# ESO-EAWS Project

**SUMMARY REPORT**

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

Varese, April 23rd 2020

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## Open challenges and opportunities

Work-related musculoskeletal disorders arise from a complex interaction of events that may accumulate over time. In contrast to the acute trauma model (injuries refer to those arising from a single identifiable event), the cumulative trauma model assumes injury may result from the accumulated effect of transient external loads that may, in isolation, be insufficient to exceed internal tolerances of tissues. It is when this loading accumulates by repeated exposures, or exposures of sufficiently long duration, that the internal tolerances of tissues are eventually exceeded. The cumulative trauma model therefore explains why many musculoskeletal disorders are associated with work, because individuals often repeat actions (often many thousands of times) throughout the workday or spend long periods of time (as much as eight hours or more daily) performing work activities in many occupations. Internal mechanical tolerance represents the ability of a structure to withstand loading. It is clearly multidimensional and is not considered a threshold but rather the capacity of tissues to prolong mechanical strain or fatigue. Internal tissue tolerances may themselves become lowered through repetitive or sustained loading.

External loads are produced in the physical work environment. These loads are transmitted through the biomechanics of the limbs and body to create internal loads on tissues and anatomical structures. Biomechanical factors include body position, exertions, forces, and motions. External loading also includes environmental factors whereby thermal or vibrational energy is transmitted to the body. Biomechanical loading is further affected by individual factors, such as anthropometry, strength, agility, dexterity, and other factors mediating the transmission of external loads to internal loads on anatomical structures of the body.

The literature contains numerous methodologies for measuring physical stress in manual work. Studies from different disciplines and research groups have concentrated on diverse external factors, workplaces, and jobs. Factors most often cited include forceful exertions, repetitive motions, sustained postures, strong vibration, and cold temperatures.

## Project objective

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 study has been carried out with the exoskeleton MATE**.

An exoskeleton is a wearable device supporting the human to generate the physical power required for manual tasks. Exoskeletons could be useful, when (i) other preventive measures are not feasible, usable or effective, and (ii) where the automation of tasks is not feasible when tasks constantly change (e.g. the job of movers, unloading loose loads from containers, patient handling). Exoskeletons could be classified as 'active' or 'passive'. An active exoskeleton is comprised of one or more actuators (e.g., electrical motors) that actively augments power to the human body. A passive system does not use an external power source, but uses materials, springs or dampers with the ability to store energy from human movements and release it when required.

Active exoskeletons have been particularly developed for the purpose of rehabilitating injured or disabled people. Active exoskeletons with an occupation or industrial purpose are being developed, but these are mainly in a laboratory stage now.

## MATE Exoskeleton

MATE (Muscular Aiding Tech Exoskeleton), Comau Exoskeleton, is an ergonomically designed structure which eases the repetitive movements and relieves the effort of the shoulder, thanks to a lightweight, breathable and effective postural support. Developed in collaboration with ÖSSUR, an Icelandic leading non-invasive orthopedic company, and IUVO, a spin-off a spin-off company of Scuola Superiore Sant'Anna (SSSA), Italian BioRobotics Institute, specialized in wearable technologies, and commercialized by Comau, MATE is replicates dynamic movements of the shoulder.

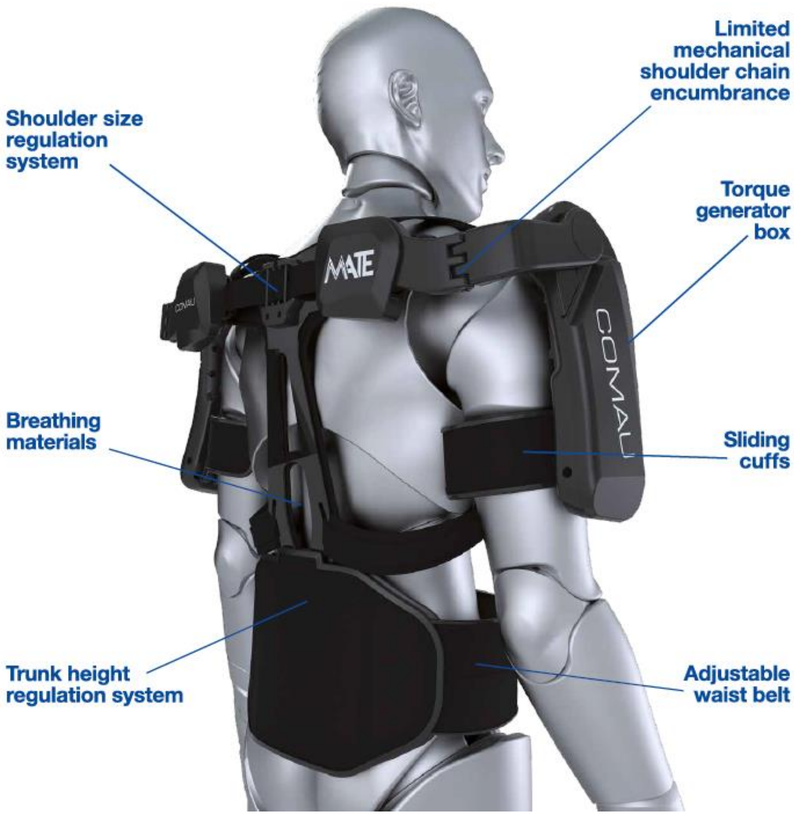



*Figure 1- MATE exoskeleton*

## Ergonomic Assessment Work-Sheet (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.

In order to effectively address ergonomic issues in the workplace, one must develop an appreciation for the trade-offs associated with ergonomics. When one considers biomechanical rationale, one finds that it is very difficult to accommodate all parts of the body in an ideal biomechanical environment. It is often the case, that in attempting to accommodate one portion of the body, the biomechanical situation at another body site is compromised. Therefore, the key to the proper employment of occupational biomechanical principles is to be able to consider the appropriate biomechanical trade-offs with various parts of the body associated with different workplace design options.

The above brief introduction to Biomechanics is reported just to give the idea of the level of complexity we have when we aim at measuring a biomechanical load index. For this reason, in the field of occupational biomechanics, researchers adopt models, which do not have the same level of accuracy as other scientific measuring systems (e.g. Methods-Time Measurement to measure the human work). We know that 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.

Nonetheless, EAWS design was done based on existing and available research with the aim of finding the most appropriate and reasonable correlation against the CEN and ISO standards dealing with biomechanical load.

The EAWS structure is the following:

a) 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).

b) Macro-Section “Upper limbs”

Section 4: Upper limb load in repetitive tasks (ref. ISO 11228.3 and EN 1005-5).

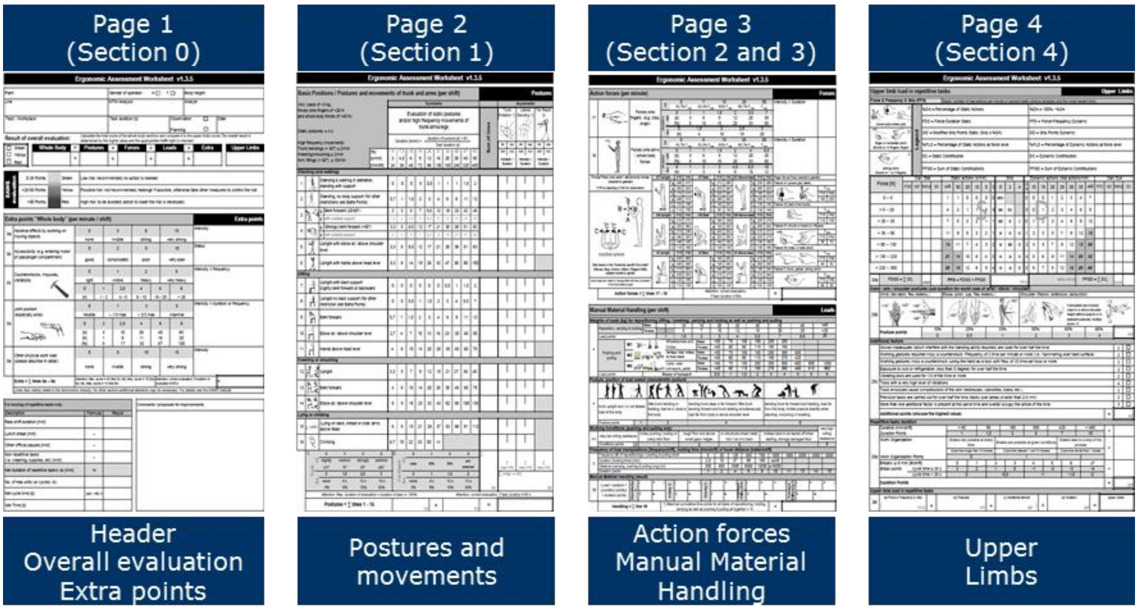
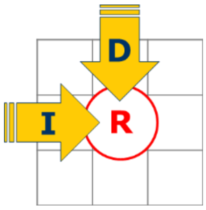



*Figure 2 - EAWS form overview*

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

**R = I × D**




In Section 1, the user must select the relevant posture in the proper row (intensity) and measure the duration (column). Intersecting the column of duration with the row of intensity, the user can easily find the score.

In Sections 2, 3 and 4, the user must calculate the intensity and the duration scores of the concerned task, following specific rules, and eventually multiply the intensity score by the duration score to find the load index.

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 |
| >25-50 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 |

*Figure 3 - EAWS traffic light result*

Whole body and upper limbs scores are evaluated on the same scale. Thus it is immediate to understand which is the most critical Macro-Section.

