OCCUPATIONAL EXOSKELETONS FOR ASSISTING WORKERS

Lorenzo Grazi
Post-doctoral researcher
Scuola Superiore Sant'Anna

Pontedera, 18 June 2024

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798

Agenda

ITEM	START	END	PRESENTER(S)
Welcome and participants presentations	10:00	10:15	All
Introduction to the Mari4_YARD project and objectives of the training	10:15	10:30	Lorenzo Grazi
Exoskeletons presentation (UL and LB exoskeletons)	10:30	11:15	Lorenzo Grazi
COFFEE BREAK	11:15	11:30	
Hands-on session on the UL and LB exoskeleton	11:30	12:30	Lorenzo Grazi, Alicia Barsacq, Andrea Parri
LUNCH	12:30	14:00	
Occupational exoskeletons research and use cases	14:00	14:45	Lorenzo Grazi
Impact on ergonomics	14:45	15:15	Lorenzo Grazi
COFFEE BREAK	15:15	15:30	
Training assessment	15:30	15:45	Lorenzo Grazi
Final remarks and group picture	15:45	16:00	Lorenzo Grazi

Participants roundtable

Your trainer for today

Lorenzo Grazi graduated in Biomedical Engineering from the University of Pisa and received his Ph.D. degree in Biorobotics from the Scuola Superiore Sant'Anna with a dissertation on the control and assessment of occupational exoskeletons. Since May 2020, Lorenzo is a post-doctoral fellow in the Wearable Robotics Lab of Scuola Superiore Sant'Anna, where he is involved in the research activities about occupational exoskeletons. Lorenzo is the author and co-author of several publications, mainly focusing on wearable robotics for occupational applications.

The Mari4_YARD project

About the project

Mari4_YARD is an EU funded project that leverages the potential of Internet of Things, mobile and ubiquitous ICT tools, and robotics to develop user-centric solutions for flexible and modular manufacturing and thus implement a novel connected shipyard. The project started in December 2020 and will last until November 2024.

Vision

Mari4_YARD aims to implement a portfolio of worker-centric solutions, by relying on novel collaborative robotics and ubiquitous portable solutions, enabling modular, flexible, reconfigurable and usable solutions targeting the execution of key labor-intensive tasks by preserving industry-specific workers' knowledge, skills and biomechanics health status.

The Mari4_YARD project

Objectives

Intuitive human-robot collaborative solutions in shared workspaces

Handheld and portable AR/MR tools for assisting shipyard workers

AI-assisted exoskeletons for reducing fatigue and physical stress

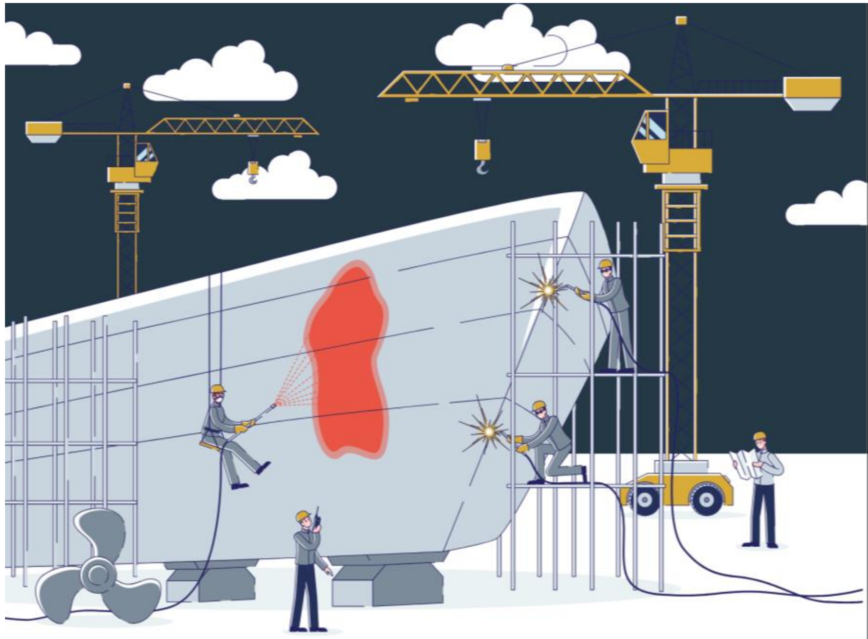
Portfolio of worked-centric tools to support labor-intensive tasks

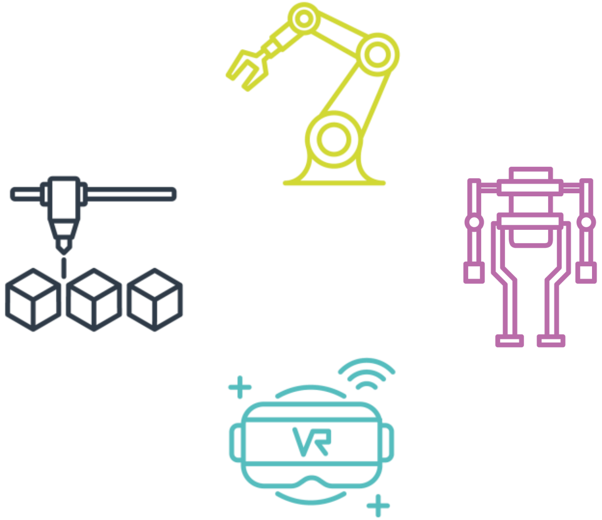
Demonstration of Mari4_YARD approach at real-scale in SME-shipyard

The Didactic Factories

Concept

The Didactic Factories consist of open and real-scale demonstrators for workforce training at the EU level to accelerate the adoption of novel methodologies in shipbuilding.





Objectives

To provide upskilling and re-skilling of the shipyard's workforce

To show how these new technologies could be used to advance shipyard processes

To provide infrastructure for third parties to test new technologies and solutions (technology developers and system integrators)

The Didactic Factories

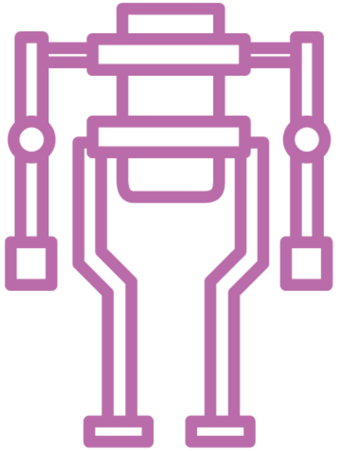
Training courses

Training of personnel is an essential part of the efficiency and competitiveness of the EU workforce, in all areas, including the shipbuilding and ship-repairing industry. For that reason, Mari4_YARD organizes a series of training activities (both internal and external to the consortium). The trainings are part of the activities linked to the Didactic Factories, where it is possible to test and have a hands-on approach on the new technologies used for the shipbuilding and retrofitting.

Analysis of the EU shipbuilding sector revealed some gaps in the digitization and optimization of production processes, data analysis, and programming, as well as the lack of skills in automation, engineering, soft skills, information and communication technologies, health and safety.

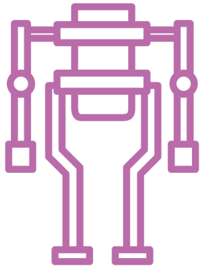
The **main objective** of the training is to contribute to fill these gaps in the current and future EU shipbuilding workforce to facilitate the adoption of the new user-centric tools developed in the project.

You are participating to the training course



Occupational Exoskeletons assisting workers

Outline of the course



Occupational Exoskeletons assisting workers

- The Mari4_YARD exoskeleton prototypes
  - Theoretical presentation of the devices
  - Practical/demo session

- Occupational exoskeletons use cases
- Ergonomic impact of occupational exoskeletons

- Training evaluation

Part I
Occupational Exoskeletons

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798

Occupational Exoskeletons

An **Occupational Exoskeleton** (OE) is a wearable technology worn by a human operator, which is conceived to assist, support, reduce muscle strain of targeted anatomical district or joint while performing the job activities

OEs classifications

OE can be grouped based on three types of classes:

Target body area	Kinematic structure	Actuation principle

OEs classifications: target body area

Upper-limb OE

Upper-limb OE mainly target the shoulder joint to support overhead static, quasi-static, and dynamic manipulation tasks

Back-support OE

Back-support OE mainly target the lumbar area to support heavy manual material handling, such as load lifting activities

Target body area

Kinematic structure

Actuation principle

OEs classifications: target body area

Upper-limb OE mainly target the shoulder joint to support overhead static, quasi-static, and dynamic manipulation tasks

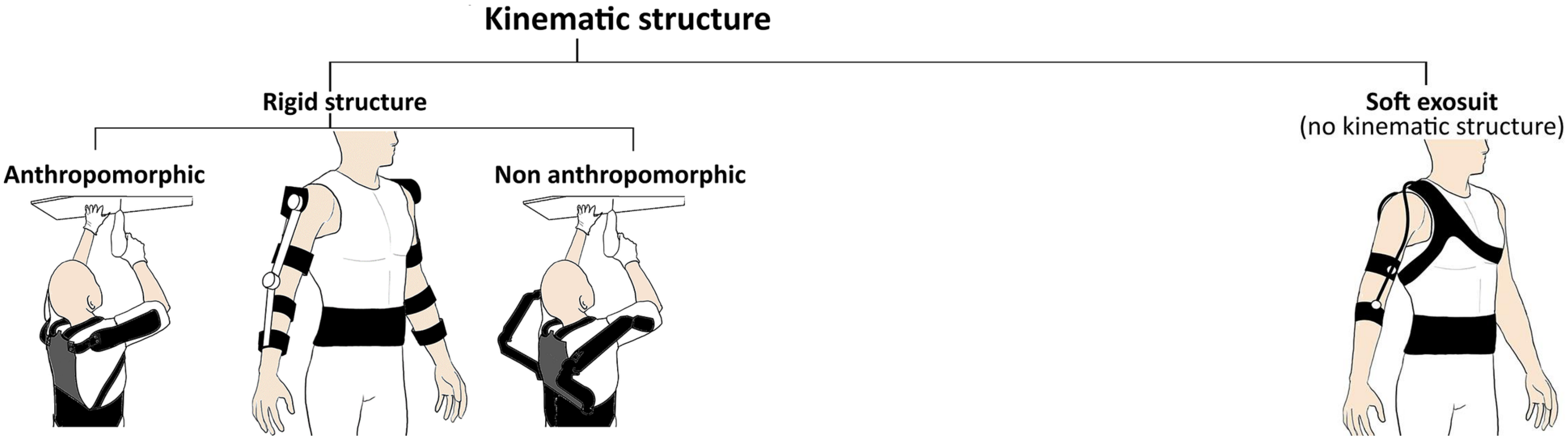
Back-support OE mainly target the lumbar area to support heavy manual material handling, such as load lifting activities

Target body area

Kinematic structure

Actuation principle

OEs classifications: kinematic structure



Target body area

Kinematic structure

Actuation principle

OEs classifications: kinematic structure

Kinematic structure

Rigid structure

Soft exosuit
(no kinematic structure)

Target body area

Kinematic structure

Actuation principle

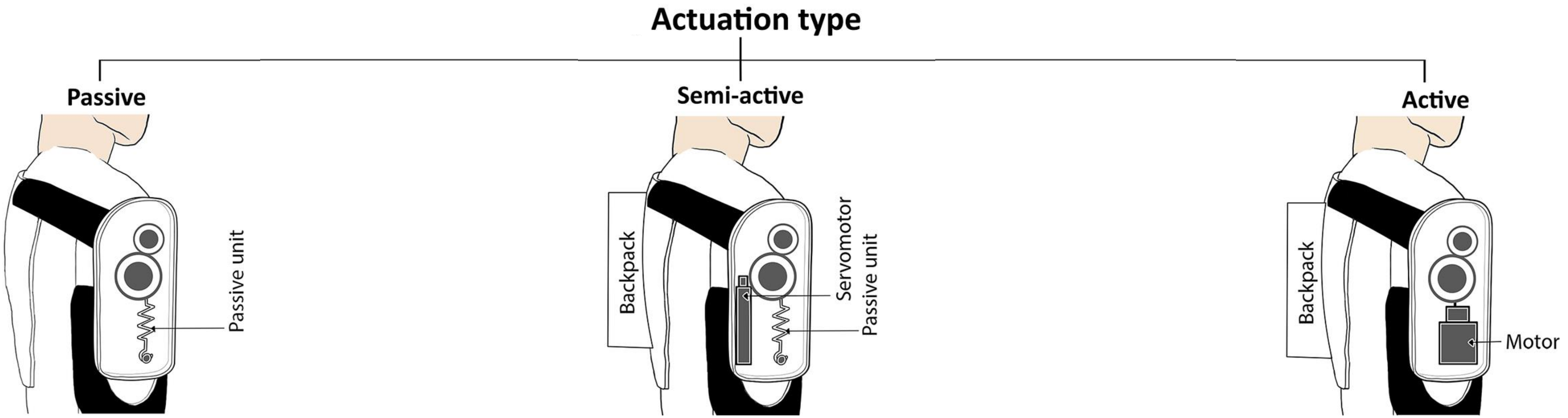
OEs classifications: kinematic structure

Exoskeletons with **anthropomorphic** kinematic structures include robotic joints that need to be aligned with the user's joint axes, thus misalignment-compensation strategies should be included to counteract the effects of axis misalignments

Exoskeletons with **non-anthropomorphic** structures do not require a direct correspondence between the robot's and user's axes of rotation

Soft exosuits are wearable **clothing-like devices** that can generate moments around biological joints through pulling cables and textiles acting in parallel to the action of muscles and tendons. In these systems compressing loads are not sustained by any external rigid structure but are sustained by the wearer's bone structure.

