Exoskeletons impacts on EAWS evaluation

Latest update: 04/08/2021

1.1 Introduction

Importance of Ergonomics
Despite the on-going trend in automation in industry, many workers are still exposed to physical workloads. Manual handling activities are associated with high rates of Work-Related Musculoskeletal Disorders (WMSDs) (Zurada, 2012; Collins and O'Sullivan, 2015). Across the EU 44M workers have MSDs which are caused by their work.

Aging population
According to the World Health Organization, world's population is aging rapidly, particularly in developed countries. By the year 2050, the number of people over 65 years old will increase by 73% in developed countries and by 20,7% worldwide. By 2030 a high percentage of the ageing EU workforce will have a long-term or chronic health condition which will affect their productivity.
It is increasingly important to understand how to manage workforce efficiently.

Exoskeleton is a potential solution
There is an increasing interest in employing exoskeletons for workplace ergonomics to reduce the physical loads, fatigue and risk of injury for workers. Exoskeletons are mechanical structures external to the human body. These devices, originally conceived for military and medical applications, are of interest in the industrial field as they may support body parts during working tasks. At present, several manufacturing companies are testing the implementation of exoskeletons.
The modern technology of exoskeletons has a limited field of research and knowledge and is in need to be studied to provide stakeholders with proper findings for understanding the impact, the acceptability and the applicability. Up to now, **few studied are made on a systematic adoption** of exoskeleton.
The introduction of exoskeleton has already provoked questions and debate from trade unions, ergonomists, companies and exoskeleton-makers. This change is progressively having an impact on jobs. What does this change mean for workers and for companies?

One of the most important open challenges can be summarized in the question: *"How are ergonomic measurement tool impacted with the use of exoskeletons?"*
From this open question Fondazione Ergo decided to launch the ESO-EAWS Project: the purpose of this study is to evaluate how the EAWS (Ergonomic Assessment Work-Sheet) ergonomic risk assessment index changes with the use of an exoskeleton.
The first body region which has been selected is the shoulder and the exoskeleton used is MATE (passive exoskeleton for the upper limbs). The objective of the project is to study and measure the quantitative impact on the EAWS system and set a procedure to certify any exoskeleton which has sufficient characteristics to have the same level of impact on EAWS.

1.1.1 Types of exoskeleton

The Eso-EAWS form and rules can be applied only to certified exoskeletons, which are classified in categories. The first category is the S-01, which is defined through the following characteristics:

S-01 (SHOULDER, PASSIVE)
Key characteristics

- 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 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
  - limited weight
  - no or very limited encumbrance outside the operator's body;
  - no entanglement prone protruding parts
- FIELD OF APPLICATION
  - handling of loads with a weight < 3 kg
  - standing body posture
  - sitting or crouching/kneeling body posture, if the exoskeleton does not interfere
  - manual task which generates awkward postures (static and dynamic) of the shoulder with a duration of at least 1/3 of the cycle time (recommendation)

Currently the certified exoskeletons are listed in the following table:

Exo Type	Exoskele-ton name	Manufacturer	Release	EAWS lines impacted
S-01	MATE	COMAU https://www.co-mau.com/en/our-compe-tences/robotics/exoskele-ton	1.0 (CR00758209-en_00/2018.12)	Sec. 1: 5,6, 10,11, 14 Sec. 4: 20b
S-01	MATE XT	COMAU https://www.co-mau.com/en/our-compe-tences/robotics/exoskele-ton ps://www.co-mau.com/en/our-compe-tences/robotics/exoskele-ton		Sec. 1: 5,6, 10,11, 14 Sec. 4: 20b

S-01	PAEXO SHOULDER	OTTOBOCK https://paexo.com/paexo-shoulder/?lang=it	1.0 (911927A-01-EN-01-1909)	Sec. 1: 5,6, 10,11, 14 Sec. 4: 20b

1.2 ESO-EAWS form and calculation: MATE – MATE XT certification

The name of the EAWS release considering the exoskeleton impact is "Eso-EAWS form 1.3.6"