**Section 0: Extra Points**

Extra Points are related to additional extraordinary loads not considered in the other total body sections and therefore assigned in this special section. The standard influencing factors in Section 0 are:

Working on moving objects;

Difficult accessibility to the working area;

Counter shocks, impulses, vibrations;

Joint position (especially wrist and neck);

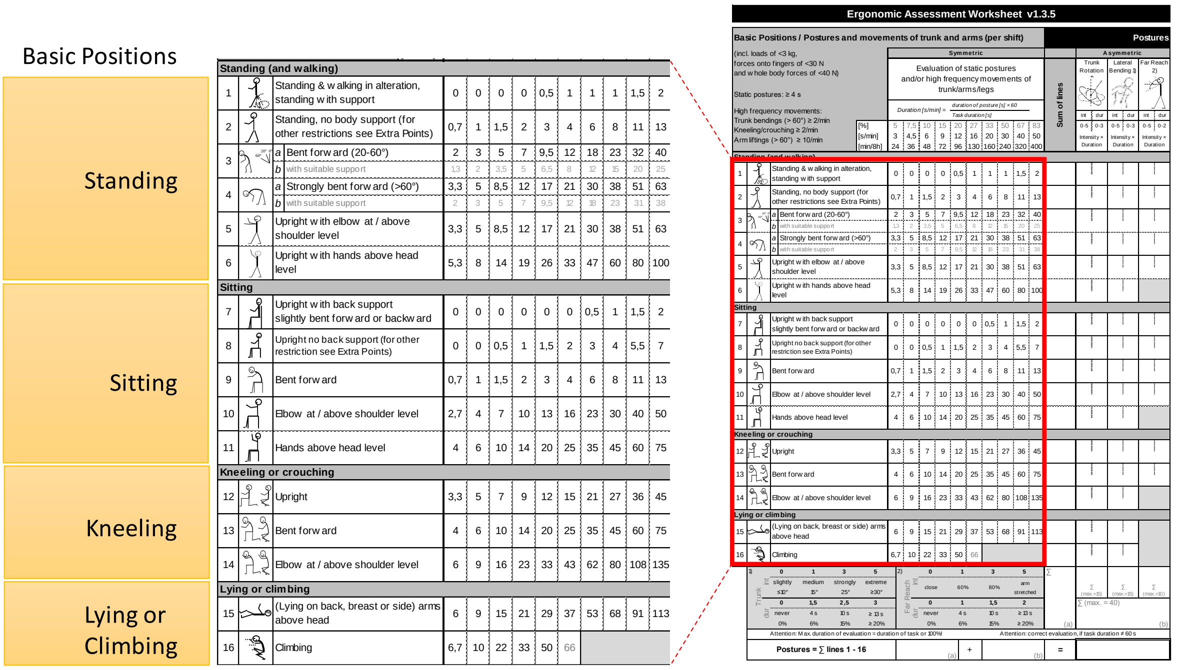
Other "special" situations, like above head control work, including looking upward (neck load).

| Extra points "Whole body" (per minute / shift) | | | | | | | | Extra points |
|---|---|---|---|---|---|---|---|---|
| 0a | Adverse effects by working on moving objects | 0 | 3 | 8 | 15 | | | Intensity |
| | | none | middle | strong | very strong | | | |
| 0b | Accessibility (e.g. entering motor or passenger compartment) | 0 | 2 | 5 | 10 | | | Status |
| | | good | complicated | poor | very poor | | | |
| 0c | Countershocks, impulses, vibrations  | 0 | 1 | 2 | 5 | | | Intensity × frequency |
| | | light | visible | heavy | very heavy | | | |
| | | 0 | 1 | 2,5 | 4 | 6 | 8 | |
| | | [n] | 1 - 2 | 4 - 5 | 8 - 10 | 18 - 20 | > 20 | |
| 0d | Joint position (especially wrist)  | 0 | 1 | 3 | 5 | | | Intensity × duration or frequency |
| | | neutral | ~ 1/3 max | ~ 2/3 max | maximal | | | |
| | | 0 | 2 | 2,5 | 4 | 6 | 8 | |
| | | [s] | 3 | 10 | 20 | 40 | 60 | |
| | | [n] | 1 | 8 | 11 | 16 | 20 | |
| | | [%] | 5 | 17 | 33 | 67 | 100 | |
| 0e | Other physical work load (please describe in detail) | 0 | 5 | 10 | 15 | | | Intensity |
| | | none | middle | strong | very strong | | | |
| | **Extra = ∑ lines 0a – 0e** | Attention: Max. score = 40 (line 0c, 0d); Max. score = 15 (line 0a, 0e); Max. score = 10 (line 0b) | | | Attention: correct evaluation, if duration of evaluation ≠ 60 s | | | = |
| | *Lines 0a-b mainly relate to the Automotive Industry, for other sectors additional elements may be necessary. For details see the EAWS manual.* | | | | | | | |

*Figure 4 - Extra points whole body*

**Section 1: Body Postures**

On the left side of the page, load points for symmetric body postures can be assigned. If there are any asymmetric static posture due to trunk rotation, lateral trunk bending or arm extension (far reach), the right side of the page has to be used.




| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **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 | | Upright with elbow at / above shoulder level | 3,3 | 5 | 8,5 | 12 | 17 | 21 | 30 | 38 | 51 | 63 |
| 6 | | Upright with hands above head level | 5,3 | 8 | 14 | 19 | 26 | 33 | 47 | 60 | 80 | 100 |
| **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 | | Elbow at / above shoulder level | 2,7 | 4 | 7 | 10 | 13 | 16 | 23 | 30 | 40 | 50 |
| 11 | | Hands above head level | 4 | 6 | 10 | 14 | 20 | 25 | 35 | 45 | 60 | 75 |
| **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 | | Elbow at / above shoulder level | 6 | 9 | 16 | 23 | 33 | 43 | 62 | 80 | 108 | 135 |
| **Lying or climbing** | | | | | | | | | | | | |
| 15 | | (Lying on back, breast or side) arms above head | 6 | 9 | 15 | 21 | 29 | 37 | 53 | 68 | 91 | 113 |
| 16 | | Climbing | 6,7 | 10 | 22 | 33 | 50 | 66 | | | | |

*Figure 5 - EAWS symmetric body postures*

On this page, static postures (which are defined in EAWS as postures maintained for at least 4 consecutive seconds) and high frequency movements are evaluated, including loads weighting less than 3 kg, action forces onto fingers less than 30N, and whole body forces less than 40 N.

In the EAWS form, Section 2, the columns indicate the duration (in % of the cycle, s/min or % of shift) of a specific posture. The rows show a graphic visualization of different posture types (intensity).

The asymmetric body postures:

trunk rotation (use duration table 1);

lateral trunk bending (use duration table 1);

arm extension (far reach) (use duration table 2),

are evaluated on the right side of the page. At the bottom of the left side of the page, there is a table to assign the “intensity” and the “duration” points.

Trunk Rotation and Lateral Bending table (use duration table 1);

Far Reach table (use duration table 2, see Figure 6 - EAWS asymmetric body postures).

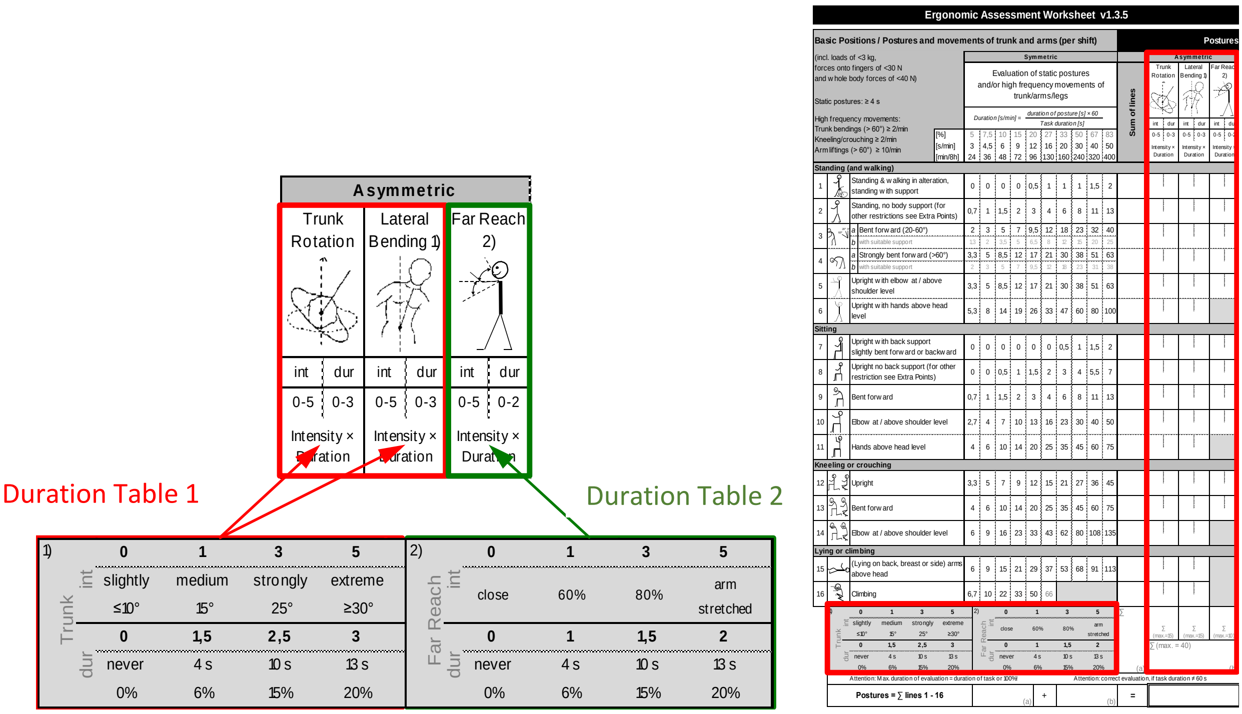



*Figure 6 - EAWS asymmetric body postures*

**Section 2 – Action Forces**

In Section 2, Action Forces are evaluated:

Row 17: Forces onto/with fingers if greater than or equal to 30 N;

Row 18: Action forces onto arms and whole-body forces if greater than or equal to 40 N (excluding manual material handling evaluated in Section 3).

In the lower part of this section data are abstracted from the “Force Atlas” and represented in figures and values. These values are the result of detailed German academic research about force limits at different anthropometric percentiles for each body and hand postures. In the Force Atlas, the statistical distribution of the maximum forces, depending on the postures of hand, arms and body, is established for significant percentiles. The force values assigned in section 2 of EAWS are the ones for the 15th and 40th percentile neutral gender (in the standard EAWS form neutral gender is set equal to feminine gender). 15th percentile data are used for planning, 40th percentile data for direct observational analyses.