OEs classifications: actuation principle



Target body area | Kinematic structure | **Actuation principle**

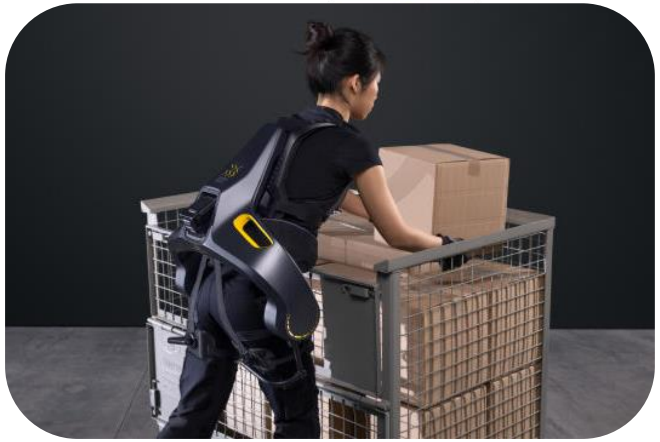
OEs classifications: actuation principle

Actuation type

Passive

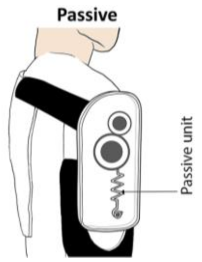
Semi-active

Active

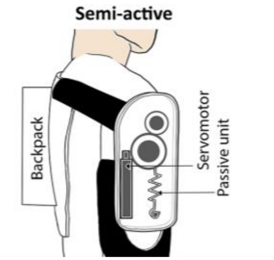


Target body area | Kinematic structure | **Actuation principle**

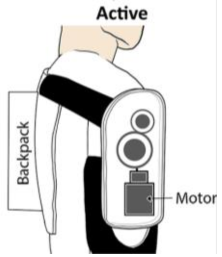
OEs classifications: actuation principle



Passive OEs typically exploit **springs** or **spring-like elements** to store and release energy in various phases of the human movement (e.g., providing anti-gravitational support at the shoulder in overhead tasks or postural support to the trunk in leaning tasks)

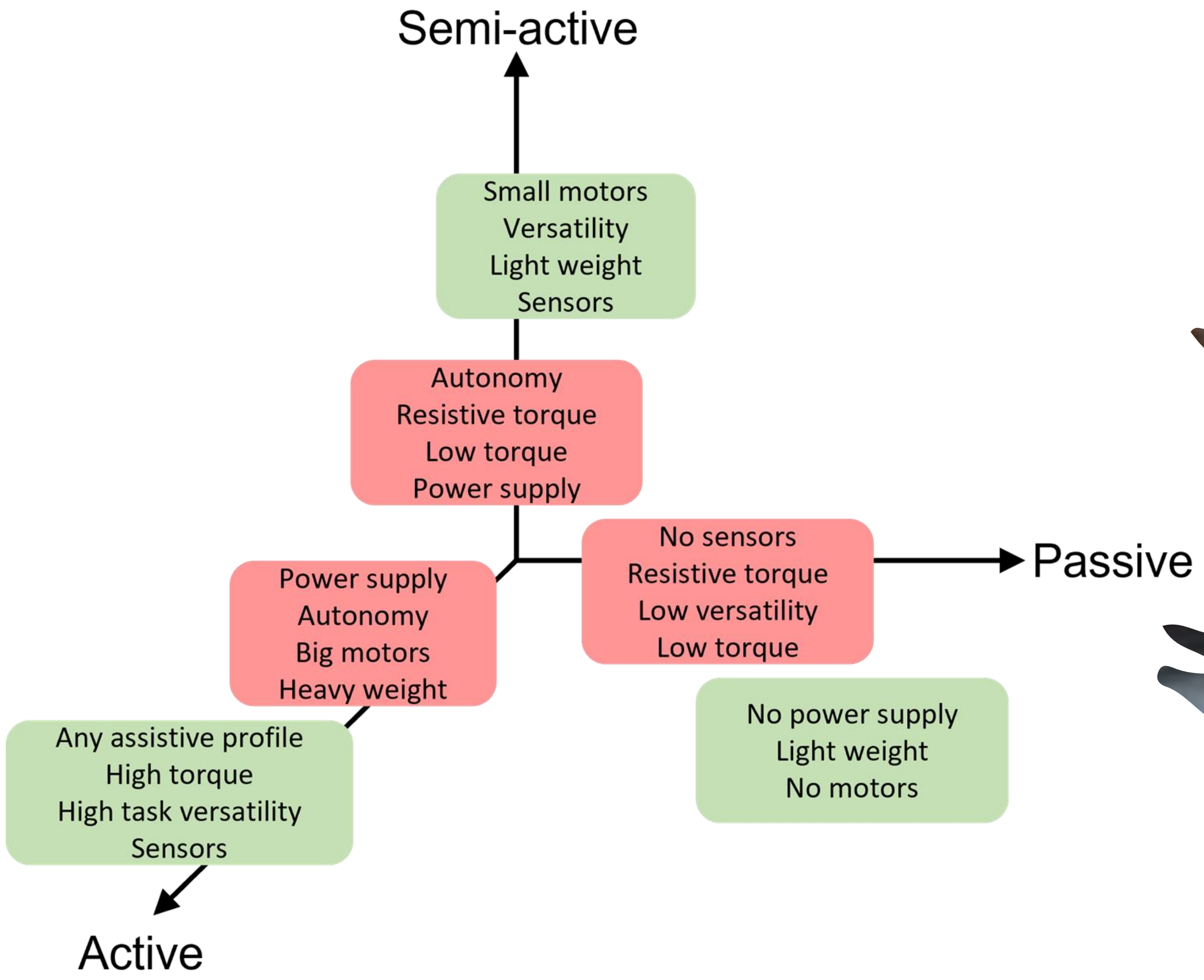


Semi-active OEs are a **trade-off that use low-power servo motors** to adapt the behavior of the device based on the user's needs, e.g., by adapting the level of assistance or engaging/disengaging the actuation mechanisms



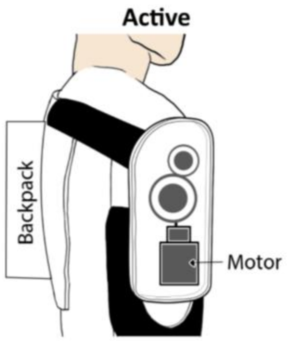
Active OEs use **powered actuators** to generate assistive torque and rely on sensors and control units to synchronize robot action with the user's motion

Comparison of OEs main features



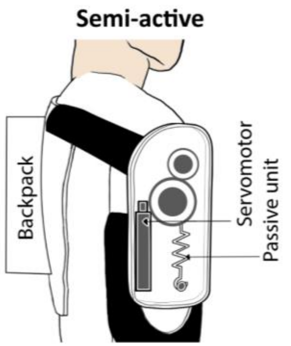
Overcoming the limits of passive OEs

Powered OEs are devices that integrate sources of mechanical power (e.g., electrical motors, pneumatic actuators). They can be categorized as:



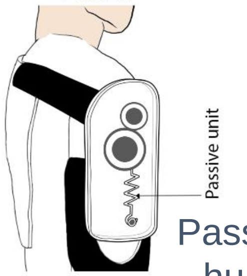
Active systems use powered actuators to generate assistive torque and rely on sensors and control units to synchronize robot action with the user's motion

Semi-active systems are a trade-off that use low-power servo motors to adapt the behavior of the device based on the user's needs, e.g., by adapting the level of assistance or engaging/disengaging the actuation mechanisms



From passive to powered OEs

Passive



Passive OEs can assist the human joints in complex static and dynamic gestures

Variability of typical work tasks

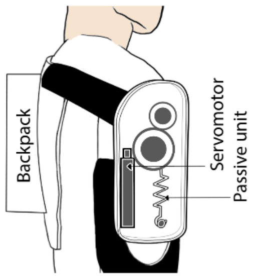
- Task pace and intensity
- Use of tools of different weight
- Working posture

Variability of workers' physical state

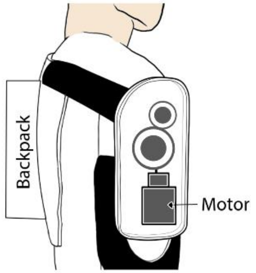
- Changes in biomechanic load on human joints
- Changes in muscles effort
- Changes in global body fatigue

The human user needs to manually change the hardware configuration of the exoskeleton to adapt the device behavior to a different situation

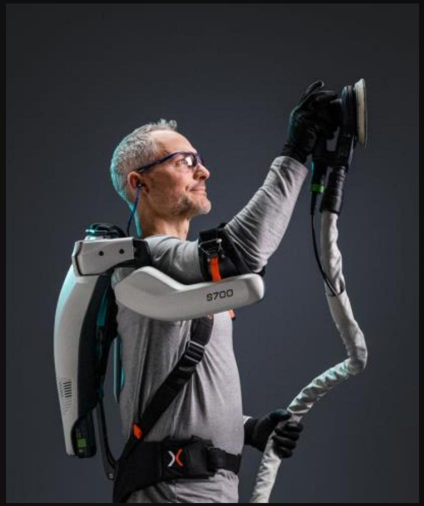
Semi-active



Active



Active systems



Active OEs are less mature than their passive counterparts and more complicated to be used:

- their functioning involves the use of actuators, batteries, wiring, and electronics
- their physical human–robot interface has a less repeatable and intuitive behavior

In highly dynamic and diverse operating environments, active OEs can be more flexible and adaptable:

- the need for extremely accurate control algorithms currently prevents their large-scale adoption
- most are for lumbar assistance (back-support OEs)

Semi-active systems


Semi-active systems have been introduced to tackle the main limitation of passive OEs, namely their lack of adaptivity, thus are designed to adapt the passive behavior of the system by:

- automatically adapting the level of assistance
- engaging/disengaging the actuation mechanisms through active clutches

Adaptation can be achieved through the observation of:

- the task being performed (e.g., static overhead or dynamic manipulation)
- the user’s physical stress level (e.g., increased muscle effort)
- other context-related factors (e.g., changes in used tools)

The Mari4_YARD OEs prototypes

Occupational Exoskeletons for the shipyard

Background: MATE XT and XB

The prototypes have been designed by IUVO Srl, spin-off company of SSSA, based on the commercially available MATE XT and MATE XB, which IUVO designed for COMAU Spa.

1

2

3

COMAU MATE XT

COMAU MATE XB

The Mari4_YARD OEs prototypes

The prototypes have been designed by IUVO Srl, spin-off company of SSSA, based on the commercially available MATE XT and MATE XB, which IUVO designed for COMAU Spa.

Physical Human-Robot interface 1

- **Sizes and regulations** to fit the device on specific users
- **Breathable and bio-compatible** materials
- **Wide contact area** to distribute reaction forces without causing pressure points

2

3

COMAU MATE XT

COMAU MATE XB

The Mari4_YARD OEs prototypes

The prototypes have been designed by IUVO Srl, spin-off company of SSSA, based on the commercially available MATE XT and MATE XB, which IUVO designed for COMAU Spa.

Physical Human-Robot interface 1

- **Sizes and regulations** to fit the device on specific users
- **Breathable and bio-compatible** materials
- **Wide contact area** to distribute reaction forces without causing pressure points

Kinematic chain 2

- **Unrestricted** movement
- **Compact** design around the body.
- Ensures **human-exoskeleton joint alignment** for user comfort

3

COMAU MATE XT

COMAU MATE XB

MARI4YARD
MARI4ALLIANCE

The Mari4_YARD OEs prototypes

The prototypes have been designed by IUVO Srl, spin-off company of SSSA, based on the commercially available MATE XT and MATE XB, which IUVO designed for COMAU Spa.