1.2.1 Perimeter of application

Whole Body

- Section 1 – Body Postures
- Section 0 – Extra Points

Ergonomic Assessment Worksheet v1.3.6

Basic Positions / Postures and movements of trunk and arms (per shift) (incl. loads of <3 kg, forces onto fingers of <30 N and whole body forces of <40 N)				Symmetric: Evaluation of static postures and/or high frequency movements of trunk/arms/legs. Duration [s/min] = duration of posture [s] × 60 / Task duration [s]										Sum of lines	Asymmetric: Trunk Rotation	Lateral Bending 1)	Far Reach 2)
Static postures: ≥ 4 s High frequency movements: Trunk bendings (> 60°) ≥ 2/min Kneeling/crouching ≥ 2/min Arm liftings (> 60°) ≥ 10/min				[%]	5	7,5	10	15	20	27	33	50	67	83		int dur	int dur	int dur
				[s/min]	3	4,5	6	9	12	16	20	30	40	50		0-5 0-3	0-5 0-3	0-5 0-2
				[min/8h]	24	36	48	72	96	130	160	240	320	400		Intensity × Duration	Intensity × Duration	Intensity × Duration
Standing (and walking)																		
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																		
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																		
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				

1) Trunk

	int	dur
0	slightly ≤10°	never 0%
1	medium 15°	4 s 6%
3	strongly 25°	10 s 15%
5	extreme ≥30°	≥ 13 s ≥ 20%

2) Far Reach

	int	dur
0	close	never 0%
1 (0,8)	60%	4 s 6%
3 (2,3)	80%	10 s 15%
5 (3,8)	arm stretched	≥ 13 s ≥ 20%

Σ (a) | Σ (max.=15) | Σ (max.=15) | Σ (max.=10) | Σ (max. = 40) (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 1 - ESO-EAWS Section 1, impacted lines

EAWS application rules do not change.
If MATE exoskeleton is worn, then use values reported in lines 5b, 6b, 10b,11b, 14b if shoulder posture respectively is analyzed with line 5, 6, 10, 11 or 14.
Lines 5, 6, 10, 11 or 14 become lines 5a, 6a, 10a, 11a and 14a.

Section 1 – Line 5 and Line 6

Added lines 5b and 6b. EAWS lines 5 and 6 (without exoskeleton) are renamed line 5a and 6a.

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

Section 1 – Line 10 and Line 11

Added lines 10b and 11b. EAWS lines 10 and 11 (without exoskeleton) are renamed line 10a and 11a.

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

Section 1 – Line 14

Added line 14b. EAWS line 14 (without exoskeleton) is renamed line 14a.

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

Section 1 – Far Reach intensity score

With reference to Table 1 here below, in Section 1, the Far Reach intensity scale shows the original values (without exoskeleton) and, in brackets, the intensity values if using MATE exoskeleton

Table 1 Far reach, Table 2 in EAWS Section 1

2)					
Far Reach	int	**0**	**1 (0,8)**	**3 (2,3)**	**5 (3,8)**
		close	60%	80%	arm stretched
	dur	**0**	**1**	**1,5**	**2**
		never	4 s	10 s	≥ 13 s
		0%	6%	15%	≥ 20%

1.2.2 Extra points "Whole body"

The use of an exoskeleton generates a tradeoff, where the positive effect of reducing the biomechanical 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 MATE 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[1] 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 a Yes/NO criteria.

1.2.3 S-01 type exoskeleton scoring

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 INTERFACE

[1] Other score can apply in special conditions. See next paragraph for further details.

  - 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 exoskeleton = 2 points (1 Base Value + 1 point)

1.2.4 Application rules in Section 4

Upper limbs
Added shoulder posture points with exoskeleton (line 20b).