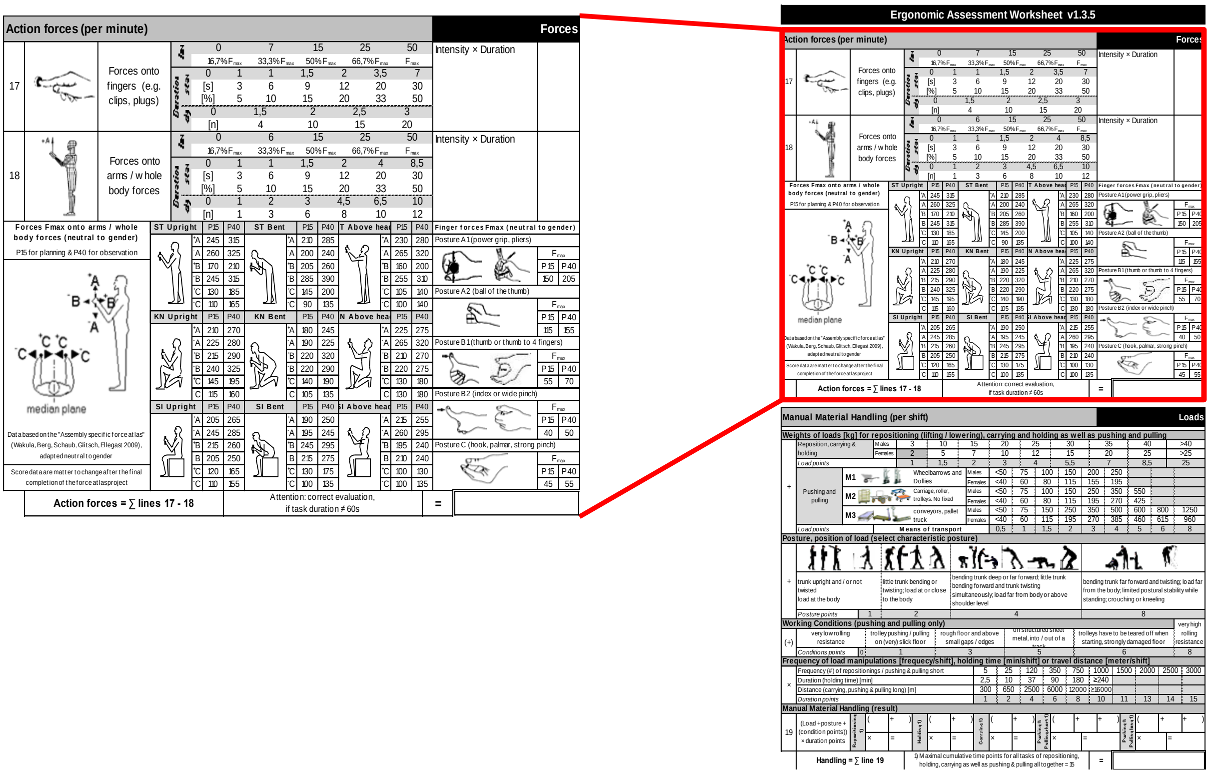



*Figure 7 - EAWS Section 2, Body Forces*

**Section 3: Manual Material Handling of Loads**

In section 3, the efforts due to manual material handling (greater than or equal to 3 kg) subdivided into repositioning, holding, carrying, pushing & pulling (short and long) are evaluated.

In the case of automotive assembly, it is recommended to enlarge these limits to 20 m or 15 s for easier application. This leads to:

Repositioning (R): get and place a load within the workplace (approximately equivalent to a maximum displacement of 20 m):

Holding (H): hold a load longer than 15 s, no carrying;

Carrying (C): get, carry and place for a distance longer than 20 m;

Pushing & Pulling (P&P): transporting a load with a means of transport;

Short, if distance ≤ 20 m

Long, if distance > 20 m

Influencing factors:

Weights of loads;

Posture;

Working conditions;

Frequency / Duration / Distance per shift.

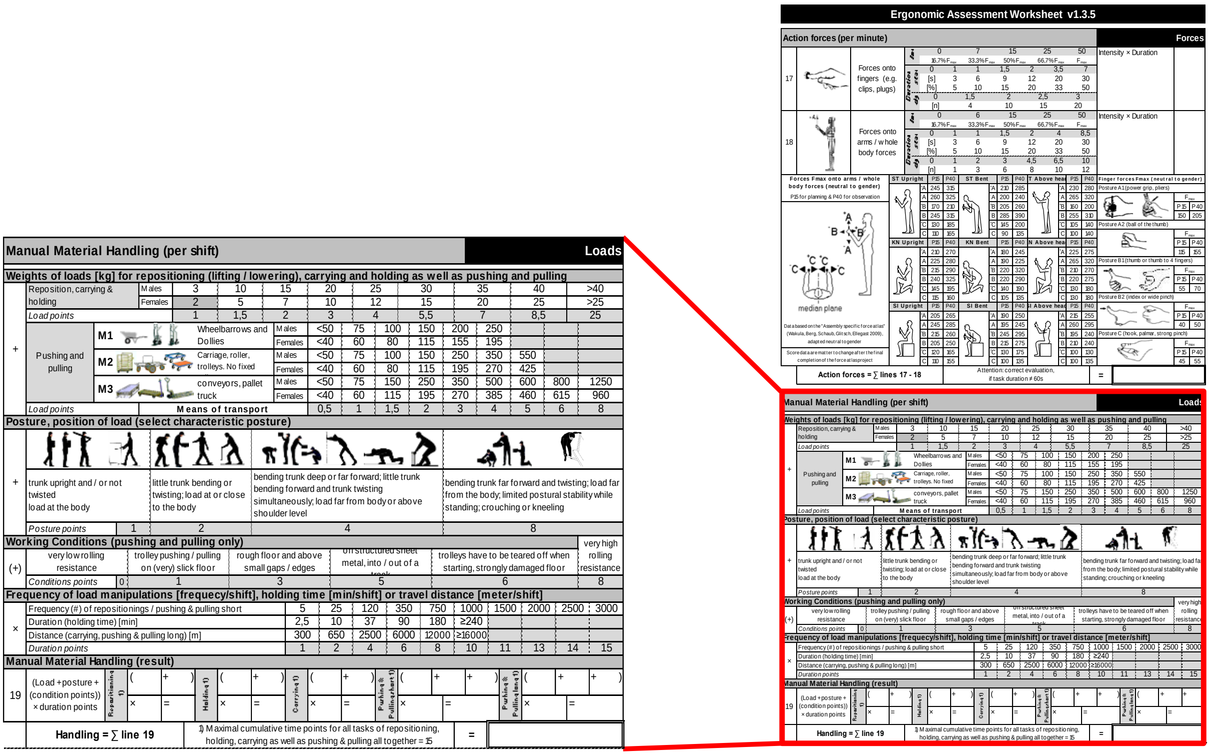



*Figure 8 - EAWS Section 3: manual material handling of loads*

**Section 4: Repetitive Motions of the Upper Limbs**

Section 4 of EAWS has been designed to meet the requirements defined in the general framework of the ISO 11228-3 standard and has been calibrated against the OCRA Index. However, the approach of section 4 EAWS differs from the OCRA Index, above all in the choice to use the concept of real action (e.g. Get & Place an object) compared to the one of technical action (Grasp an object), choice dictated by the intention of the EAWS authors to adopt a design logic, less tied to the behaviour of the individual performer of the work cycle. The following are other significant differences between EAWS section 4 and OCRA Index:

The type of Grip in section 4 is evaluated for each real action jointly with the level of force and the frequency / duration of the action itself;

The pinch-type Grip without force does not generate additional load points compared to those assigned to the real action;

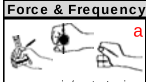
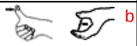
In EAWS there is no step effect between different intervals of intensity or duration level of the influencing factors. The value curves are the result of continuous linear interpolations between known benchmark points.

In the upper part of the page, the following information is analysed:

Frequency of dynamic real actions / duration of real static actions;

Force or load level of each real action;

Type of grip of each real action.

| Upper limb load in repetitive tasks | | Upper Limbs |
|---|---|---|
| Force & Frequency & Grip (FFG) | Basis: number of real actions per minute or percent static actions (analyze only the most loaded limb) | |
|  a<br>power grip/contact grip | %SA = Percentage of Static Actions | %DA = 100% - %SA |
| | FDS = Force-Duration Static | FFD = Force-Frequency Dynamic |
|  b<br>finger or moderate pinch (thumb to >2 fingers, finger) | GS' = Modified Grip Points Static (Grip x %SA) | GD = Grip Points Dynamic |
| Legend | %FLS = Percentage of Static Actions at force level | %FLD = Percentage of Dynamic Actions at force level |
|  c | SC = Static Contribution | DC = Dynamic Contribution |
| strong pinch (thumb to 1or 2 fingers) | FDGS = Sum of Static Contributions | FFGD = Sum of Dynamic Contributions |

| Force [N] | Calc Stat | | | | Static actions (s/min) | | | | | | Grip | | | Dynamic actions (real actions/min) | | | | | | | | Calc Dyn | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FDS | GS' | %FLS | SC | ≥45 | 30 | 20 | 10 | 5 | 3 | 0 | 2 | 4 | 2-5 | 10 | 15 | 20 | 25 | 30 | 35 | ≥40 | FFD | GD | %FLD | DC |
| 0 – 5 | | | | | 1 | 1 | 0 | 0 | 0 | 0 | abc | | | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 7 | | | | |
| > 5 – 20 | | | | | 4 | 2 | 1 | 1 | 0 | 0 | ab | bc | | 0 | 0 | 1 | 2 | 3 | 4 | 6 | 9 | | | | |
| > 20 – 35 | | | | | 7 | 5 | 3 | 2 | 1 | 1 | ab | b | c | 0 | 1 | 2 | 3 | 4 | 6 | 8 | 12 | | | | |
| > 35 – 90 | | | | | 11 | 8 | 5 | 3 | 2 | 1 | a | b | b | 1 | 2 | 3 | 5 | 7 | 9 | 12 | 18 | | | | |
| > 90 – 135 | | | | | 16 | 11 | 7 | 4 | 3 | 2 | a | ab | b | 2 | 3 | 5 | 7 | 9 | 12 | 15 | ***24*** | | | | |
| > 135 – 225 | | | | | ***21*** | 14 | 10 | 6 | 4 | 3 | a | a | b | 4 | 5 | 6 | 8 | 11 | 14 | ***20*** | ***32*** | | | | |
| > 225 – 300 | | | | | ***28*** | 18 | 12 | 8 | 5 | 4 | a | a | b | 5 | 6 | 7 | 9 | 12 | 16 | ***26*** | ***40*** | | | | |
| 20a | FDGS = $\sum SC_i$ | | 100% | | **FFG** = FDGS + FFGD | | | | | | FFG | | | | | | | %DA = ΣFLDj | | FFGD = $\sum DC_j$ | | | %DA | | |

*Figure 9 - EAWS Section 4: force-frequency-grip score*

The following items are evaluated in the lower part of the page:

Posture of hands, arms and shoulders;

Special points, and;

Duration of repetitive tasks;

Work Organization;

Number of breaks;

Shift duration.