Physical Human-Robot interface (1)

- **Sizes and regulations** to fit the device on specific users
- **Breathable and bio-compatible** materials
- **Wide contact area** to distribute reaction forces without causing pressure points

Kinematic chain (2)

- **Unrestricted** movement
- **Compact** design around the body.
- Ensures **human-exoskeleton joint alignment** for user comfort

Torque generating box (3)

- **Smooth and continuous** assistance
- **Customizable** assistance levels
- Assistance selection **based on physiological torque (upper limbs, trunk)** during flexion/extension

COMAU MATE XT

COMAU MATE XB

Part II

Hands-on session

This project has received funding from
the European Union's Horizon 2020
research and innovation programme
under grant agreement No 101006798

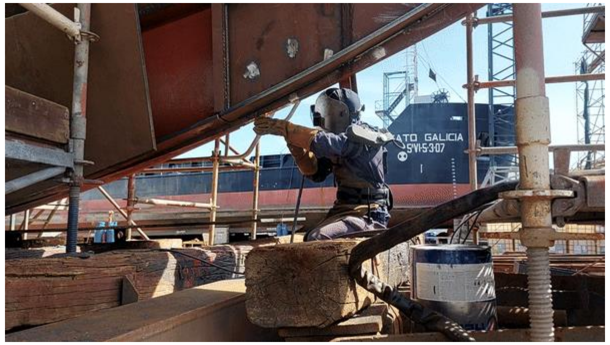
The Mari4_YARD prototypes

Mari4S_Exo (Spring-loaded semi-active exoskeleton for shoulder flexion support)

Mari4L_Exo (Light-weight spring-loaded exoskeleton for lumbar support)

The Mari4_YARD prototypes

Mari4S_Exo



The Mari4_YARD prototypes

Mari4L_Exo

Part III

Occupational exoskeletons research and use cases

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798

Scientific research on OEs

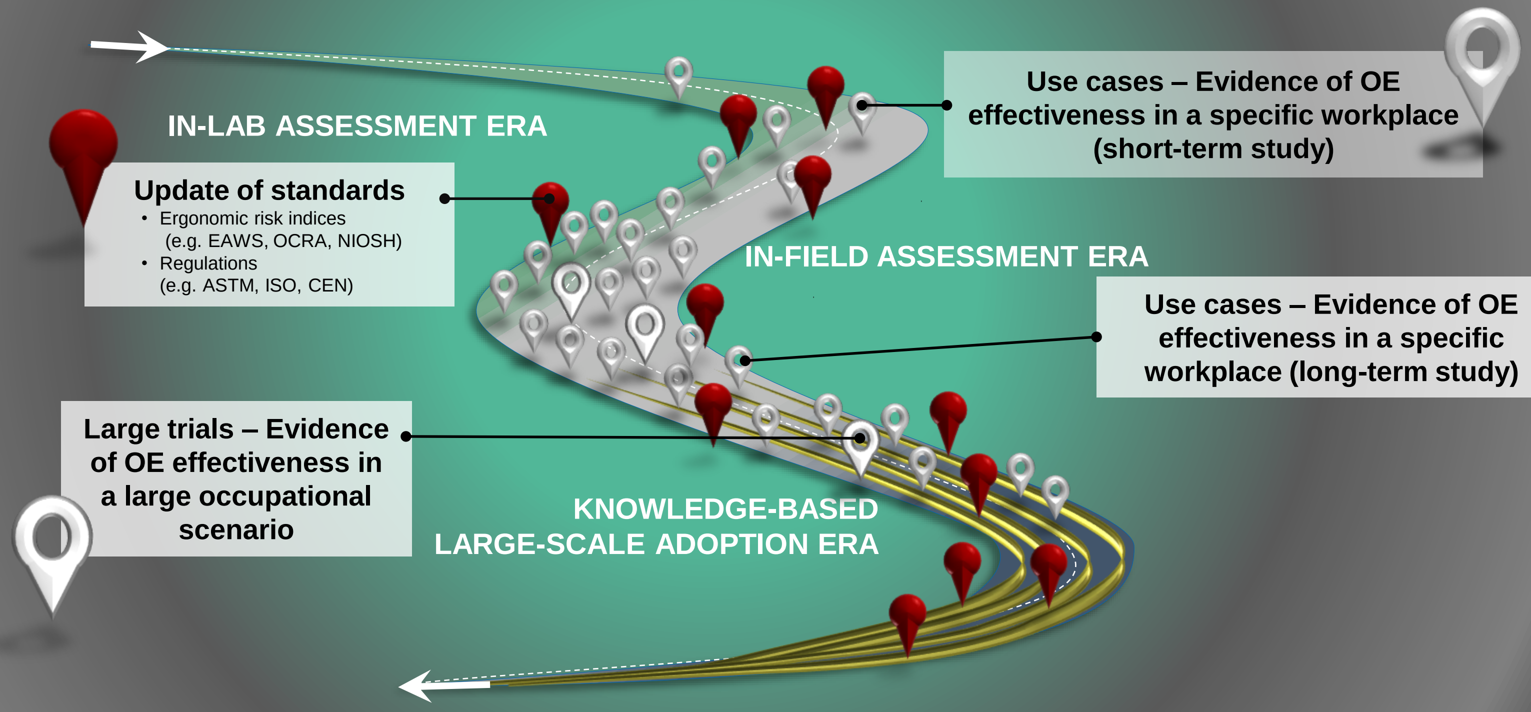
The **large-scale adoption** of occupational exoskeletons (OEs) will only happen if **clear evidence of effectiveness** of the devices is available

Building knowledge

Performing product-specific field validation studies would allow the **stakeholders and decision makers** to assess OEs’ effectiveness in their **specific work contexts** and with **experienced workers**, who could further provide useful insights on practical issues related to exoskeleton daily use

Crea et al., Wearable Technologies, 2021

A roadmap toward OEs large-scale adoption



Crea et al., Wearable Technologies, 2021

Collecting evidence is a must!

Limited-scale adoption of occupational exoskeleton can be due to:

- Lack of clear **evidence of effectiveness** of the devices in the final workplaces

- Lack of **clear information to communicate** with all the stakeholders:

  - Workers
  - Unions and workers' associations
  - Policy makers
  - Ergonomists, kinesiologists, occupational medical doctors, and HSE
  - Corporate management
  - Company' decision makers
  - Insurance companies

Crea et al., Wearable Technologies, 2021

IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING, VOL. 29, 2021 173

Passive Shoulder Exoskeletons: More Effective in the Lab Than in the Field?

Sander De Bock, Jo Ghillebert, Renée Govaerts, Shirley A. Elprama, Uros Marusic, Ben Serrien, An Jacobs, Joost Geeroms, Romain Meeusen, and Kevin De Pauw

MARI4YARD
MARI4ALLIANCE

De Bock et al., Transactions on Neural Systems and Rehabilitation Engineering, 2021

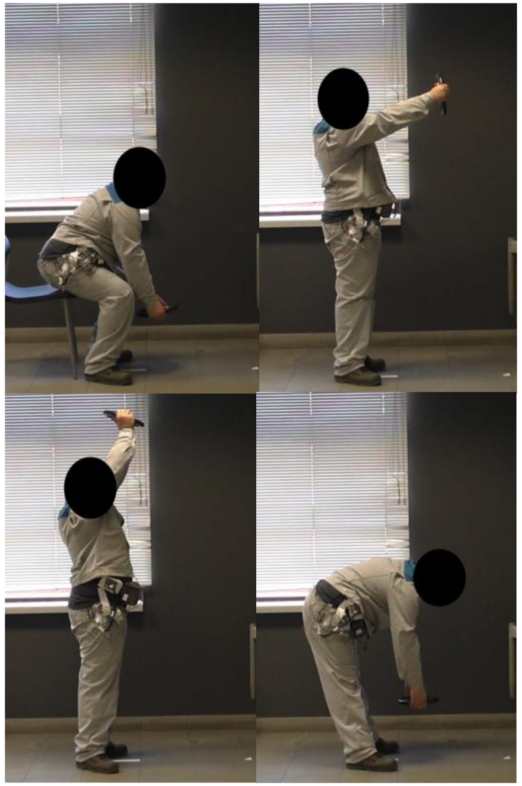
Objectives of the study

To evaluate the effectiveness of two passive shoulder exoskeletons and **explore the transfer of laboratory-based results to the field**.

Experimental activity

Simulated trials: a set of isolated tasks based on frequent movements in an industrial environment and previous passive shoulder exoskeleton evaluations were executed.

In-field trials: participants transferred windscreens from a trailer or a from a forklift into storage racks (placed in different positions) and subsequently placed all windscreens back onto the trailer or forklift.



IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING, VOL. 29, 2021 173

Passive Shoulder Exoskeletons: More Effective in the Lab Than in the Field?

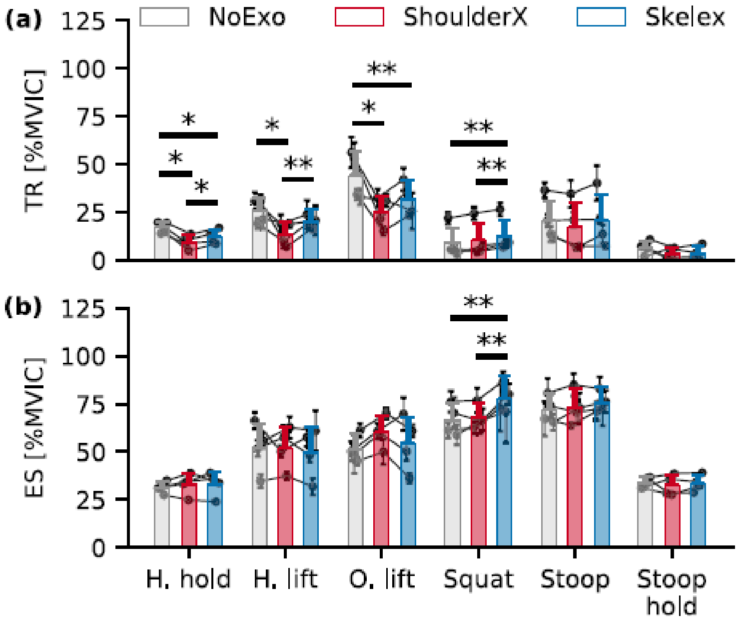
Sander De Bock, Jo Ghillebert, Renée Govaerts, Shirley A. Elprama, Uros Marusic, Ben Serrien, An Jacobs, Joost Geeroms, Romain Meeusen, and Kevin De Pauw

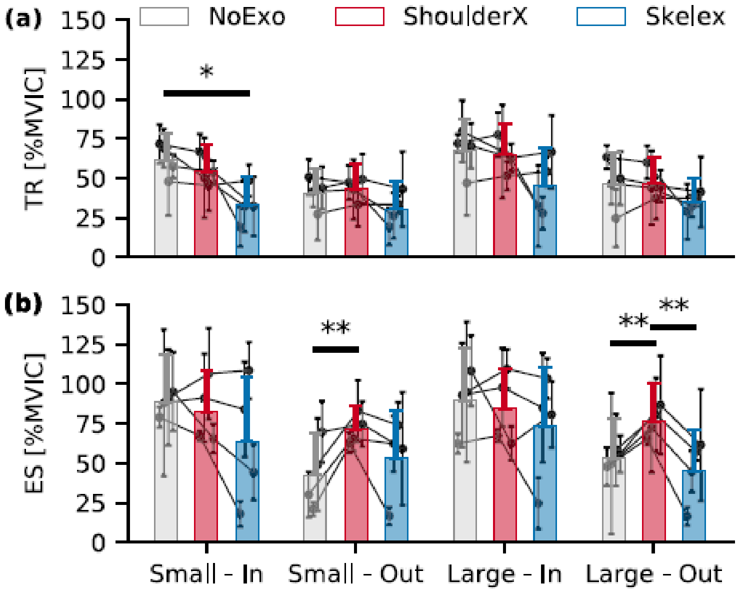
MARI4YARD
MARI4ALLIANCE

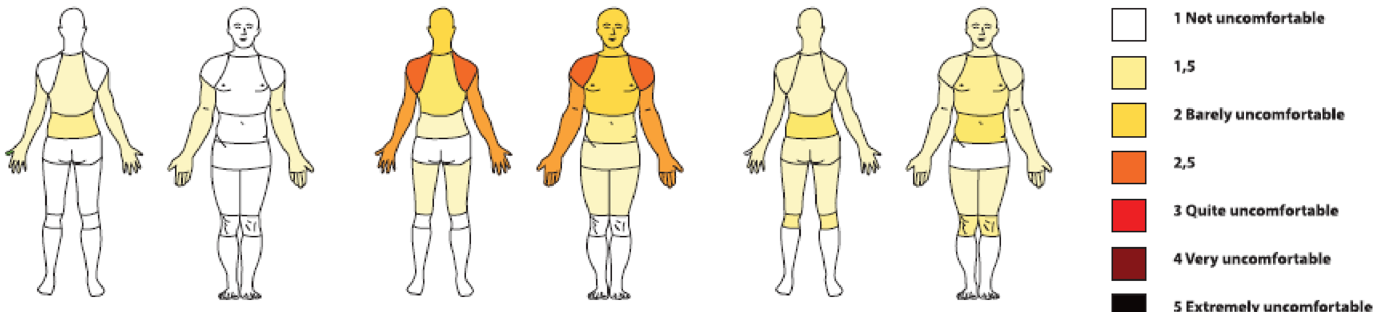
De Bock et al., Transactions on Neural Systems and Rehabilitation Engineering, 2021

Key results

- The **exoskeletons decreased upper trapezius activity and heart rate** in isolated tasks.
- **In the field**, the effects of both exoskeletons were **less prominent** while lifting windscreens.
- One exoskeleton received high discomfort scores in the shoulder region and **usability of both exoskeletons was moderate**.
- Overall, both exoskeletons **positively affected the isolated tasks**, but in the field the support of both exoskeletons was limited.







a. No exoskeleton (n = 4)   b. ShoulderX (n = 4)   c. Skelex (n = 4)

Applied Ergonomics 101 (2022) 103679
Contents lists available at ScienceDirect
Applied Ergonomics
journal homepage: www.elsevier.com/locate/apergo

Pacifico et al., Applied Ergonomics, 2022

Exoskeletons for workers: A case series study in an enclosures production line

Ilaria Pacifico[a,g,*], Andrea Parri[b], Silverio Taglione[c], Angelo Maria Sabatini[a], Francesco Saverio Violante[d,e], Franco Molteni[f], Francesco Giovacchini[b], Nicola Vitiello[a,g,h,1], Simona Crea[a,g,h,1,**]

Objectives of the study

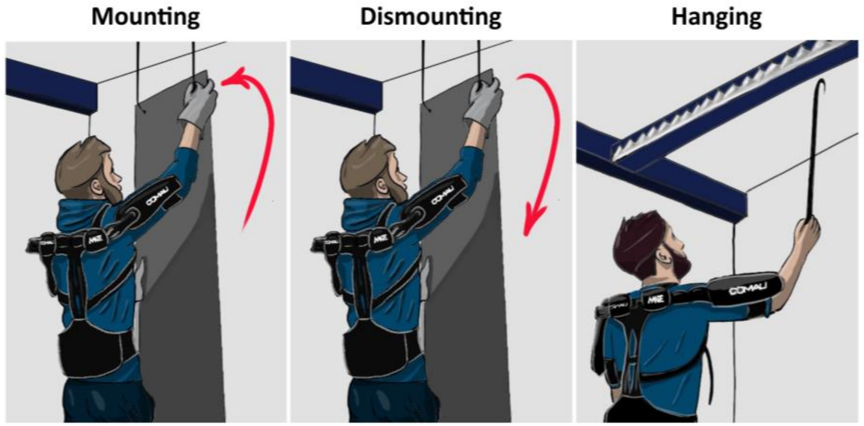
To investigate the effects of a passive shoulder support exoskeleton on experienced workers during their regular work shifts in **an enclosures production site**.

