guarantee ever more widespread diffusion of these systems, responding more and more precisely to the real needs that users manifest.

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Thank you for the attention!

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