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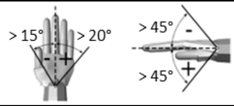
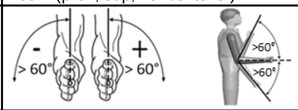
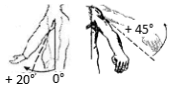
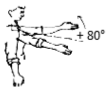
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Hand / arm / shoulder postures (use duration for worst case of wrist / elbow / shoulder)** | | | | | | | | |
| 20b | Wrist (deviaton, flex./extens.) | | Elbow (pron, sup, flex./extens.) | | Shoulder (flexion, extension, abduction) | | | |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

| | | | |
|---|---|---|---|
| **Additional factors** | | | |
| 20c | Gloves inadequate (w hich interfere w ith the handling ability required) are used for over half the time | 2 | ☐ |
| | Working gestures required imply a countershock. Frequency of 2 time per minute or more (i.e.: hammering over hard surface | 2 | ☐ |
| | Working gestures imply a countershock (using the hand as a tool) w ith freq. of 10 time per hour or more | 2 | ☐ |
| | Exposure to cold or refrigeration (less than 0 degree) for over half the time | 2 | ☐ |
| | Vibrating tools are used for 1/3 of the time or more | 2 | ☐ |
| | Tools w ith a very high level of vibrations | 4 | ☐ |
| | Tools employed cause compressions of the skin (rednesses, callosities, blebs, etc.) | 2 | ☐ |
| | Precision tasks are carried out for over half the time (tasks over areas smaller than 2-3 mm) | 2 | ☐ |
| | More than one additional factor is present at the same time and overall occupy the w hole of the time | 3 | ☐ |
| | **Additional points (choose the highest value)** | = | AF |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Repetitive tasks duration** | | | | | | | | | | |
| 20d | Net Duration [min/shift] | < 60 | 90 | 180 | 300 | 420 | ≥ 480 | | + | |
| | *Duration Points* | 1 | 1,5 | 3 | 5 | 7 | 10 | | | |
| | Work Organization | Breaks are possible at every time (Cycle time longer than 10 minutes) | | Breaks are possible at given conditions (Cycle time between 1 and 10 minutes) | | Breaks lead to a stop of the process (Cycle time shorter than 1 minute) | | | + | |
| | *Work Organization Points* | 0 | | 1 | | 2 | | | | |
| | Breaks (≥ 8 min) [#/shift] | 0 | 1 | 2 | 3 | 4 | 5 | 6 | ≥7 | + |
| | *Break points* *cycle time ≤ 30 s* | 3 | 2 | 1 | 0 | -1 | -2 | -3 | -4 | |
| | *cycle time > 30 s* | 0 | | -0,5 | | -1 | | -1,5 | -2 | |
| | **Duration Points** | | | | | | | | = | DP |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Upper limb load in repetitive tasks** | | | | | | | | | | |
| 20 | (a) Force & Frequency & Grip<br>( FFG | + | (b) Postures<br>PP | + | (c) Additional factors<br>AF ) | × | (d) Duration<br>DP | = | Upper Limbs | |

*Figure 10 - EAWS Section 4: postures, additional factors and work organization*

# Methods

## Participants

Twelve young volunteers (20-30 years) were tested in this experimental protocol. Subjects with specific anthropometric characteristics (i.e., height: 160-195 cm, weight: 45-100 kg) were recruited to allow the correct fitting of the passive exoskeleton. Participants reporting any osteo-muscular problem in the 12 months prior to the tests were excluded of the study. All subjects were asked to provide a written informed consent before participating in the study. Experimental procedures were conducted in accordance with the *Declaration of Helsinki.*

## Experimental conditions

Subjects were instructed to perform 12 simulated conditions (8 static and 4 dynamic) without and with the passive exoskeleton MATE (Figure 1) to shoulder support. The tasks were selected from two sessions of the Ergonomic Assessment Work-Sheet (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°, elbow flexed at 90°, elbow pronated at 90° (Figure 12A);

(2) shoulder flexed at 90°, elbow flexed at 90°, elbow pronated at 90° (Figure 12B);

(3) shoulder flexed at 90°, elbow pronated at 90° (Figure 12C);

(4) shoulder abducted at 90°, elbow pronated at 90° (Figure 12D).


*Figure 11 - Anterior (A) and posterior (B) view of subject while wearing MATE*

The standard anatomical position (Figure 12E) was considered for the description of all joint movements indicated above. Here, *shoulder* refers to the glenohumeral joint and *elbow* refers to humeroulnar and proximal radioulnar joint.

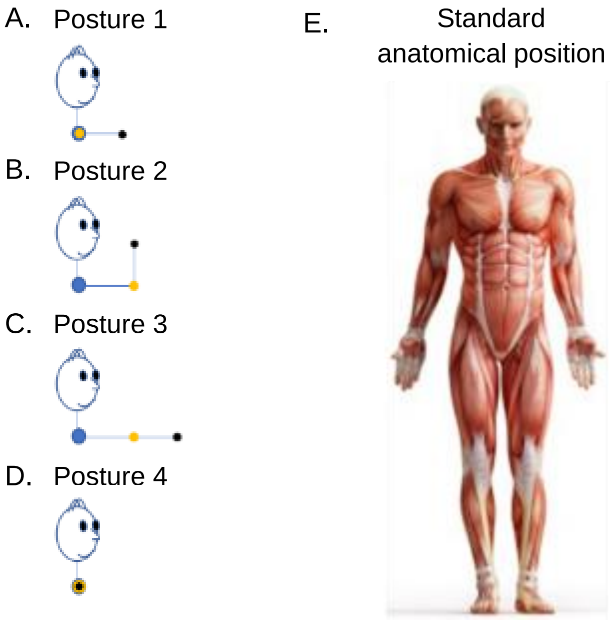



*Figure 12 - Schematic representation of the postures which were studied in the present study*

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. All 12 tasks were performed in random order and were applied with a rest time in-between equal to the duration of the task just performed.

## Electromyography

Pairs of circular surface electrodes (30 mm inter-electrode center-to-center distance, 24 mm diameter, Spes Medica, Battipaglia, Italy) were used to collect bilaterally surface electromyograms (EMGs) from the following upper limb muscles:

- anterior deltoid
- medial deltoid
- posterior deltoid
- biceps brachii (short head and long head)
- triceps brachii (lateral head)
- the upper portion of trapezius muscle

These muscles were selected because they contribute to shoulder movement and stabilization (Itoi et al. 1993; Elser et al. 2011; Hawkes et al. 2019). After carefully shaving and cleaning the skin with abrasive paste, surface electrodes were positioned on the skin surface over the muscle of interest (Figure 13). Bipolar EMGs were recorded with a wireless system (200 V/V gain; 10–500 Hz bandwidth amplifier; DuePro system, OTBioelettronica and LISiN, Politecnico di Torino, Turin, Italy). EMGs were digitized at 2,048 Hz with a 16 bits A/D converter.

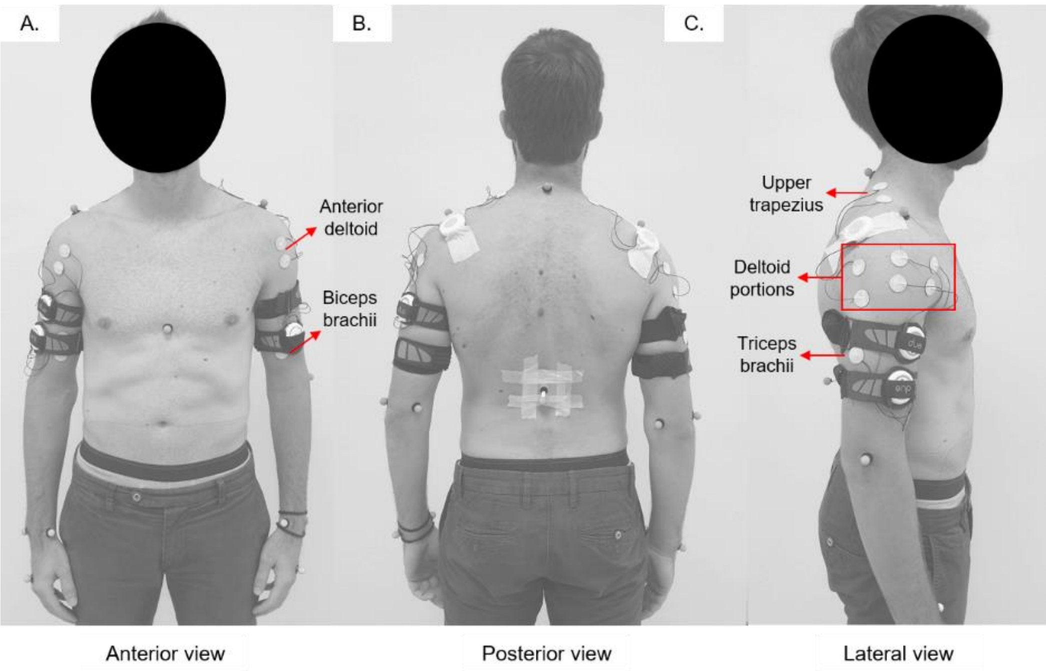



*Figure 13 - Positioning of a pair of electrodes on the six upper limb muscles tested during the experimental conditions with and without exoskeleton; anterior view (A), posterior view (B) and lateral view (C).*

## Motion analysis

Kinematic data were record during the tasks to segment sEMG according to movement phases. Movements were captured by a 12 camera VICON system (100 Hz, Vero v2.2, Nexus 2.9 software, Oxford, UK), through markers positioned in the upper limbs according to the protocol proposed by Hebert et al. (2014).

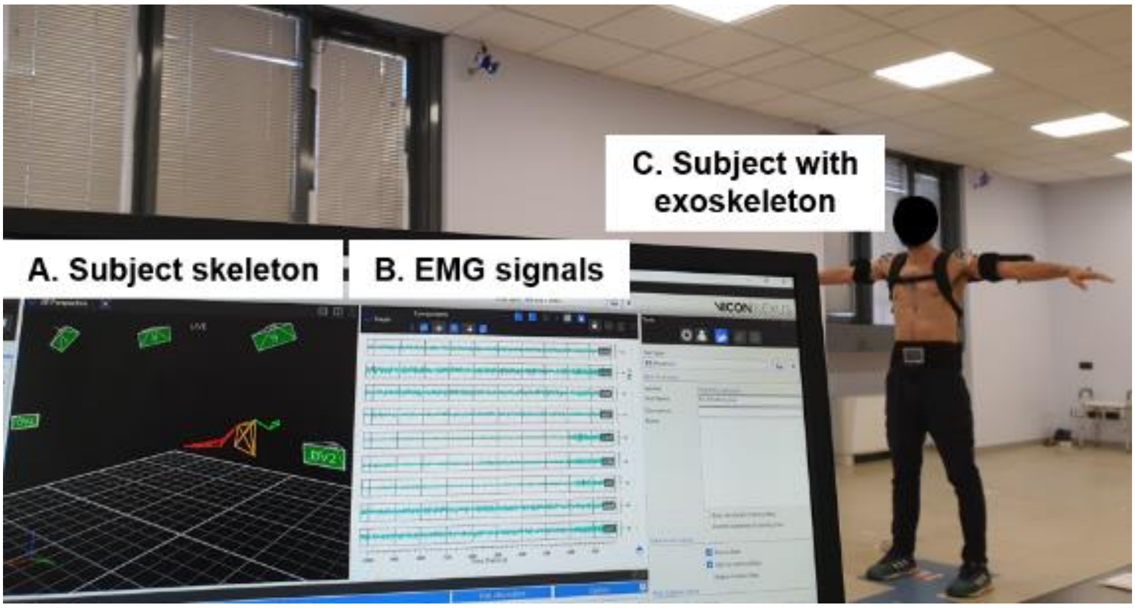



*Figure 14 - Real-time visualization of subject skeleton, created with markers, in the 3D perspective view (A) and real-time visualization of EMG signals (B) from software Nexus 2.9 while subject performing an experimental condition with exoskeleton MATE (C).*

## Assessment of muscle activity

Individual sustained phases or concentric/eccentric phases depending on the condition (static or dynamic) were first identified bilaterally from the angular variations of shoulder joint with and without exoskeleton. This procedure is useful to evaluate the effect of exoskeleton on the amplitude of surface EMGs during the maintenance of a given posture and phases of movement to reach the required posture. The first and last second of sustained phase were not considered to segment the surface EMGs in order to ensure periods of constant EMG activity (Figure 15).