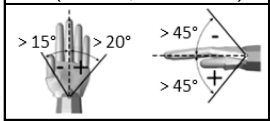
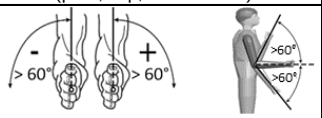
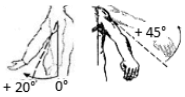
Hand / arm / shoulder postures (use duration for worst case of wrist / elbow / shoulder)								
20b	Wrist (deviaton, flex./extens.) 		Elbow (pron, sup, flex./extens.) 		Shoulder (flexion, extension, abduction)  If shoulders are involved close to or above shoulder height without support or in awkward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

Figure 2 - ESO/-EAWS Section 4, impacted line

1.3 ESO-EAWS form and calculation: PAEXO Shoulder certification

The name of the EAWS release considering the exoskeleton impact is "Eso-EAWS form 1.3.6"

1.3.1 Perimeter of application

Whole Body
- Section 1 – Body Postures
- Section 0 – Extra Points

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 whole body forces of <40 N) Static postures: ≥ 4 s High frequency movements: Trunk bendings (> 60°) ≥ 2/min Kneeling/crouching ≥ 2/min Arm liftings (> 60°) ≥ 10/min	**Symmetric** Evaluation of static postures and/or high frequency movements of trunk/arms/legs *Duration [s/min] = duration of posture [s] × 60 / Task duration [s]*	**Sum of lines**	**Asymmetric** Trunk Rotation 1) / Lateral Bending 1) / Far Reach 2)	

				[%]	5	7,5	10	15	20	27	33	50	67	83		int 0-5 / dur 0-3	int 0-5 / dur 0-3	int 0-5 / dur 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)																		
5		a	Elbow at/above shoulder level		3,3	5	8,5	12	17	21	30	38	51	63				
		b	With certif. exoskeleton		2,2	3,4	5,7	8,0	11,8	14,6	20,8	26,0	35,0	43,0				
6		a	Hands above head level		5,3	8	14	19	26	33	47	60	80	100				
		b	With certif. exoskeleton		3,7	5,6	10,0	13,4	18,0	23,0	33,0	42,0	56,0	70,0				
Sitting																		
10		a	Elbow at / above shoulder level		2,7	4	7	10	13	16	23	30	40	50				
		b	With certif. exoskeleton		1,6	2,4	4,2	6,0	7,8	9,6	13,8	18,0	24,0	30,0				
11		a	Hands above head level		4	6	10	14	20	25	35	45	60	75				
		b	With certif. exoskeleton		2,4	3,6	6,0	8,4	12,0	15,0	21,0	27,0	36,0	45,0				
Kneeling or crouching																		
14		a	Elbow at / above shoulder level		6	9	16	23	33	43	62	80	108	135				
		b	With certif. exoskeleton		4,9	7,4	13,2	19,0	27,8	36,6	52,8	68,0	92,0	115				

1) Trunk

	0	1	3	5
int	slightly ≤10°	medium 15°	strongly 25°	extreme ≥30°
dur	0 never 0%	1,5 4 s 6%	2,5 10 s 15%	3 ≥ 13 s ≥ 20%

2) Far Reach

	0	1 (0,7)	3 (2)	5 (3,3)
int	close	60%	80%	arm stretched
dur	0 never 0%	1 4 s 6%	1,5 10 s 15%	2 ≥ 13 s ≥ 20%

Σ (a) — Σ (max.=15) — Σ (max.=15) — Σ (max.=10) — Σ (max. = 40) (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 3 - ESO-EAWS Section 1, impacted lines

EAWS application rules do not change.
If PAEXO Shoulder exoskeleton is worn, then use values reported in lines 5b, 6b, 10b,11b, 14b if shoulder posture respectively is analyzed with line 5, 6, 10, 11 or 14.
Lines 5, 6, 10, 11 or 14 become lines 5a, 6a, 10a, 11a and 14a.

Section 1 – Line 5 and Line 6

Added lines 5b and 6b. EAWS lines 5 and 6 (without exoskeleton) are renamed line 5a and 6a.