Experimental activity

Experimental activities included three sessions, two of which were conducted **in-field** (at two workstations of the painting line, where panels were mounted and dismounted from the line), and one session was carried out in a **realistic simulated environment** (workstations were recreated in a laboratory).

a) **In-field session**

b) **Simulated session**



Applied Ergonomics 101 (2022) 103679

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

MARI4YARD
MARI4ALLIANCE

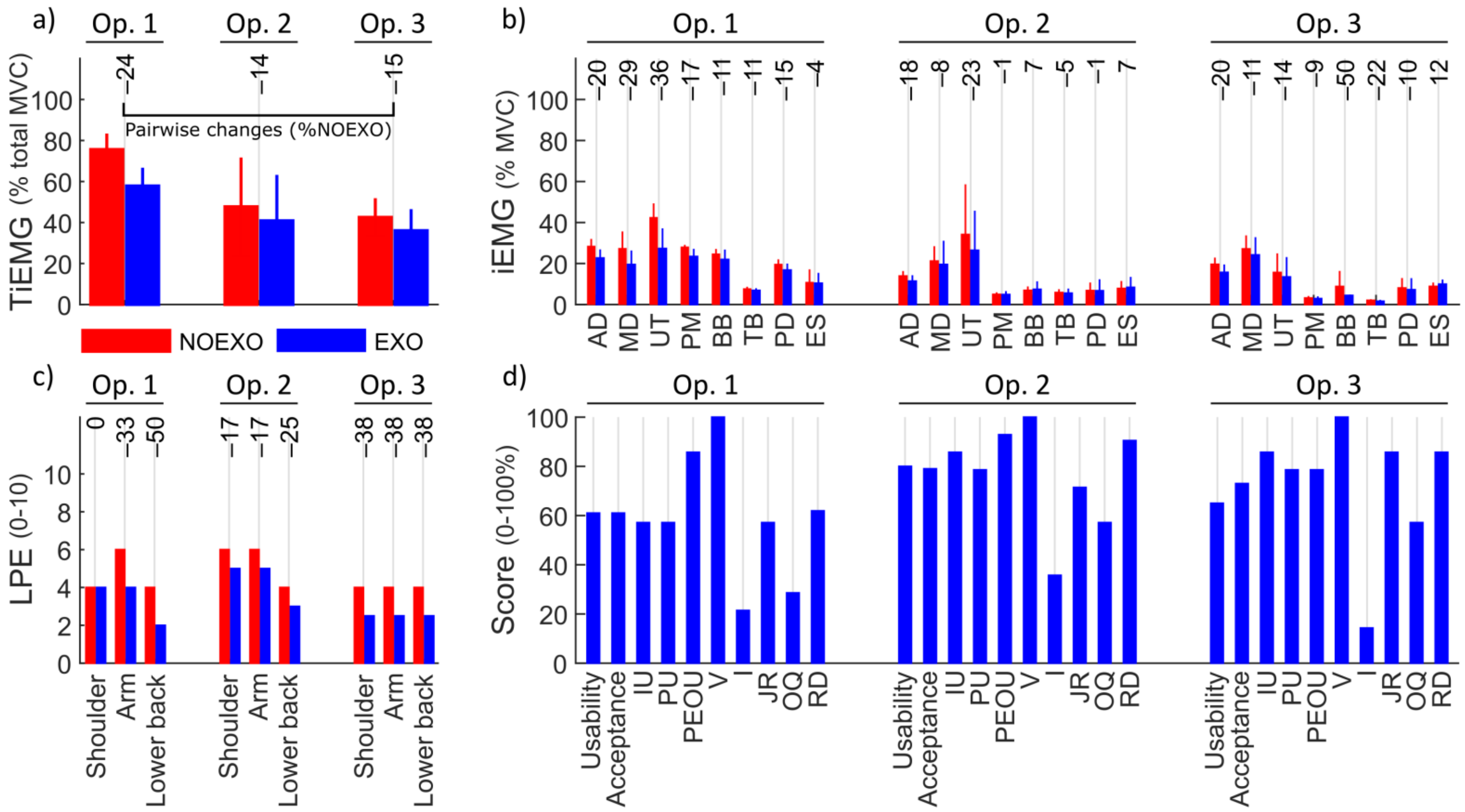
Pacifico et al., Applied Ergonomics, 2022

Exoskeletons for workers: A case series study in an enclosures production line

Ilaria Pacifico[a,g,*], Andrea Parri[b], Silverio Taglione[c], Angelo Maria Sabatini[a], Francesco Saverio Violante[d,e], Franco Molteni[f], Francesco Giovacchini[b], Nicola Vitiello[a,g,h,1], Simona Crea[a,g,h,1,**]

Key results

- The use of the exoskeleton **reduced the total shoulder muscular activity** compared to normal working conditions, in all subjects and experimental sessions.
- The use of the exoskeleton resulted in **reductions of the perceived effort** in the shoulder, arm, and lower back.
- Overall, participants indicated **high usability and acceptance** of the device. This case series invites larger validation studies, also in diverse operational contexts.



Applied Ergonomics 106 (2023) 103877

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Pacifico et al., Applied Ergonomics, 2023

Evaluation of a spring-loaded upper-limb exoskeleton in cleaning activities

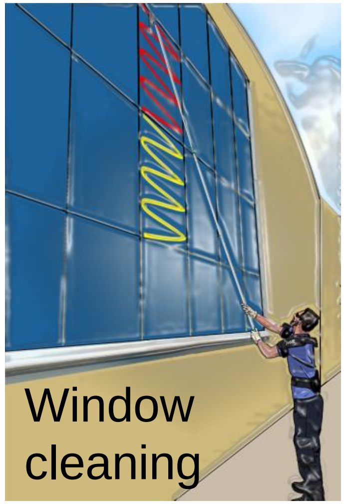
Ilaria Pacifico[b,*], Federica Aprigliano[b], Andrea Parri[b], Giusi Cannillo[c], Ilaria Melandri[c], Angelo Maria Sabatini[a], Francesco Saverio Violante[d], Franco Molteni[e], Francesco Giovacchini[b], Nicola Vitiello[a,f,g,1], Simona Crea[a,f,g,1,**]

Objectives of the study

To investigate the **in-field efficacy, usability, and acceptance** of a commercial spring-loaded upper-limb exoskeleton in **cleaning job activities**.

Experimental activity

The operators were required to maintain prolonged overhead postures while holding and moving a pole equipped with tools for window and ceiling cleaning.



Applied Ergonomics 106 (2023) 103877

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

MARI4YARD
MARI4ALLIANCE

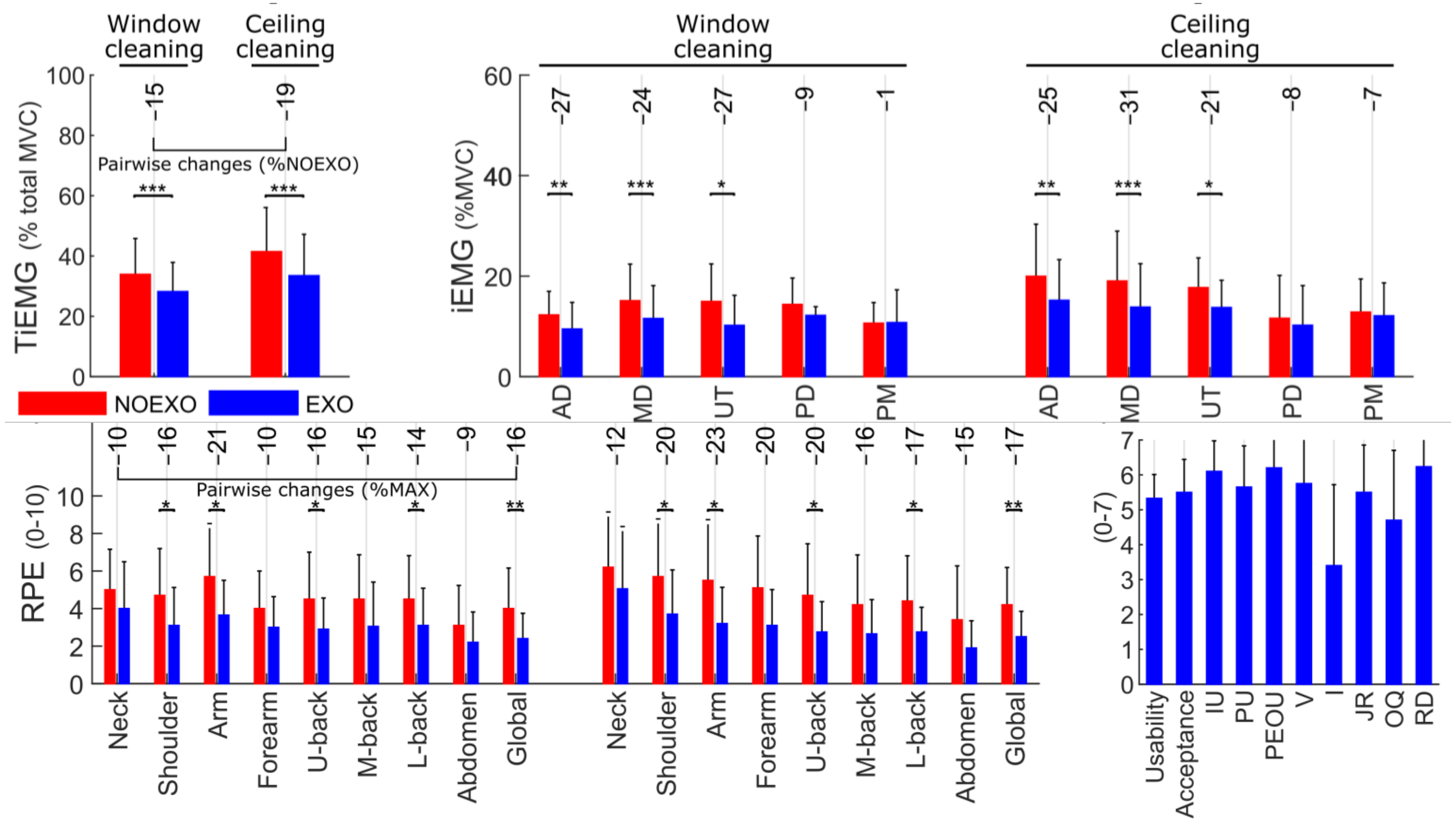
Pacifico et al., Applied Ergonomics, 2023

Evaluation of a spring-loaded upper-limb exoskeleton in cleaning activities

Ilaria Pacifico [b,*], Federica Aprigliano [b], Andrea Parri [b], Giusi Cannillo [c], Ilaria Melandri [c], Angelo Maria Sabatini [a], Francesco Saverio Violante [d], Franco Molteni [e], Francesco Giovacchini [b], Nicola Vitiello [a,f,g,1], Simona Crea [a,f,g,1,**]

Key results

- The exoskeleton **significantly reduced** the total shoulder muscle activity, the activity of the anterior deltoid, medial deltoid, and upper trapezius.
- The operators perceived **reduced global effort** as well as a **reduced local effort** in the shoulder, arm, upper and lower back.
- Acceptance and usability scores corroborated the beneficial effect of the exoskeleton and its suitability in cleaning settings.



Wearable Technologies (2022), 3, e23
doi:10.1017/wtc.2022.20

CAMBRIDGE UNIVERSITY PRESS

MARI4YARD
MARI4ALLIANCE

Electromyography-based fatigue assessment of an upper body exoskeleton during automotive assembly

Gillette et al., Wearable Technologies, 2022

Jason C. Gillette[1]*, Shekoofe Saadat[1] and Terry Butler[2]

Objectives of the study

To determine if an upper body exoskeleton could **reduce muscle fatigue risk** during automotive assembly job tasks at Toyota, and to identify if there were job tasks that could appear to benefit more than others from exoskeleton usage and explore possible explanations for differences.

Experimental activity

Sixteen team members at Toyota Motor Manufacturing Canada were fitted with a Levitate Airframe, and each team member performed between one and three processes with and without the exoskeleton. A total of 16 assembly processes were studied.