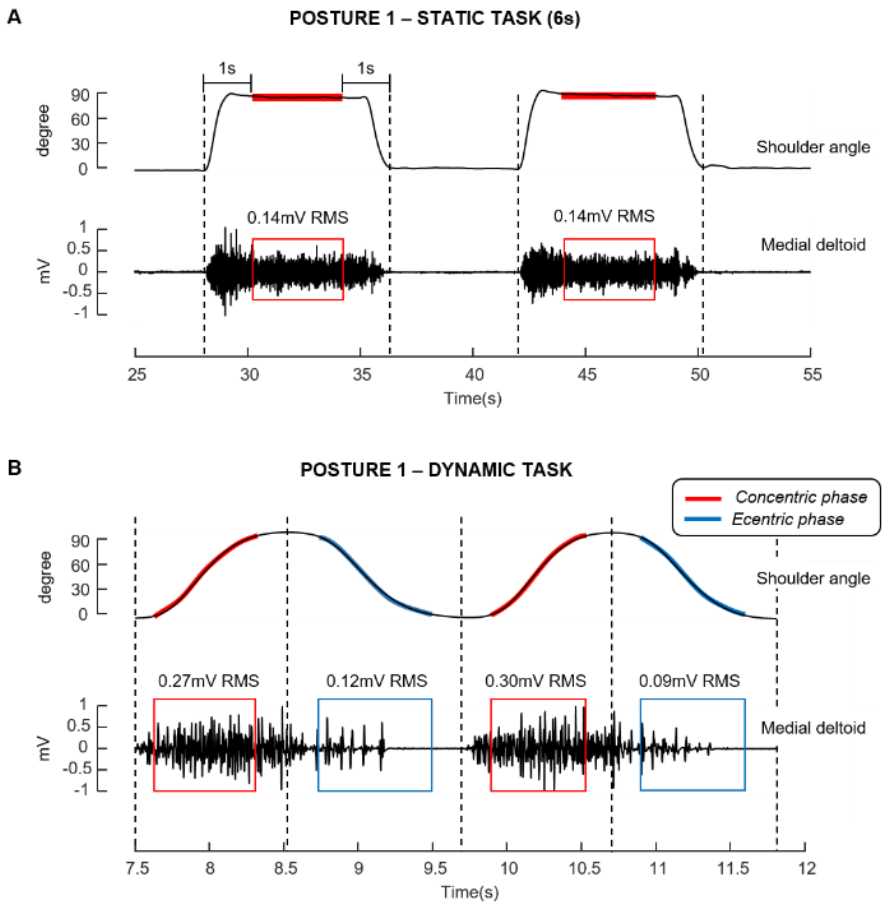



*Figure 15 - (A) Shoulder angle in the frontal plane and bipolar EMG sampled from the medial portion of deltoid (right side), acquired while subject performed the Posture 1. Vertical and dashed lines indicate the instants corresponding to the start and the end of sustained phase. Red line over the shoulder angle indicate the epoch considered to select the portion of surface EMG related to the sustained phase (red square). (B) Angle data and bipolar EMG collected respectively from the same joint and muscle during two cycles while subject repeated 15 consecutive times the Posture 1. Vertical and dashed lines indicate the instants corresponding to the local minima and maxima of angle data. Red and blue lines over the shoulder angle indicate respectively the segment considered to identify the surface EMG epochs corresponding to the concentric and eccentric phases of movement (red and blue squares).*

For the dynamic tasks, the concentric and eccentric phases were defined from the shoulder angle in the sagittal or frontal plane, depending on the posture.

After the identification of cycles from variations in the shoulder angle within each experimental condition, bipolar surface EMGs collected from all muscles were visually inspected. Whenever any signal presented contact problems, likely due to unstable electrode-amplifier connection, or artefacts resulting from wearing the exoskeleton, the corresponding signal was disregarded (see general considerations below). After controlling for signal quality, bipolar EMGs were band-pass filtered with a fourth order Butterworth bidirectional filter (15–350Hz cut-off) and the level of muscle activity was estimated from the Root Mean Square (RMS) amplitude of surface EMG. For the static tasks, the RMS amplitude was computed over epochs corresponding to the sustained phases. Afterwards, for each condition and muscle, we specifically: i) identify the overall RMS value between the condition performed with and without exoskeleton; ii) average the RMS amplitude across the phases identified, providing a global indication of the level of muscle activity; iii) compute the relative variation in the average RMS amplitude between each posture executed without and with exoskeleton with respect to the overall RMS value. This index was considered to assess for how much the exoskeleton reduces the level of activity in each upper limb muscles evaluated during the 12 simulated conditions.

### Statistical analysis

Inferential statistics was only applied to test for the hypothesis of differences in the relative variation in EMG amplitude between static trials of different durations (6s and 20s were studied here). These results would possibly indicate whether the attenuation effect of exoskeleton on the EMG amplitude depends on the duration of static task. Parametric statistic was applied after verifying the data distribution was Gaussian (Kolmogorov-Smirnov, $p > 0.05$ in all cases). A two-way analysis of variance (ANOVA) for repeated measures was used to evaluate the effect of duration of static trials (2 levels: 6s and 20s) on the relative variation in EMG amplitude, with posture as between factor (4 levels). Whenever any significant difference was revealed by ANOVA, paired comparisons were assessed with the Newman-Keuls post-hoc test. The level of statistical significance was set at 5%.

## Results

### General considerations

The 12 subjects tested successfully completed all static and dynamic trials. None reported any discomfort while wearing the exoskeleton during both static and dynamics trials. No artefacts resulting from wearing the exoskeleton were observed on the surface EMGs either.

### Qualitative considerations from a representative example

Although statistical analysis was only applied to test for a duration effect of static trials on the relative variation in EMG amplitude, results from all subjects tested were inspected closely. Data from a representative subject are shown in Figures 6 and 7, for an individual static (Figure 16) and dynamic (Figure 17) cycle.

### Static trial

Upon reaching the end-point target, the participant successfully maintained the requested posture with and without the exoskeleton. Variations in shoulder abduction angle were remarkably smaller than 1° within the 18s period of posture maintenance, regardless of whether the subject wore the exoskeleton or not. The steady maintenance of shoulder position is further evidenced by the roughly constant degree of activity observed in the raw EMGs collected for the three main muscles crossing the shoulder joint. The activity of the deltoid muscles decreased by roughly 20% when this specific participant maintained posture 1 with assistance from the exoskeleton, although the decreased activity appear to be muscle specific.

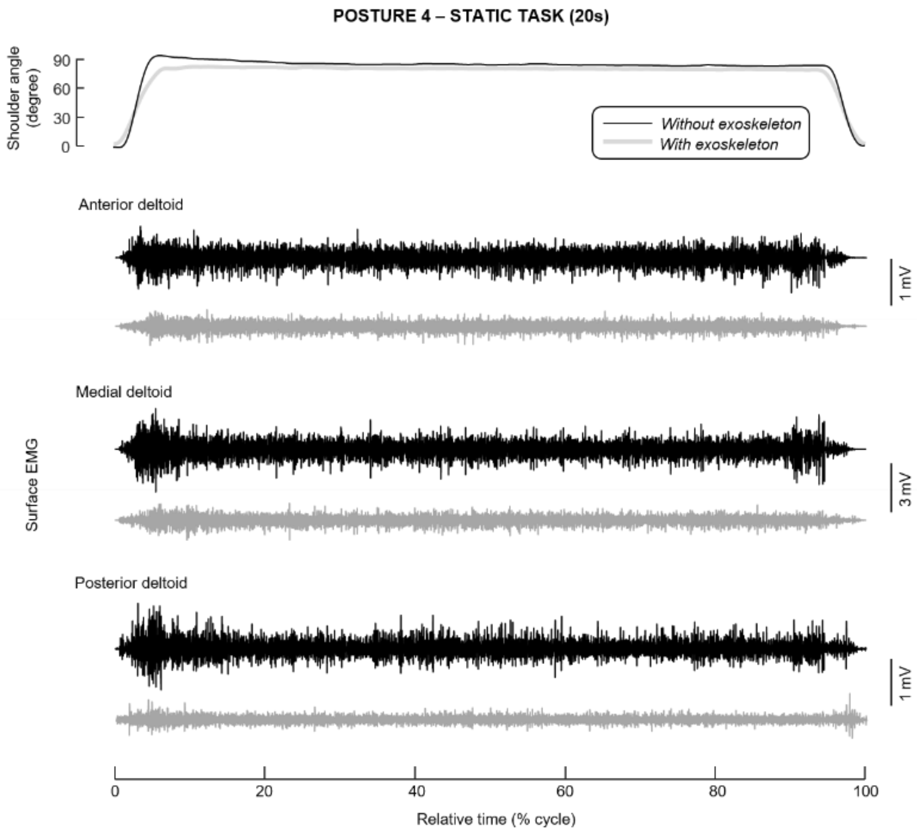



*Figure 16 - (A) Shoulder angle in the frontal plane and bipolar EMGs sampled from the three portions of deltoid muscle (right side), acquired while subject maintaining the Posture 4 for 20 seconds With (grey color) and Without (black color) the passive exoskeleton*

## Dynamic trial

As for the static trial, similar considerations on the consistency of kinematic data and on the amplitude of EMGs across conditions apply for the dynamic trials. The range of shoulder motion while a representative participant repeatedly abducted his left and right shoulders differed by less than 3° when performing with and without the exoskeleton. Variations in the average duration of cycles between the two conditions were less than 0.1 s across the four postures. Regarding the degree of muscle excitation, the effect of the exoskeleton appears to be contraction dependent. During the concentric phase, the amplitude of EMGs decreased by ca. 25% for the three deltoid muscles. During the eccentric phase, in particular for the posterior deltoid, there appears to be an increase in EMG amplitude. Contrarily to trials without the exoskeleton, the EMG amplitude peaked equally for the three muscles when the subject reached the maximal, shoulder abduction position while wearing the exoskeleton.