5		*a*	Elbow at/above shoulder level	3,3	5	8,5	12	17	21	30	38	51	63
		b	With certif. exoskeleton	2,2	3,4	5,7	8,0	11,8	14,6	20,8	26,0	35,0	43,0
6		a	Hands above head level	5,3	8	14	19	26	33	47	60	80	100
		b	With certif. exoskeleton	3,7	5,6	10,0	13,4	18,0	23,0	33,0	42,0	56,0	70,0

Section 1 – Line 10 and Line 11

Added lines 10b and 11b. EAWS lines 10 and 11 (without exoskeleton) are renamed line 10a and 11a.

10		*a*	Elbow at / above shoulder level	2,7	4	7	10	13	16	23	30	40	50
		b	With certif. exoskeleton	1,6	2,4	4,2	6,0	7,8	9,6	13,8	18,0	24,0	30,0
11		a	Hands above head level	4	6	10	14	20	25	35	45	60	75
		b	With certif. exoskeleton	2,4	3,6	6,0	8,4	12,0	15,0	21,0	27,0	36,0	45,0

Section 1 – Line 14

Added line 14b. EAWS line 14 (without exoskeleton) is renamed line 14a.

14		a	Elbow at / above shoulder level	6	9	16	23	33	43	62	80	108	135
		b	With certif. exoskeleton	4,9	7,4	13,2	19,0	27,8	36,6	52,8	68,0	92,0	115

Section 1 – Far Reach intensity score

With reference to Table 2 here below, in Section 1, the Far Reach intensity scale shows the original values (without exoskeleton) and, in brackets, the intensity values if using a PAEXO Shoulder exoskeleton

Table 2 Far reach, Table 2 in EAWS Section 1

2)					
Far Reach	int	**0**	**1 (0,7)**	**3 (2)**	**5 (3,3)**
		close	60%	80%	arm stretched
	dur	**0**	**1**	**1,5**	**2**
		never	4 s	10 s	≥ 13 s
		0%	6%	15%	≥ 20%

1.3.2 Extra points "Whole body"

The use of an exoskeleton generates a tradeoff, where the positive effect of reducing the biomechanical 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 PAEXO Shoulder 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[2] 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;

[2] Other score can apply in special conditions. See next paragraph for further details.

  - 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 a Yes/NO criteria.

1.3.3 S-01 type exoskeleton scoring

The Extra points for wearing a S-01 type 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

  Full support unfolds from 60 degree upwards.
- 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 < 3 kg = **0 points**
  - no or very limited encumbrance outside the operator's body;
  - no entanglement prone protruding parts

Total extra points for Paexo Shoulder exoskeleton = 1 point (Base Value)

1.3.4 Application rules in Section 4

Upper limbs

Added shoulder posture points with exoskeleton (line 20b).

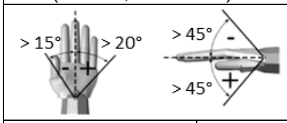
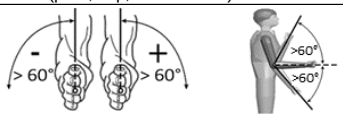
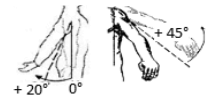
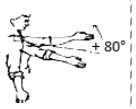
Hand / arm / shoulder postures (use duration for worst case of wrist / elbow / shoulder)								
	Wrist (deviaton, flex./extens.)		Elbow (pron, sup, flex./extens.)			Shoulder (flexion, extension, abduction)		
20b						 If shoulders are involved close to or above shoulder height without support or in awkward postures, multiply score ×3 		
	Posture points	10%	25%	33%	50%	65%	85%	PP
	Wrist/Elbow	0	0,5	1	2	3	4	
	Shoulder	0	1,5	3	6	9	12	
	Shoulder w/exosk	0	1,2	2,4	4,8	7,2	9,6	

Figure 4 - ESO/-EAWS Section 4, impacted line