Wearable Technologies (2022), 3, e23
doi:10.1017/wtc.2022.20

CAMBRIDGE UNIVERSITY PRESS

MARI4YARD
MARI4ALLIANCE

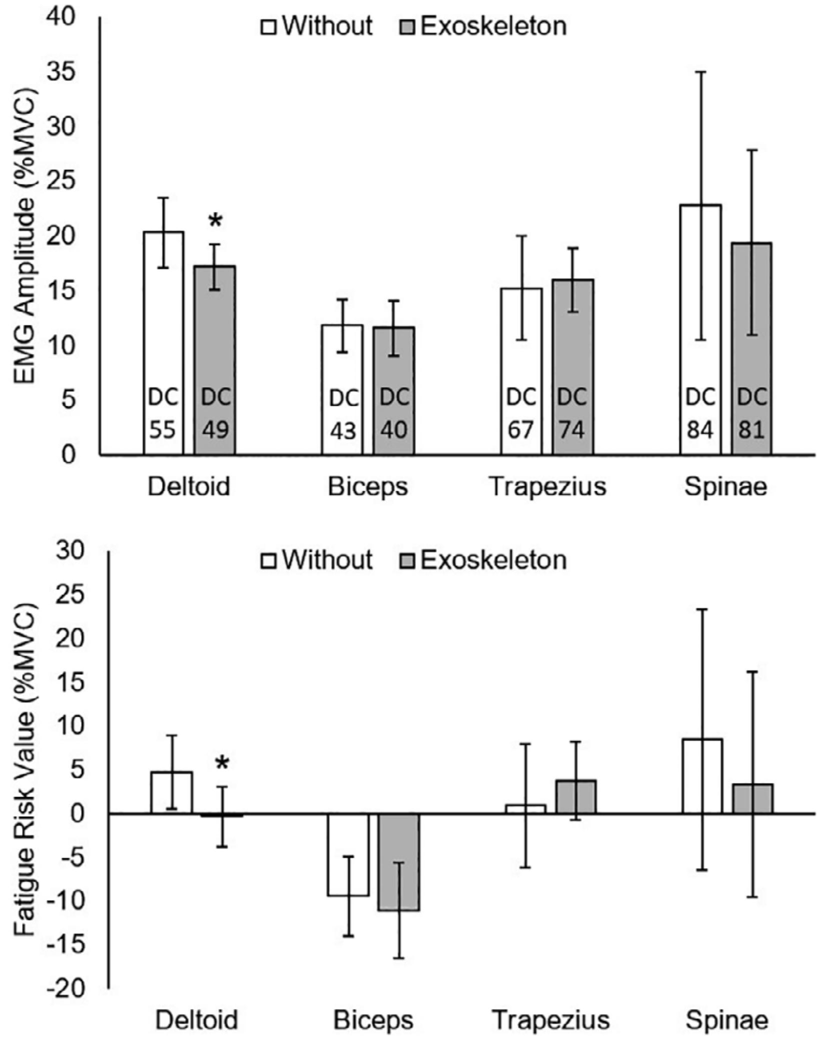
Electromyography-based fatigue assessment of an upper body exoskeleton during automotive assembly

Jason C. Gillette[1]*, Shekoofe Saadat[1] and Terry Butler[2]

Gillette et al., Wearable Technologies, 2022

Key results

- The exoskeleton **significantly reduced Anterior Deltoid mean active EMG amplitude and fatigue risk value** across the assembly processes, with no significant changes for the other muscles tested.
- A subset of nine assembly processes with a greater amount of time spent in arm elevations at or above 90° and at or above 135° appeared to benefit more from exoskeleton usage.
- Team members **responded positively about comfort and fatigue benefits**, although there were concerns about the exoskeleton hindering certain job duties.
- The **results support quantitative testing to match exoskeleton usage with specific job tasks** and surveying team members for perceived benefits/drawbacks.



IISE Transactions on Occupational Ergonomics and Human Factors

ISSN: 2472-5838 (Print) 2472-5846 (Online) Journal homepage: https://www.tandfonline.com/loi/uehf21

Hensel & Keil, Transactions on Occupational Ergonomics and Human Factors, 2022

Subjective evaluation of a passive industrial exoskeleton for lower-back support: a field study in the automotive sector

Dr. Ralph Hensel & Dr. Mathias Keil

Objectives of the study

To obtain **subjective evaluations** of the impacts of exoskeleton use, including discomfort, usability, and user acceptance through a 4-week field study with the Laevo exoskeleton in the automotive industry.

Experimental activity

The study was conducted at five workplaces in the assembly and press shop (ground screw connection footwell, trunk insulation, installation cable harness, maintenance, and press set up) with tasks performed in a static forward bend. Moreover, three workplaces with high upper-body flexion in logistics were selected to evaluate dynamic-repositioning activities.



Taylor & Francis
Taylor & Francis Group

IISE Transactions on Occupational Ergonomics and Human Factors

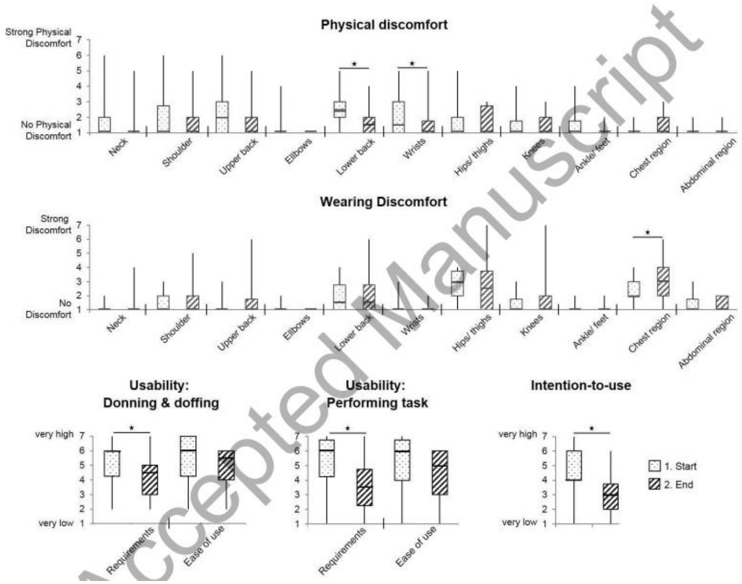
ISSN: 2472-5838 (Print) 2472-5846 (Online) Journal homepage: https://www.tandfonline.com/loi/uehf21

MARI4YARD
MARI4ALLIANCE

Hensel & Keil, Transactions on Occupational Ergonomics and Human Factors, 2022

Subjective evaluation of a passive industrial exoskeleton for lower-back support: a field study in the automotive sector

Dr. Ralph Hensel & Dr. Mathias Keil



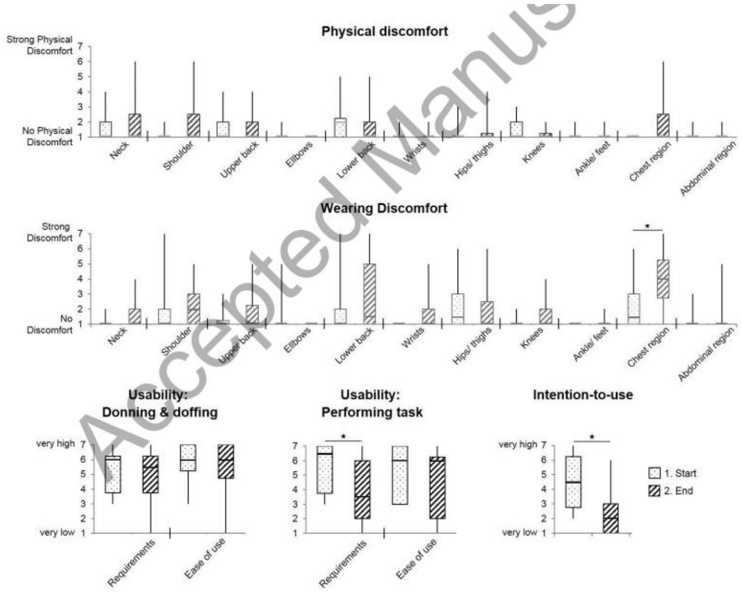
Key results

- Workers overall reported a **decrease of physical discomfort** in the lower-back when using the passive exoskeleton, although this decrease was only evident in work requiring static vs. dynamic postures.

- Evidence of a **load redistribution**, specifically to the chest region, in terms of **increased wearing discomfort**.

- Workers provided **moderate-to-high ratings of perceived usability**, though these ratings were lower at the end of the field study.

- **User acceptance was strongly influenced by perceived usability**, as well as the level of discomfort experienced when using the exoskeleton.



Applied Ergonomics 93 (2021) 103373

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: http://www.elsevier.com/locate/apergo

Hwang et al., Applied Ergonomics, 2021

Effects of passive back-support exoskeletons on physical demands and usability during patient transfer tasks

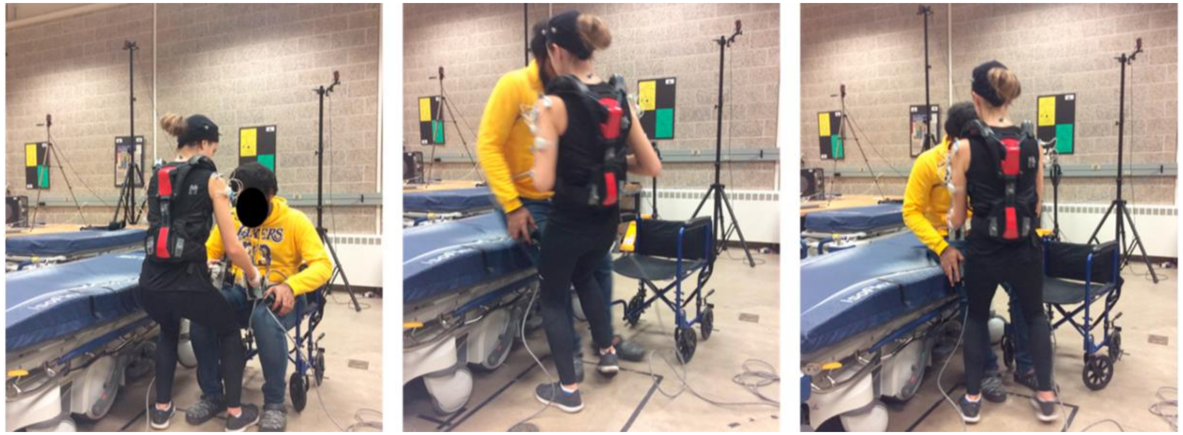
Jaejin Hwang [a,*], Venkata Naveen Kumar Yerriboina [a], Hemateja Ari [a], Jeong Ho Kim [b]

Objectives of the study

To evaluate and **compare the effects of three passive back-support exoskeletons** (FLx ErgoSkeleton, V22 ErgoSkeleton, Laevo V2.5) and patient transfer methods on physical demands in the low back and shoulders during patient transfer.

Experimental activity

Professional caregivers performed a series of **simulated patient transfer tasks** between a wheelchair and a bed with three different patient transfer methods including the squat pivot, stand pivot, and scoot with two directions (wheelchair to bed and vice versa).



Applied Ergonomics 93 (2021) 103373

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: http://www.elsevier.com/locate/apergo

Effects of passive back-support exoskeletons on physical demands and usability during patient transfer tasks

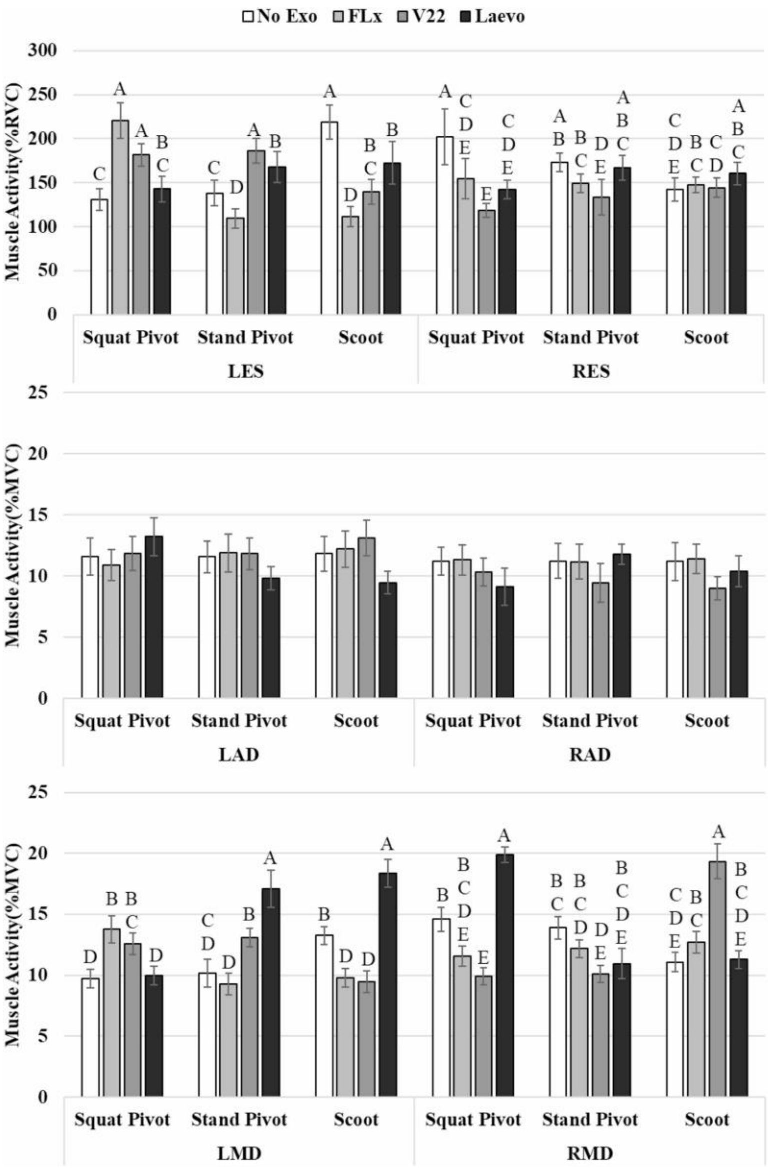
Jaejin Hwang [a,*], Venkata Naveen Kumar Yerriboina [a], Hemateja Ari [a], Jeong Ho Kim [b]

MARI4YARD
MARI4ALLIANCE

Hwang et al., Applied Ergonomics, 2021

Key results

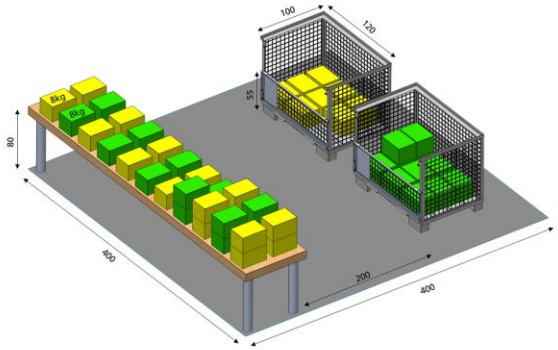
- The passive exoskeletons **significantly affected trunk postures** (forward flexion and lateral flexion), **shoulder postures** (flexion and abduction), **hand pull forces**, **muscle activities** of erector spinae and middle deltoid.
- The **biomechanical benefits and usability varied** by passive exoskeleton designs.
- The lower muscle activities of the erector spinae suggest that the back-support exoskeletons may be a **viable intervention to reduce the low back strain** during patient transfer tasks.