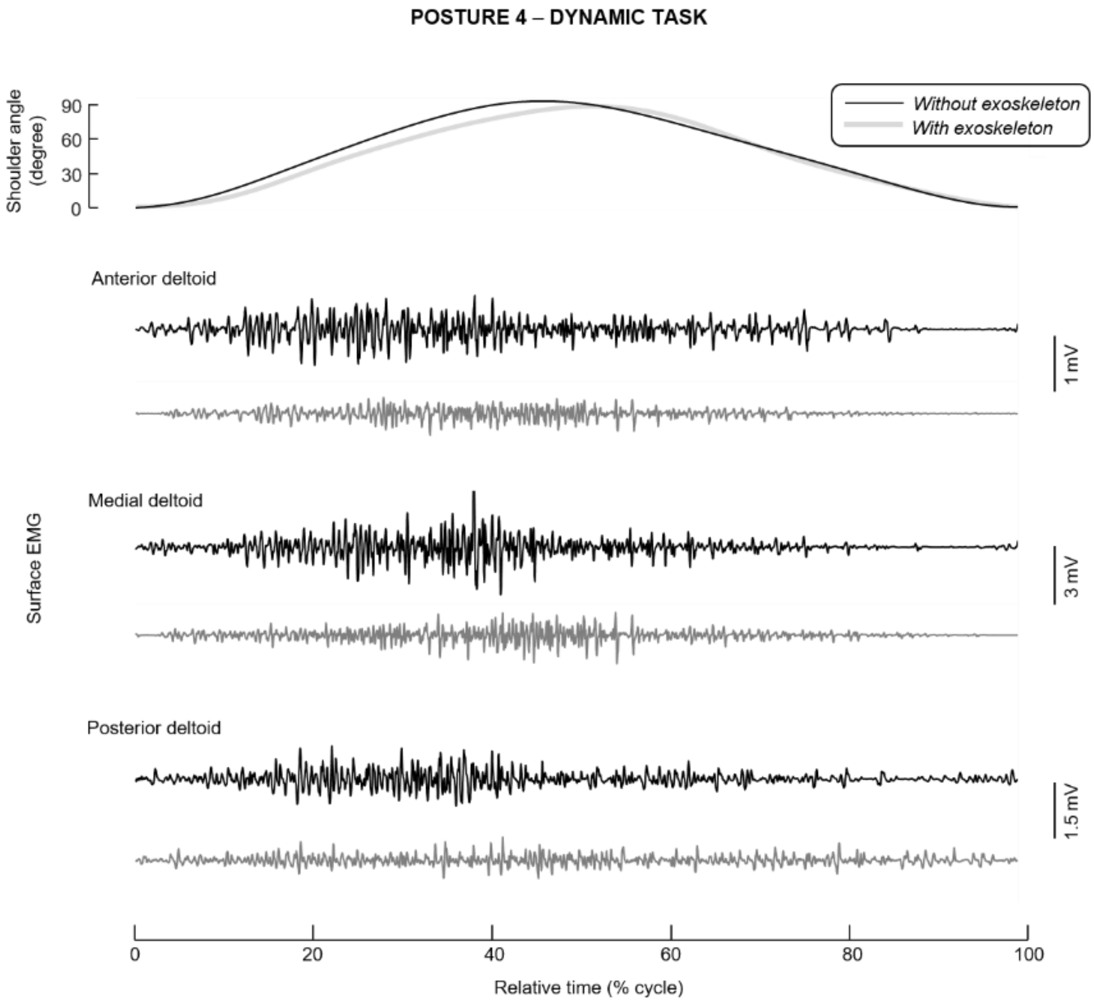



*Figure 17 - Figure 7: (A) Shoulder angle in the frontal plane and bipolar EMGs sampled from the three portions of deltoid muscle (right side), acquired during a single cycle while subject repeated 15 consecutive times the Posture 4 With (grey color) and Without (black color) the passive exoskeleton.*

## Considerations from group data

### *Static trial*

ANOVA did not reveal a significant Duration main effect on the relative variation in EMG amplitude ($F<2.36$, $p>0.13$ for all cases), except for the posterior deltoid ($F=4.80$, $p=0.03$). For the posterior deltoid, the percentage decrease in the EMG amplitude with exoskeleton was higher (~10%) when subjects kept the static postures for a shorter than a longer duration. In general, however, no significant differences in the relative variation in EMG amplitude were observed between trials of different durations for all other muscles, indicating the percentage decrease in EMG amplitude is likely to manifest equally in tasks of different durations.

ANOVA also demonstrated an interaction between Duration and Posture ($F=3.09$, $p=0.03$) for the upper portion of trapezius muscle, with higher percentage decrease in the EMG amplitude with exoskeleton (~10%) for 6s than 20s static trial in posture 4 (post-hoc test: $p = 0.02$). Even though ANOVA also revealed a main Posture effect for some muscles (biceps brachii and anterior deltoid; $F>3.44$, $p<0.02$ in all cases), boxplots in below Figure 18 suggest the EMG amplitude of all muscles generally decreased when participants wore the exoskeleton during static condition regardless posture.

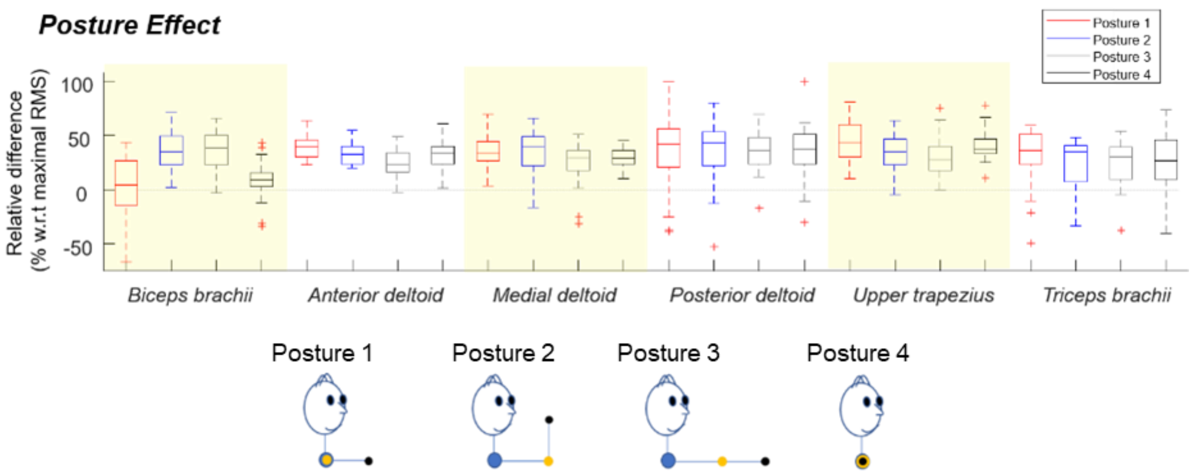



*Figure 18 - The median and interquartile interval of the percentage variation in EMG amplitude with the use of the exoskeleton MATE, pooled across static trials of different durations, for each posture and muscle reductions. Positive values indicate percentage decrease in EMG amplitude. Red cross denotes outlier value.*

### *Dynamic trial*

Visual inspection of group data suggests the amplitude of EMGs generally decreased when participants wore the exoskeleton, in both phases of dynamic condition (Figure 19). During eccentric contractions however, in particular for postures 2 and 3, a percentage increase in EMG amplitude was found for posterior deltoid with the exoskeleton (Figure 19). This higher EMG activity of posterior deltoid with than without exoskeleton could be presumably due to the resistance provided by the exoskeleton to shoulder extension for returning to the reference anatomical position. These results indicate the global, attenuation effect of exoskeleton on muscle activity was phase dependent for specific muscles and postures during the dynamic condition.

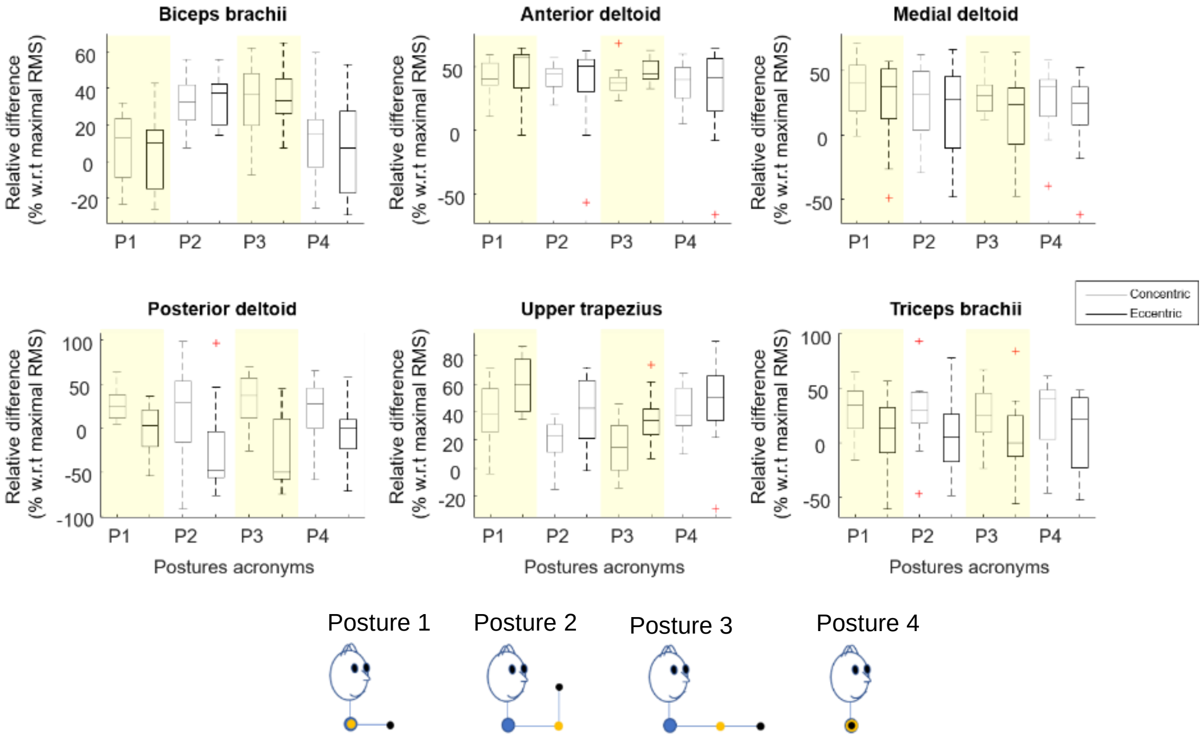



*Figure 19 - Boxplots of the percentage reductions in EMG amplitude during the concentric (grey boxes) and eccentric (black boxes) phases of dynamic condition. Positive values indicate percentage decreases in EMG amplitude with the exoskeleton. Red cross denotes outlier value.*

## Muscles to be considered to define the percentage reduction of muscle activity

The choice of muscles was motivated by their mechanical action over the body segments for the different postures evaluated.

The percentage reduction of muscle activity was computed by averaging the percentage values among specific muscles. For the dynamic conditions, average value was computed considering the entire movement cycle, i.e. concentric and eccentric phases.

*Table 1 - Muscles considered for static conditions and percentage reduction of muscle effort – **Static***

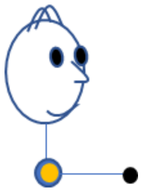
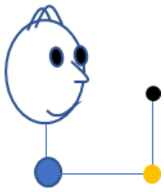
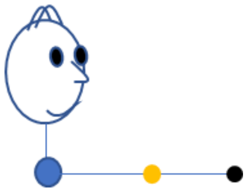
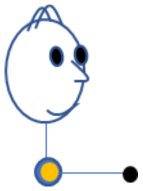
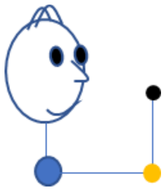
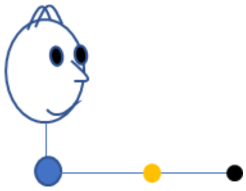
| Posture | | | |
|---|---|---|---|
|  |  |  |  |
| **Muscle** | | | |
| Trapezius<br>Medial deltoid | Trapezius<br>Anterior deltoid<br>Biceps brachii | Trapezius<br>Anterior deltoid<br>Biceps brachii | Trapezius<br>Medial deltoid<br>Anterior deltoid<br>Posterior deltoid |
| **Percentage reduction** | | | |
| **38.3%** | **33.9%** | **28.9%** | **34.2%** |

*Table 2 - Muscles considered for dynamic conditions and percentage reduction of muscle effort – **Dynamic***

| Posture | | | |
|---|---|---|---|
|  |  |  |  |
| **Muscles** | | | |
| Trapezius<br>Medial deltoid<br>Posterior deltoid | Trapezius<br>Anterior deltoid<br>Posterior deltoid<br>Biceps Brachii | Trapezius<br>Anterior deltoid<br>Posterior deltoid<br>Biceps Brachii | Trapezius<br>Medial deltoid<br>Anterior deltoid<br>Posterior deltoid |
| **Percentage reduction** | | | |
| **33.4%** | **23.4%** | **28.9%** | **31.1%** |

# Impact on EAWS

## Section 0

**Impact of wearing an exoskeleton during work tasks on Extra Points**

The use of an exoskeleton generates a tradeoff, where the positive effect of reducing the bio-mechanical load is mitigated by an increase of load or discomfort due to a reduced capacity of movement and an increased weight to support.

To consider the negative effect of wearing an exoskeleton, the following criteria have been adopted to provide a standard value of extra points (use line 0e) to be considered in the Whole Body index calculation.

Line 0e = + 1 point to score the discomfort of wearing the exoskeleton – Base Value

Line 0e = + 1 point for each further requirement not met

**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

*Note about "weight": The weight is the only requirement assessed on different degrees of intensity. All other requirements follow an on-off criteria.*

**MATE exoskeleton scoring on Section 0**

The Extra points for wearing MATE exoskeleton in Section 0 is assessed as follows

- TORQUE SUPPLY FUNCTION
  - zero torque at flexion angle 0°;
  - max torque at flexion angle 90°;
  - continuity during torque supply;
  - torque tuning
- 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 INTERFAC
  - 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 < 4,5 kg = **1 point**
  - no or very limited encumbrance outside the operator's body;
  - no entanglement prone protruding parts

**Total extra points for MATE = 2 points (1 Base Value + 1 point)**

## Section 1

**Symmetric body postures involving shoulder**

In Section 1 EAWS deals with static body postures and the lines influenced by the use of the exoskeleton MATE are lines 5 and 6 (standing), 10 and 11 (sitting) and line 14 (crouching or kneeling).

Based on a massive sample of motion and time studies carried out by the Fondazione Ergo, we know that the most frequent shoulder awkward posture in a typical manual industrial task is Posture 2 in Figure 20. That posture presents the most conservative percentage reduction (33,9%, see Table 1 - Muscles considered for static conditions and percentage reduction of muscle effort – **Static**), therefore we set the reference EAWS score reduction at 30%.

The reference percentage score reduction (RSR%) has been applied to Section 1 of the EAWS system only to Lines 10 and 11 (Sitting), in which the biomechanical load is completely driven by the awkward posture of the shoulder (sitting with a proper back support does not generate significant biomechanical load).

Line 10b scores = Line 10a scores x (1 – 30%)

To calculate the percentage score reduction (SR%) for the other lines (5b, 6b and 14b), the following formula has been applied:

With reference to Figure 21 - Lines affected using the exoskeleton MATE:

Line 5b scores = Line 5a scores – (Line 10a scores – Line 10b scores)

Line 6b scores = Line 6a scores – (Line 11a scores – Line 11b scores)

Line 14b scores = Line 14a scores – (Line 11a scores – Line 11b scores)

Where the difference (Line 11a scores – Line 11b scores) represents the reduction of score imputable to the effect of the exoskeleton on the shoulder.

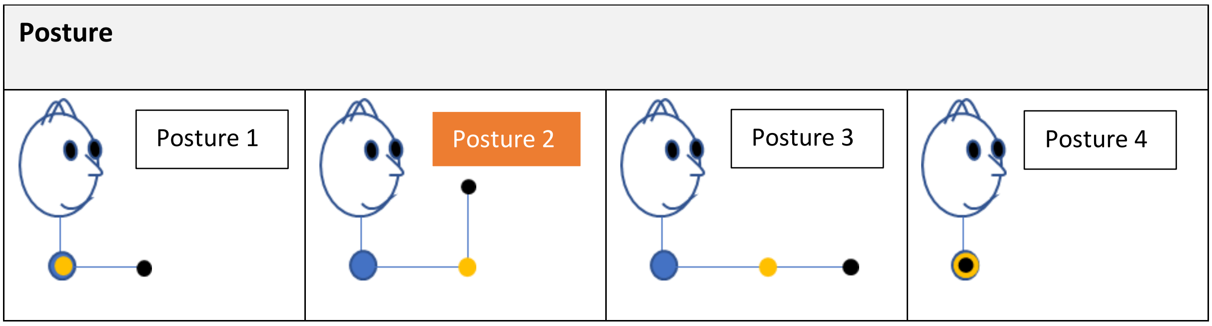



*Figure 20 - Analied shoulder postures*

**SECTION 1**

**STANDING**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | a | Elbow at/above shoulder level | 3,3 | 5 | 8,5 | 12 | 17 | 21 | 30 | 38 | 51 | 63 |
| | b | With certiied exoskeleton | 2,5 | 3,8 | 6,4 | 9,0 | 13,1 | 16,2 | 23,1 | 29,0 | 39,0 | 48,0 |
| | | **RS% w/certified exoskeleton (ref. Line 10)** | **25%** | **24%** | **25%** | **25%** | **23%** | **23%** | **23%** | **24%** | **24%** | **24%** |
| 6 | a | Hands above head level | 5,3 | 8 | 14 | 19 | 26 | 33 | 47 | 60 | 80 | 100 |
| | b | With certiied exoskeleton | 4,1 | 6,2 | 11 | 14,8 | 20 | 25,5 | 36,5 | 46,5 | 62 | 77,5 |
| | | **RS% w/certified exoskeleton (ref. Line 11)** | **23%** | **23%** | **21%** | **22%** | **23%** | **23%** | **22%** | **23%** | **23%** | **23%** |

SITTING

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | a | Elbow at/above shoulder level | 2,7 | 4 | 7 | 10 | 13 | 16 | 23 | 30 | 40 | 50 |
| | b | With certiied exoskeleton | 1,9 | 2,8 | 4,9 | 7,0 | 9,1 | 11,2 | 16,1 | 21,0 | 28,0 | 35,0 |
| | | **RS% w/certified exoskeleton** | **30%** | **30%** | **30%** | **30%** | **30%** | **30%** | **30%** | **30%** | **30%** | **30%** |
| 11 | a | Hands above head level | 4 | 6 | 10 | 14 | 20 | 25 | 35 | 45 | 60 | 75 |
| | b | With certiied exoskeleton | 2,8 | 4,2 | 7 | 9,8 | 14 | 17,5 | 24,5 | 31,5 | 42 | 52,5 |
| | | **RS% w/certified exoskeleton** | **30%** | **30%** | **30%** | **30%** | **30%** | **30%** | **30%** | **30%** | **30%** | **30%** |

CROUCHING

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | a | Elbow at/above shoulder level | 6 | 9 | 16 | 23 | 33 | 43 | 62 | 80 | 108 | 135 |
| | b | With certiied exoskeleton | 5,2 | 7,8 | 13,9 | 20,0 | 29,1 | 38,2 | 55,1 | 71,0 | 96,0 | 120,0 |
| | | **RS% w/certified exoskeleton (ref. Line 10)** | **14%** | **13%** | **13%** | **13%** | **12%** | **11%** | **11%** | **11%** | **11%** | **11%** |

*Figure 21 - Lines affected using the exoskeleton MATE*

### Asymmetric body postures involving shoulder

The asymmetric body posture involving the shoulder is the “far reach” (see Figure 6 - EAWS asymmetric body postures at page 10). In our study, that situation is represented by posture 3 in the following figure.

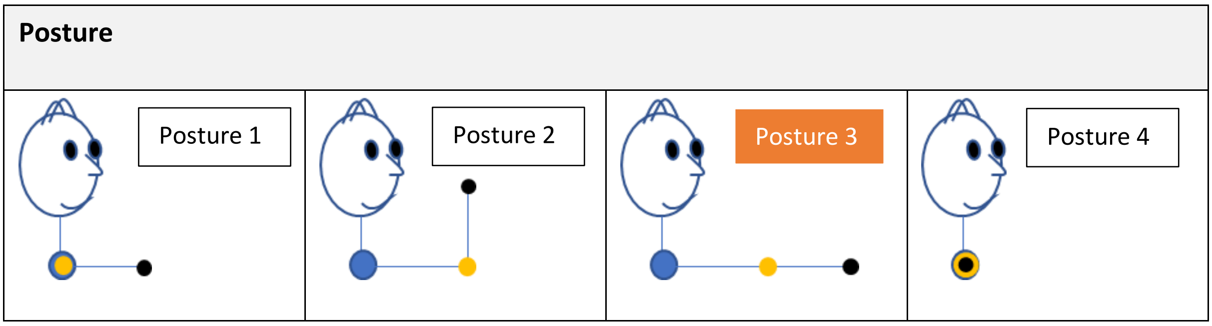



*Figure 22- Analized shoulder postures, asymmetric (far reach)*

In Table 1 - Muscles considered for static conditions and percentage reduction of muscle effort – **Static** at page 24, the percentage reduction for that posture is 28,9%, therefore we set the reference EAWS score reduction at 25% and applied that reduction to the score values of far reach intensity scale (see Figure 23 - Far reach intensity scale).