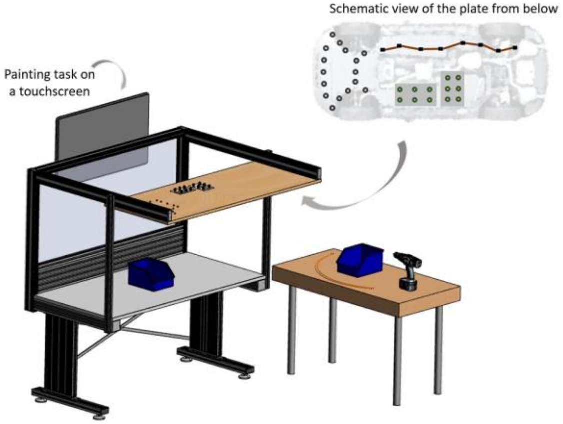
EXOWORKATHLON

Fraunhofer IPA & IFF University of Stuttgart

6 testing scenarios or *parcours*

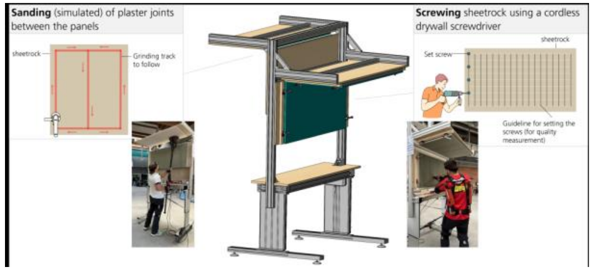


Logistics – Box Handling

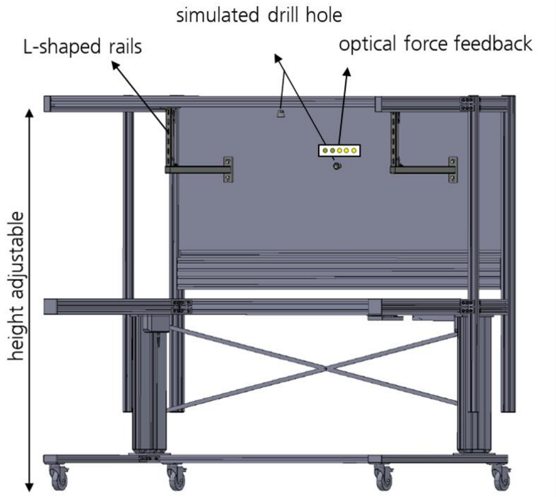


Automotive – Car Assembly

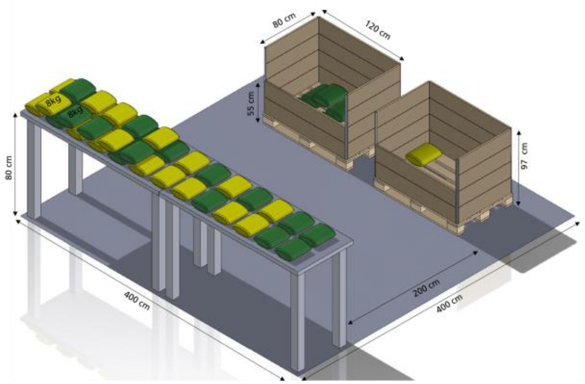
Welding



Construction – Drywall



Construction – Installation of rail systems



Logistics – Box Handling

From 2021 to 2023, a total of 125 subjects participated in the study.

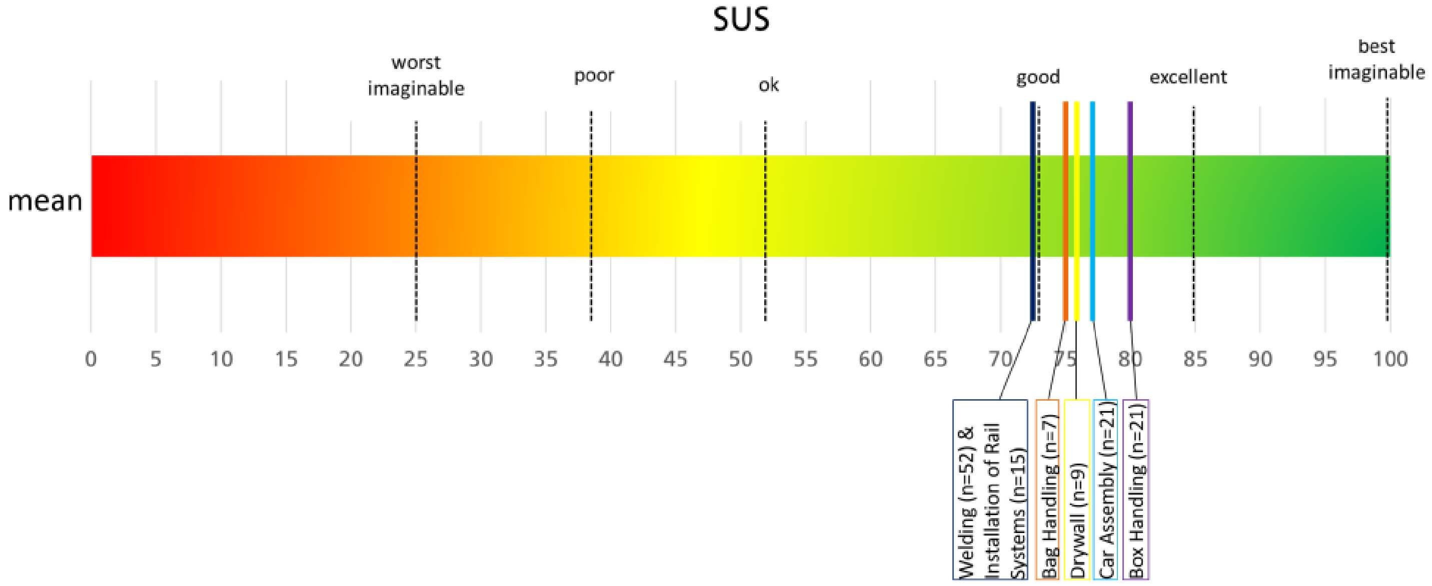
- Box Handling (Logistics): n=21
- Car Assembly (Automotive): n=21
- Welding: n=52; Sack Handling (Logistics): n=7
- Installation of Rail Systems (Construction): n=15
- Drywall (Construction): n=9)

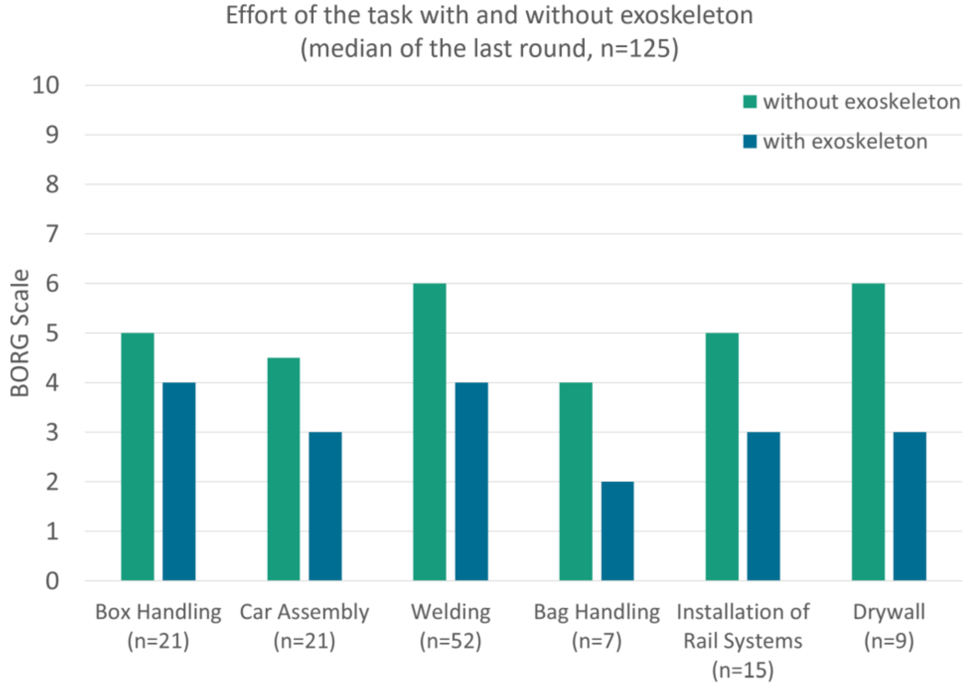
The subjects were young men and women aged 17 to 34 years and an average age of 24 years, who were familiar with the work they had to do in the Parcours.

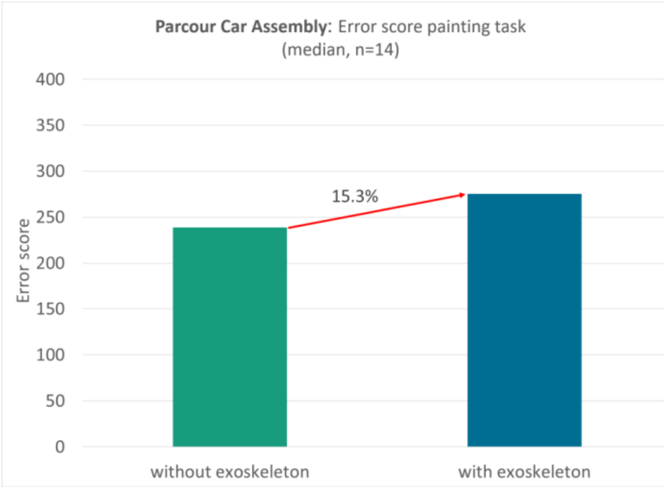
The experiments took place at Audi Education Lab, Neckarsulm, Wilhelm Maybach Berufsschule Stuttgart, Messe Duesseldorf, SLV Nord Hamburg, and Steinbeisschule Stuttgart.

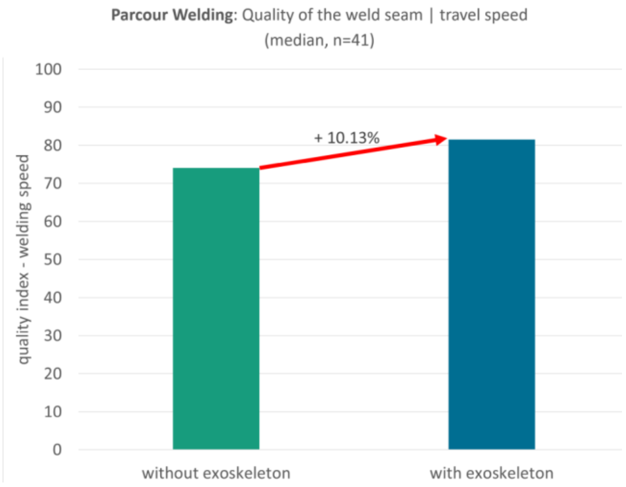
Exoskeletons from different manufacturers were randomly assigned to the subjects to maintain market neutrality and not indicate the advantages and disadvantages of a particular system.

An eye on the results









Part IV

Ergonomic impact of occupational exoskeletons

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798

Ergonomics risk assessment

Objective measure of the risk factors in the work environment that may lead to MSDs or injuries among the workforce.

The goal of an ergonomic assessment is to identify these risk factors and quantify them so that you can make measurable improvements in the work environment.

A thorough ergonomic assessment is the foundation for creating a safer, healthier, less injury-prone workplace and improving overall workplace wellness

There are several tools used for performing ergonomic risk assessment

- The NIOSH Lifting Equation
- Rapid Entire Body Assessment (REBA)
- Rapid Upper Limb Assessment (RULA)
- Occupational repetitive Action (OCRA)
- ...

ESO-EAWS Project

fondazionergo
.BELLAFACTORY.

MARI4YARD
MARI4ALLIANCE

ESO-EAWS Project

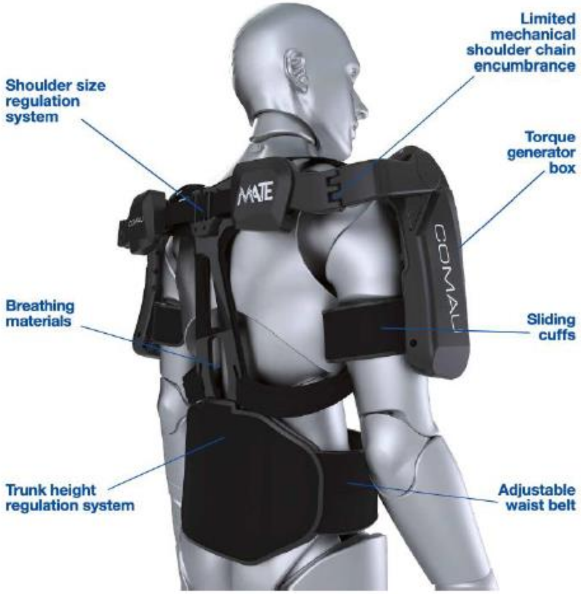
SUMMARY REPORT

"How the exoskeleton changes the assessment of biomechanical overload risk for the EAWS system"

Objective of the project

The objective of this study is to evaluate how the EAWS (Ergonomic Assessment Work-Sheet) ergonomic risk assessment index changes with the use of a passive exoskeleton supporting shoulder awkward postures.