FAR REACH

| | | | | |
|---|---|---|---|---|
| a | Far Reach intensity | 1 | 3 | 5 |
| b | With certiied exoskeleton | 0,8 | 2,3 | 3,8 |
| | **RS% w/certified exosk. (Far-Reach Intensity scale)** | **25%** | **25%** | **25%** |

*Figure 23 - Far reach intensity scale*

## Section 4

Section 4 deals with the repetitive movements of the upper limbs, which tend to have a dynamic behavior rather than a static one. To set the percentage score reduction (SR%), we refer to

Table 2 - Muscles considered for dynamic conditions and percentage reduction of muscle effort – ***Dynamic*** at page 24.

In Figure 24 we show the calculation of the RS% as the weighted average of the RS% of each posture studied. The weights have been set based on our extensive work analysis experience.

| Posture | 1 | 2 | 3 | 4 | WAVG |
|---|---|---|---|---|---|
| RS% | 33,4% | 23,4% | 28,9% | 31,1% | **25,6%** |
| weight | 10,0% | 70,0% | 15,0% | 5,0% | 100,0% |

*Figure 24 - SR% dynamic actions*

Based on the weighted average result, we set the RS% for the dynamic shoulder postures at 25%.

Line 20b in Section 4 is redesigned as it appears in Figure 25:

**SECTION 4**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 20b | | **Posture points (Duration)** | 10% | 25% | 33% | 50% | 65% | 85% |
| | a | Intensity | 0 | 0,5 | 1 | 2 | 3 | 4 |
| | b | Intensity w/ certified exoskeleton (only for shoulders) | 0,0 | 1,1 | 2,3 | 4,5 | 6,8 | 9,0 |

*Figure 25 - Section 4, Intensity Posture Scores*

## 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. The certification procedure is the procedure that was designed and applied in this study.

**MATE exoskeleton, used to conduct the study, 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. This certification must be renewed whenever MATE exoskeleton undergoes changes.**

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# ESO-EAWS form – Section 1

**Ergonomic Assessment Worksheet v1.3.6**

| **Basic Positions / Postures and movements of trunk and arms (per shift)** | | | | | | | | | | | | | | | | **Postures** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (incl. loads of <3 kg, forces onto fingers of <30 N and w hole body forces of <40 N)<br><br>Static postures: ≥ 4 s<br><br>High frequency movements:<br>Trunk bendings (> 60°) ≥ 2/min<br>Kneeling/crouching ≥ 2/min<br>Arm liftings (> 60°) ≥ 10/min | | | **Symmetric** | | | | | | | | | | Sum of lines | **Asymmetric** | | |
| | | | Evaluation of static postures and/or high frequency movements of trunk/arms/legs<br>*Duration [s/min] = duration of posture [s] × 60 / Task duration [s]* | | | | | | | | | | | Trunk Rotation | Lateral Bending 1) | Far Reach 2) |
| | | | | | | | | | | | | | | int ¦ dur | int ¦ dur | int ¦ dur |
| | | [%] | 5 | 7,5 | 10 | 15 | 20 | 27 | 33 | 50 | 67 | 83 | | 0-5 ¦ 0-3 | 0-5 ¦ 0-3 | 0-5 ¦ 0-2 |
| | | [s/min] | 3 | 4,5 | 6 | 9 | 12 | 16 | 20 | 30 | 40 | 50 | | Intensity × Duration | Intensity × Duration | Intensity × Duration |
| | | [min/8h] | 24 | 36 | 48 | 72 | 96 | 130 | 160 | 240 | 320 | 400 | | | | |
| **Standing (and walking)** | | | | | | | | | | | | | | | | |
| 1 | | Standing & w alking in alteration, standing w ith 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 forw ard (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 forw ard (>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 w ith back support slightly bent forw ard or backw ard | 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 forw ard | 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 forw ard | 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 | | | | |
| **Lying or climbing** | | | | | | | | | | | | | | | | |
| 15 | | (Lying on back, breast or side) arms above head | 6 | 9 | 15 | 21 | 29 | 37 | 53 | 68 | 91 | 113 | | | | |
| 16 | | Climbing | 6,7 | 10 | 22 | 33 | 50 | 66 | | | | | | | | |

| 1) Trunk | 0 | 1 | 3 | 5 | 2) Far Reach | 0 | 1 (0,8) | 3 (2,3) | 5 (3,8) | ∑ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| int | slightly ≤10° | medium 15° | strongly 25° | extreme ≥30° | int | close | 60% | 80% | arm stretched | | ∑ (max.=15) | ∑ (max.=15) | ∑ (max.=10) |
| | 0 | 1,5 | 2,5 | 3 | | 0 | 1 | 1,5 | 2 | | ∑ (max. = 40) | | |
| dur | never 0% | 4 s 6% | 10 s 15% | ≥ 13 s ≥ 20% | dur | never 0% | 4 s 6% | 10 s 15% | ≥ 13 s ≥ 20% | (a) | | | (b) |

note: Max. duration of evaluation = duration of task or 100%!

note: correct evaluation, if task duration ≠ 60 s

| | | | | | |
|---|---|---|---|---|---|
| **Postures = ∑ lines 1 - 16** | (a) | + | (b) | = | |

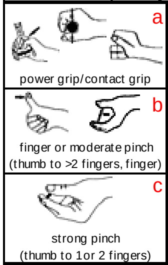
*Figure 26 - ESO-EAWS form, Section 1*

# ESO-EAWS form – Section 4

## Ergonomic Assessment Worksheet v1.3.6

| Upper limb load in repetitive tasks | Upper Limbs |
|---|---|

**Force & Frequency & Grip (FFG)** Basis: number of real actions per minute or percent static actions (analyze only the most loaded limb)




| Legend | | |
|---|---|---|
| | %SA = Percentage of Static Actions | %DA = 100% - %SA |
| | FDS = Force-Duration Static | FFD = Force-Frequency Dynamic |
| | GS' = Modified Grip Points Static (Grip x %SA) | GD = Grip Points Dynamic |
| | %FLS = Percentage of Static Actions at force level | %FLD = Percentage of Dynamic Actions at force level |
| | SC = Static Contribution | DC = Dynamic Contribution |
| | FDGS = Sum of Static Contributions | FFGD = Sum of Dynamic Contributions |

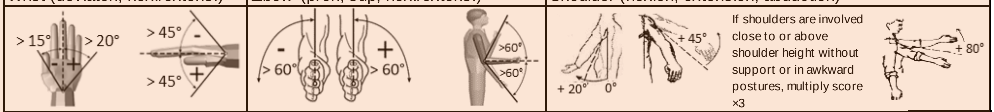
| Force [N] | Calc Stat | | | | Static actions (s/min) | | | | | | Grip | | | Dynamic actions (real actions/min) | | | | | | | | Calc Dyn | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FDS | GS' | %FLS | SC | ≥45 | 30 | 20 | 10 | 5 | 3 | 0 | 2 | 4 | 2-5 | 10 | 15 | 20 | 25 | 30 | 35 | ≥40 | FFD | GD | %FLD | DC |
| 0 – 5 | | | | | 1 | 1 | 0 | 0 | 0 | 0 | abc | | | 0 | 0 | 0 | 1 | 2 | 3 | 4 | 7 | | | | |
| > 5 – 20 | | | | | 4 | 2 | 1 | 1 | 0 | 0 | ab | bc | | 0 | 0 | 1 | 2 | 3 | 4 | 6 | 9 | | | | |
| > 20 – 35 | | | | | 7 | 5 | 3 | 2 | 1 | 1 | ab | b | c | 0 | 1 | 2 | 3 | 4 | 6 | 8 | 12 | | | | |
| > 35 – 90 | | | | | 11 | 8 | 5 | 3 | 2 | 1 | a | b | b | 1 | 2 | 3 | 5 | 7 | 9 | 12 | 18 | | | | |
| > 90 – 135 | | | | | 16 | 11 | 7 | 4 | 3 | 2 | a | ab | b | 2 | 3 | 5 | 7 | 9 | 12 | 15 | ***24*** | | | | |
| > 135 – 225 | | | | | ***21*** | 14 | 10 | 6 | 4 | 3 | a | a | b | 4 | 5 | 6 | 8 | 11 | 14 | ***20*** | ***32*** | | | | |
| > 225 – 300 | | | | | ***28*** | 18 | 12 | 8 | 5 | 4 | a | a | b | 5 | 6 | 7 | 9 | 12 | 16 | ***26*** | ***40*** | | | | |

| 20a | $FDGS = \sum SC_i$ | 100% | | **FFG** = FDGS + FFGD | FFG | %DA = ΣFLDj | $FFGD = \sum DC_j$ | %DA | |
|---|---|---|---|---|---|---|---|---|---|

**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) |
|---|---|---|




| **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 | |

**Additional factors**

| 20c | | | |
|---|---|---|---|
| | Gloves inadequate (which interfere with the handling ability required) are used for over half the time | 2 | ☐ |
| | Working gestures required imply a countershock. Frequency of 2 time per minute or more (i.e.: hammering over hard surface | 2 | ☐ |
| | Working gestures imply a countershock (using the hand as a tool) with freq. of 10 time per hour or more | 2 | ☐ |
| | Exposure to cold or refrigeration (less than 0 degree) for over half the time | 2 | ☐ |
| | Vibrating tools are used for 1/3 of the time or more | 2 | ☐ |
| | Tools with a very high level of vibrations | 4 | ☐ |
| | Tools employed cause compressions of the skin (rednesses, callosities, blebs, etc.) | 2 | ☐ |
| | Precision tasks are carried out for over half the time (tasks over areas smaller than 2-3 mm) | 2 | ☐ |
| | More than one additional factor is present at the same time and overall occupy the whole of the time | 3 | ☐ |
| | **Additional points (choose the highest value)** | = | AF |

**Repetitive tasks duration**

| 20d | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Net Duration [min/shift] | < 60 | 90 | 180 | 300 | 420 | > 480 | | | + | |
| | *Duration Points* | 1 | 1,5 | 3 | 5 | 7 | 10 | | | | |
| | Work Organization | Breaks are possible at every time (Cycle time longer than 10 minutes) | | Breaks are possible at given conditions (Cycle time between 1 and 10 minutes) | | Breaks lead to a stop of the process (Cycle time shorter than 1 minute) | | | | + | |
| | *Work Organization Points* | 0 | | 1 | | 2 | | | | | |
| | Breaks (≥ 8 min) [#/shift] | 0 | 1 | 2 | 3 | 4 | 5 | 6 | ≥7 | + | |
| | *Break points* cycle time ≤ 30 s | 3 | 2 | 1 | 0 | -1 | -2 | -3 | -4 | | |
| | cycle time > 30 s | 0 | | -0,5 | | -1 | | -1,5 | -2 | | |
| | **Duration Points** | | | | | | | | | = | DP |

**Upper limb load in repetitive tasks**

| 20 | (a) Force & Frequency & Grip | | (b) Postures | | (c) Additional factors | | (d) Duration | | Upper Limbs |
|---|---|---|---|---|---|---|---|---|---|
| | ( FFG | + | PP | + | AF ) | × | DP | = | |

*Figure 27 - ESO-EAWS form, Section 4*