The first evaluation of the impact of a passive exoskeleton on EAWS ergonomic risk assessment index has been carried out with the COMAU MATE exoskeleton.



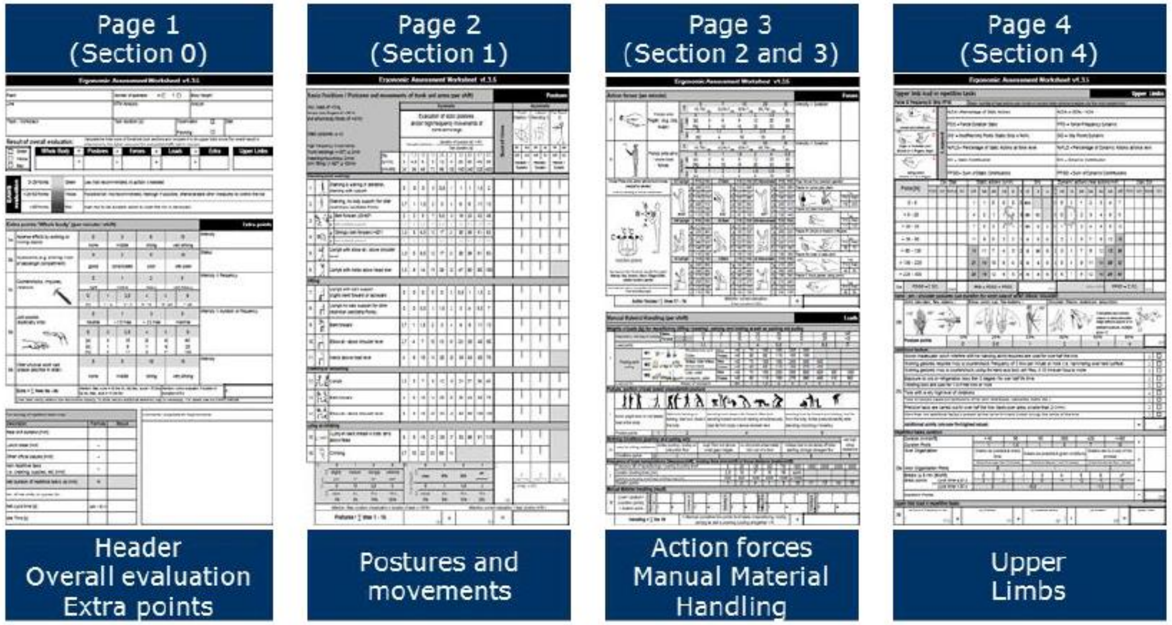
EAWS

EAWS is an ergonomic tool for a detailed biomechanical overload risk assessment, developed to provide an overall risk evaluation that includes every biomechanical risk to which an operator may be exposed during a working task.

All existing systems are an attempt to **model the effects of forces and motions** on our muscular-skeletal system and none of them currently reflect the exact actual situation. Proper use of these models and methods involves **recognizing the limitations and assumptions of each technique** so that they are not applied inappropriately. When properly used, these assessments **can help assess the risk** of work-related injury and illness.

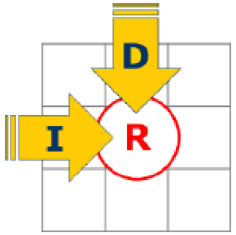
The EAWS structure is the following:

- Macro-Section **"Whole body"**:
    - Section 0: Extra Points;
    - Section 1: Postures (ref. ISO 11226 and EN 1005-4);
    - Section 2: Action forces (ref. ISO 11228.2 and EN 1005-3);
    - Section 3: Manual material handling (ref. ISO 11228.1/2 and EN 1005-2).
- Macro-Section **"Upper limbs"**
    - Section 4: Upper limb load in repetitive tasks (ref. ISO 11228.3 and EN 1005-5).



EAWS

The EAWS system calculates a load index (R), given by the product of the Intensity (I) by the Duration (D):



R = I × D

The EAWS sheet provides one score for each Macro-Section. The overall load index of each Macro-Section is then connected to a traffic light scheme (green, yellow, red) according to the Machinery Directive 2006/42/EC (EN 614).

0 – 25 Points	green	Low risk: recommended; no action is needed
26 – 50 Points	yellow	Possible risk: not recommended; redesign if possible, otherwise take other measures to control the risk
> 50 Points	red	High risk: to be avoided; action to lower the risk is necessary

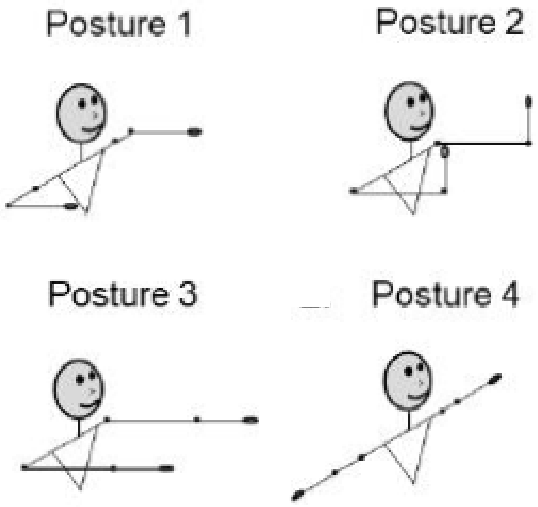
The evaluation study

Subjects were instructed to perform 12 simulated conditions (8 static and 4 dynamic) without and with the passive exoskeleton MATE.

The tasks were selected from two sessions of the EAWS: *Postures and movements* and *Upper limb.*

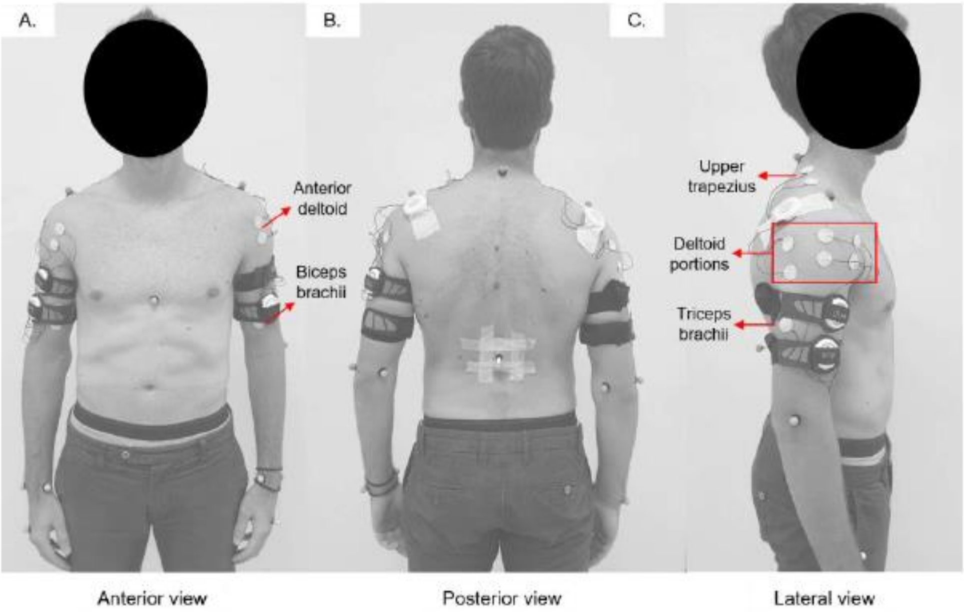
The **static tasks** consist in maintaining four different postures for two different periods (6 and 20 seconds). Each static task was repeated 5 consecutive times. The postures studied were:

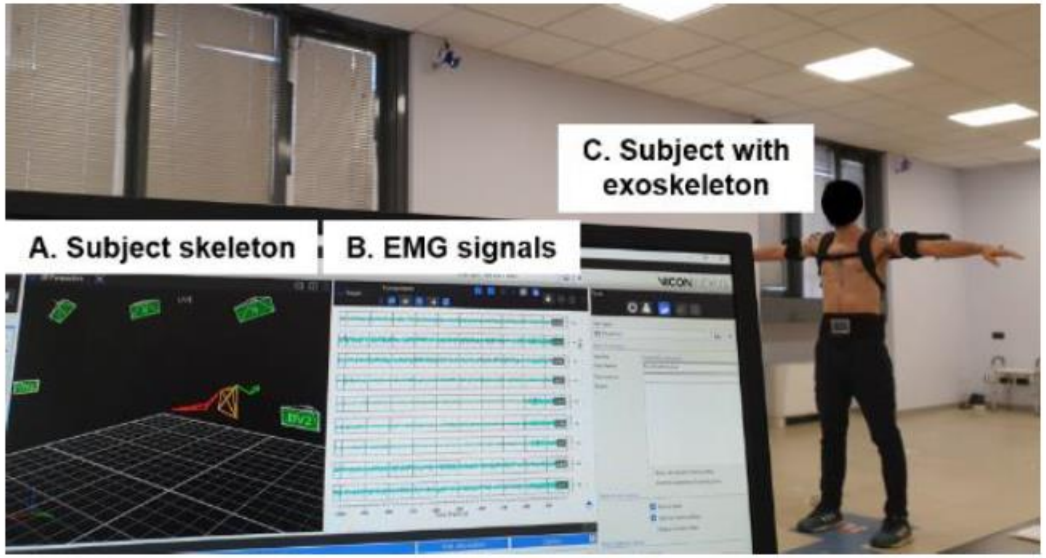
1. shoulder abducted at 90 deg, elbow flexed at 90 deg, elbow pronated at 90 deg;
2. shoulder flexed at 90 deg, elbow flexed at 90 deg, elbow pronated at 90 deg;
3. shoulder flexed at 90 deg, elbow pronated at 90 deg;
4. shoulder abducted at 90 deg, elbow pronated at 90 deg.

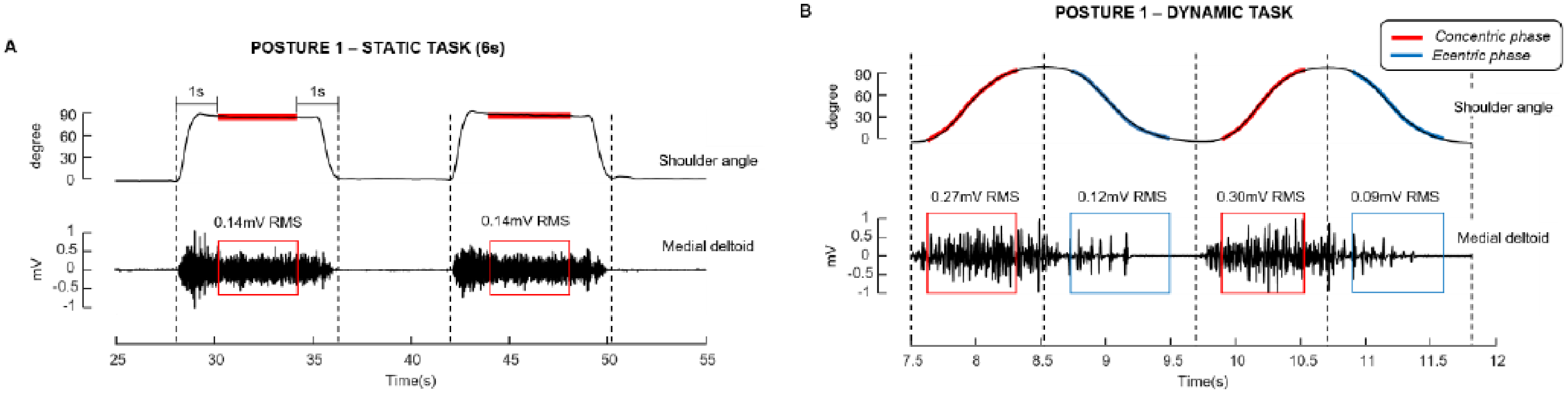


The **dynamic tasks** consisted in achieving each static posture from the standard anatomical position and returning to the anatomical position, defined as action. Each *action* lasted 3 seconds, and it was repeated 15 consecutive times without rest.

The evaluation study

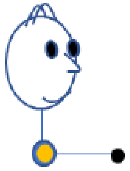
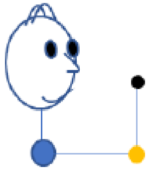
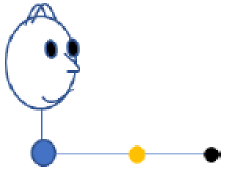
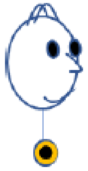




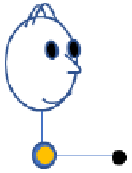
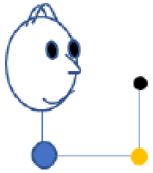
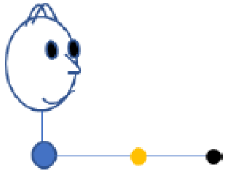
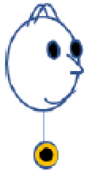


Results

Static trials

Posture			
			
Muscle			
Trapezius Medial deltoid	Trapezius Anterior deltoid Biceps brachii	Trapezius Anterior deltoid Biceps brachii	Trapezius Medial deltoid Anterior deltoid Posterior deltoid
Percentage reduction			
38.3%	**33.9%**	**28.9%**	**34.2%**

Dynamic trials

Posture			
			
Muscles			
Trapezius Medial deltoid Posterior deltoid	Trapezius Anterior deltoid Posterior deltoid Biceps Brachii	Trapezius Anterior deltoid Posterior deltoid Biceps Brachii	Trapezius Medial deltoid Anterior deltoid Posterior deltoid
Percentage reduction			
33.4%	**23.4%**	**28.9%**	**31.1%**

Overall, the MATE exoskeleton has been effective in reducing the muscular load in both static postures and dynamic movements

Impact on EAWS

Section 0

Requirements

- TORQUE SUPPLY FUNCTION
  - zero torque at flexion angle 0°;
  - max torque at flexion angle 90°;
  - continuity during torque supply;
  - torque tuning
  - amount of biomechanical load reduction
- PASSIVE KINEMATIC CHAIN
  - shoulder motion freedom;
  - absence of encumbrance on the upper side of the shoulder (relatively to the type of workstation where the exoskeleton is used);
- PHYSICAL HUMAN ROBOT INTERFACE
  - sizes and regulations to fit the device on specific users available;
  - breathable material;
  - no overheating;
  - contact area to distribute reaction forces without causing high force points;
- SAFETY AND USABILITY
  - Weight < 3kg = 0 points | Weight < 4,5 kg = 1 point | Weight < 6 kg = 2 points | Weight >= 6 kg = 5 point
  - no or very limited encumbrance outside the operator's body;
  - no entanglement prone protruding parts

MATE score = 2 points
(1 Base Value + 1 Point)

Impact on EAWS

Section 1

		Standing (and walking)										
1		Standing & walking in alteration, standing with support	0	0	0	0	0,5	1	1	1	1,5	2
2		Standing, no body support (for other restrictions see Extra Points)	0,7	1	1,5	2	3	4	6	8	11	13
3	a	Bent forward (20-60°)	2	3	5	7	9,5	12	18	23	32	40
	b	with suitable support	1,3	2	3,5	5	6,5	8	12	15	20	25
4	a	Strongly bent forward (>60°)	3,3	5	8,5	12	17	21	30	38	51	63
	b	with suitable support	2	3	5	7	9,5	12	18	23	31	38
5	a	Elbow at/above shoulder level	3,3	5	8,5	12	17	21	30	38	51	63
	b	With certif. exoskeleton	2,5	3,8	6,4	9,0	13,1	16,2	23,1	29,0	39,0	48,0
6	a	Hands above head level	5,3	8	14	19	26	33	47	60	80	100
	b	With certif. exoskeleton	4,1	6,2	11,0	14,8	20,0	25,5	36,5	46,5	62,0	77,5

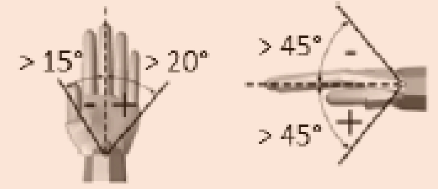
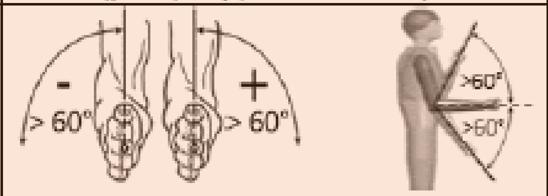
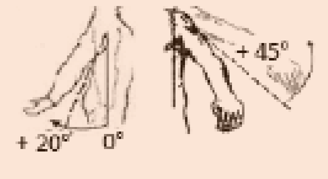
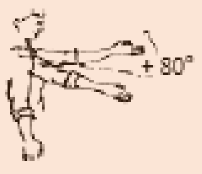
		Sitting										
7		Upright with back support slightly bent forward or backward	0	0	0	0	0	0	0,5	1	1,5	2
8		Upright no back support (for other restriction see Extra Points)	0	0	0,5	1	1,5	2	3	4	5,5	7
9		Bent forward	0,7	1	1,5	2	3	4	6	8	11	13
10	a	Elbow at / above shoulder level	2,7	4	7	10	13	16	23	30	40	50
	b	With certif. exoskeleton	1,9	2,8	4,9	7,0	9,1	11,2	16,1	21,0	28,0	35,0
11	a	Hands above head level	4	6	10	14	20	25	35	45	60	75
	b	With certif. exoskeleton	2,8	4,2	7,0	9,8	14,0	17,5	24,5	31,5	42,0	52,5

		Kneeling or crouching										
12		Upright	3,3	5	7	9	12	15	21	27	36	45
13		Bent forward	4	6	10	14	20	25	35	45	60	75
14	a	Elbow at / above shoulder level	6	9	16	23	33	43	62	80	108	135
	b	With certif. exoskeleton	5,2	7,8	13,9	20,0	29,1	38,2	55,1	71,0	96,0	120

Scores reduce when the exoskeleton is used

Impact on EAWS

Section 4

Hand / arm / shoulder postures (use duration for worst case of wrist / elbow / shoulder)								
20b	Wrist (deviaton, flex./extens.)		Elbow (pron, sup, flex./extens.)		Shoulder (flexion, extension, abduction)			
					 If shoulders are involved close to or above shoulder height without support or in awkward postures, multiply score x3 			
	Posture points	10%	25%	33%	50%	65%	85%	PP
	Wrist/Elbow	0	0,5	1	2	3	4	
	Shoulder	0	1,5	3	6	9	12	
	Shoulder w /exosk	0	1,1	2,3	4,5	6,8	9	

Scores about shoulder reduce when the exoskeleton is used

Certification of the exoskeleton MATE

- The results of the study confirm the **biomechanical load reduction effect**, measured by the EAWS system, generated by awkward shoulder postures in both static and dynamic situations.

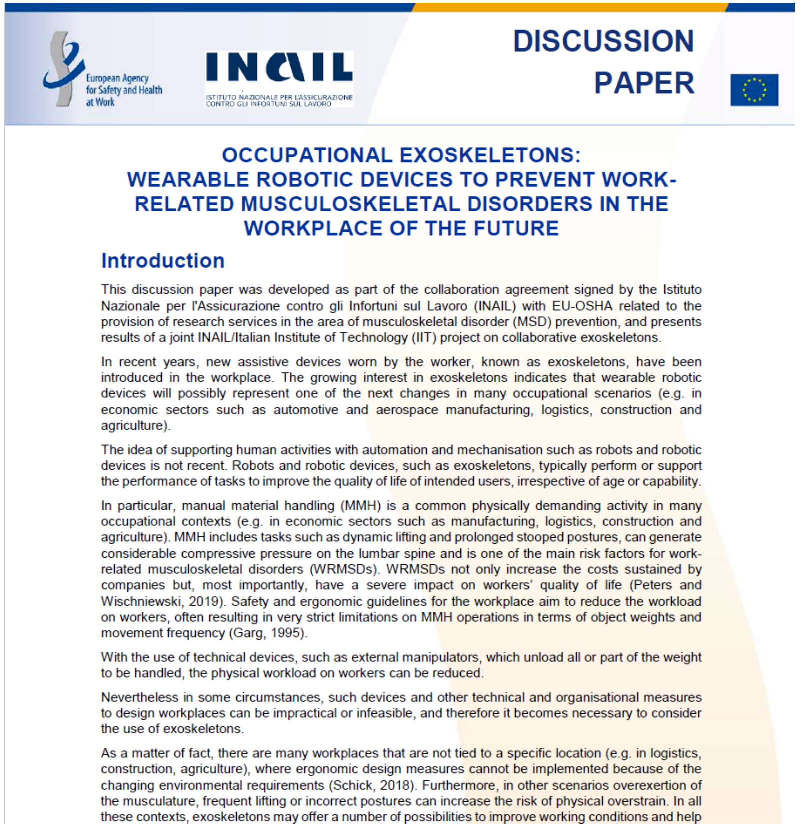
- The application of the attenuated values shown on the modified EAWS form (called ESO-EAWS) is **conditioned using an exoskeleton certified by the Fondazione Ergo**.

MATE exoskeleton is therefore certified by the Fondazione Ergo as an **effective tool to reduce the EAWS score of Section 1 and Section 4**, where awkward shoulder postures are involved.

INAIL/EU-OSHA Collaboration for the Prevention of MSD

This discussion paper was developed as part of a collaboration between the National Institute for Insurance against Accidents at Work (INAIL) and the European Agency for Safety and Health at Work (EU-OSHA).

The paper explores the use of OEs as wearable robotic devices to prevent work-related MSDs in the workplace.


European Agency for Safety and Health at Work

INAIL

ISTITUTO NAZIONALE PER L'ASSICURAZIONE CONTRO GLI INFORTUNI SUL LAVORO

DISCUSSION PAPER

OCCUPATIONAL EXOSKELETONS: WEARABLE ROBOTIC DEVICES TO PREVENT WORK-RELATED MUSCULOSKELETAL DISORDERS IN THE WORKPLACE OF THE FUTURE

Introduction

This discussion paper was developed as part of the collaboration agreement signed by the Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro (INAIL) with EU-OSHA related to the provision of research services in the area of musculoskeletal disorder (MSD) prevention, and presents results of a joint INAIL/Italian Institute of Technology (IIT) project on collaborative exoskeletons.

In recent years, new assistive devices worn by the worker, known as exoskeletons, have been introduced in the workplace. The growing interest in exoskeletons indicates that wearable robotic devices will possibly represent one of the next changes in many occupational scenarios (e.g. in economic sectors such as automotive and aerospace manufacturing, logistics, construction and agriculture).

The idea of supporting human activities with automation and mechanisation such as robots and robotic devices is not recent. Robots and robotic devices, such as exoskeletons, typically perform or support the performance of tasks to improve the quality of life of intended users, irrespective of age or capability.

In particular, manual material handling (MMH) is a common physically demanding activity in many occupational contexts (e.g. in economic sectors such as manufacturing, logistics, construction and agriculture). MMH includes tasks such as dynamic lifting and prolonged stooped postures, can generate considerable compressive pressure on the lumbar spine and is one of the main risk factors for work-related musculoskeletal disorders (WRMSDs). WRMSDs not only increase the costs sustained by companies but, most importantly, have a severe impact on workers' quality of life (Peters and Wischniewski, 2019). Safety and ergonomic guidelines for the workplace aim to reduce the workload on workers, often resulting in very strict limitations on MMH operations in terms of object weights and movement frequency (Garg, 1995).

With the use of technical devices, such as external manipulators, which unload all or part of the weight to be handled, the physical workload on workers can be reduced.

Nevertheless in some circumstances, such devices and other technical and organisational measures to design workplaces can be impractical or infeasible, and therefore it becomes necessary to consider the use of exoskeletons.

As a matter of fact, there are many workplaces that are not tied to a specific location (e.g. in logistics, construction, agriculture), where ergonomic design measures cannot be implemented because of the changing environmental requirements (Schick, 2018). Furthermore, in other scenarios overexertion of the musculature, frequent lifting or incorrect postures can increase the risk of physical overstrain. In all these contexts, exoskeletons may offer a number of possibilities to improve working conditions and help

Key points of the document

Terminology and definitions

Define the terminology and definitions adopted in the sector of OEs

General design principles

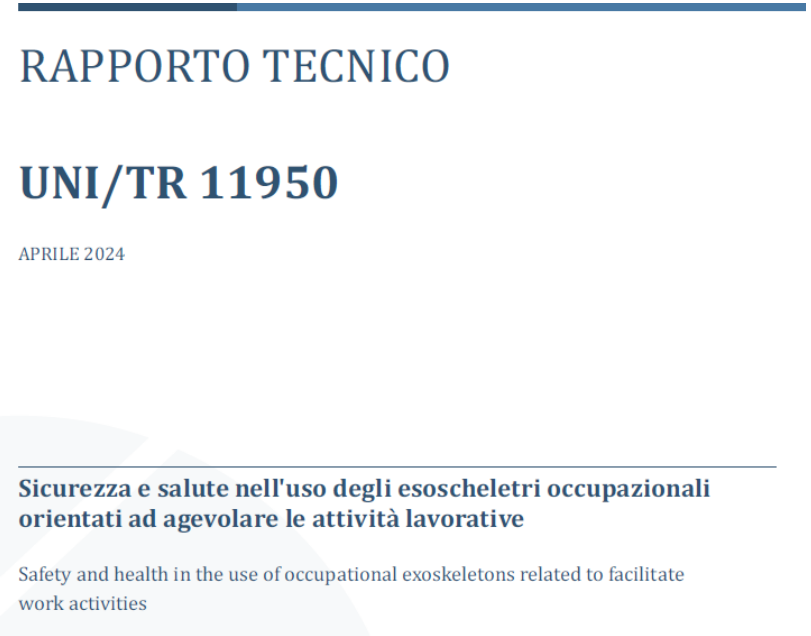
Illustrate the general design and construction principles of exoskeletons, with a focus on human-centered design to maximize user benefits and minimize negative impacts through ergonomic design

Regulations and Standards on OEs
Technical Report UNI 11950

Written by the UNI/CT 042/SC 01/GL 16 group and directed by Luigi Monica of INAIL, this technical report involves a wide variety of experts in the field, including researchers, safety professionals, trade union representatives and academics.

The **UNI/TR 11950:2024** technical report offers a significant contribution to proceeding in the understanding and conscious use of these advanced devices in various production fields and aims to:

- **establish terminology and definitions** commonly used in the field of OEs;
- identify and **describe the characteristics of exoskeletons** currently developed and used in work contexts;
- outline the **general principles of design** and construction of these devices;
- illustrate the **work sectors** in which exoskeletons have been implemented;
- examine the **potential and challenges** associated with their use.


RAPPORTO TECNICO

UNI/TR 11950

APRILE 2024

Sicurezza e salute nell'uso degli esoscheletri occupazionali orientati ad agevolare le attività lavorative

Safety and health in the use of occupational exoskeletons related to facilitate work activities

Thank you for your attention!

Lorenzo Grazi

lorenzo.grazi@santannapisa.it

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101006798