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Emerging risks in industry 4.0:
innovative approaches for safety and security

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Developing exoskeletons for the industry of today

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RoboMate XoSoft INAIL ISTITUTO NAZIONALE PER L'ASSICURAZIONE CONTRO GLI INFORTUNI SUL LAVORO esa

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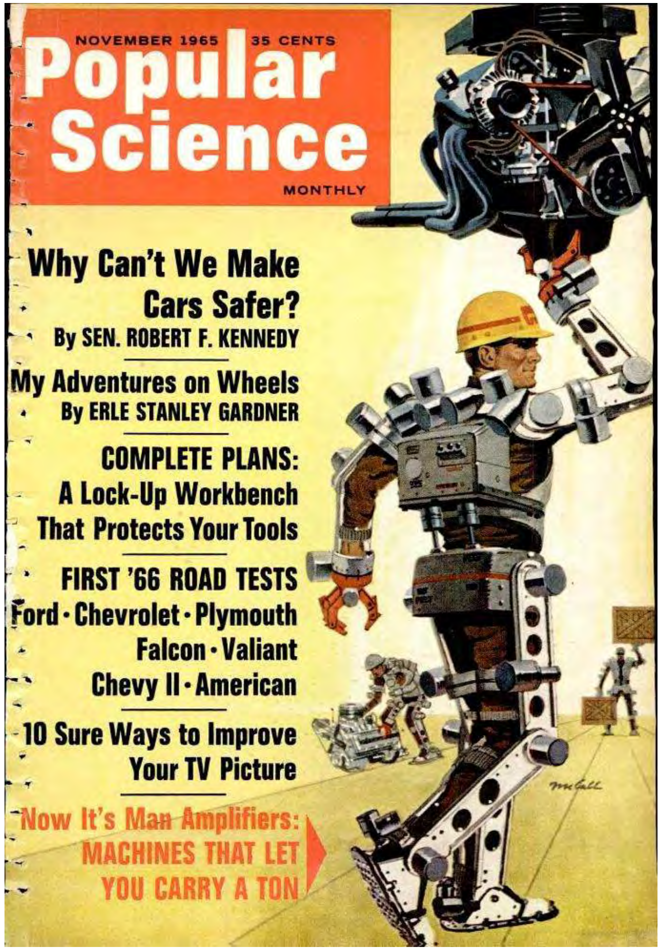
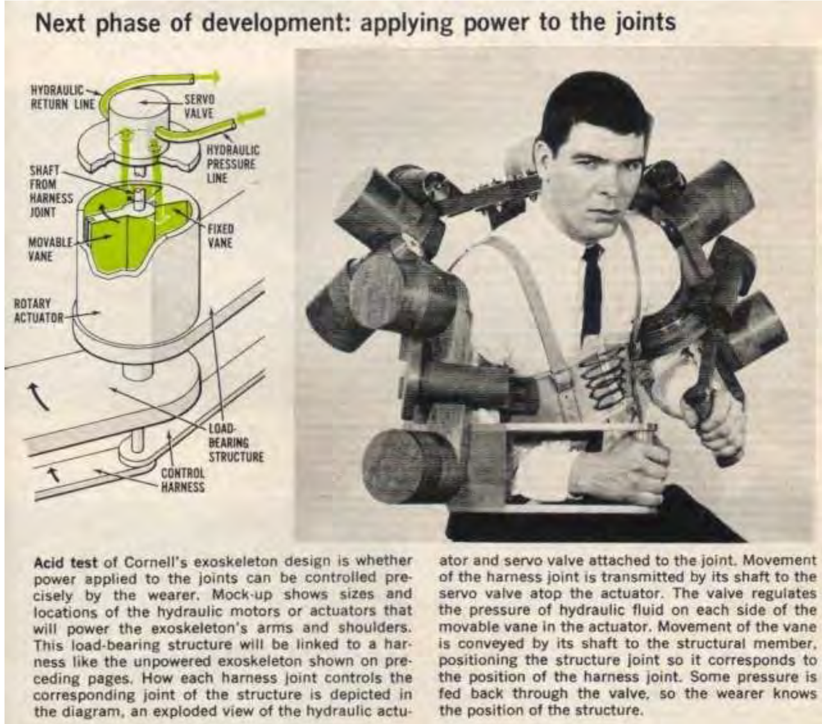
Exoskeletons - First concepts



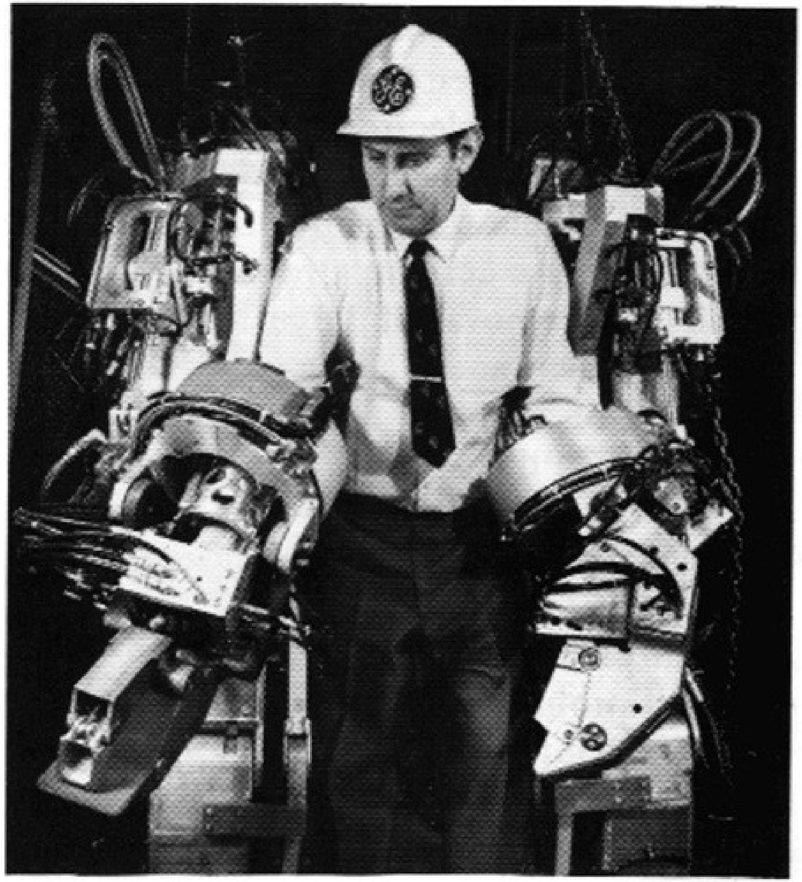


Next phase of development: applying power to the joints

Acid test of Cornell's exoskeleton design is whether power applied to the joints can be controlled precisely by the wearer. Mock-up shows sizes and locations of the hydraulic motors or actuators that will power the exoskeleton's arms and shoulders. This load-bearing structure will be linked to a harness like the unpowered exoskeleton shown on preceding pages. How each harness joint controls the corresponding joint of the structure is depicted in the diagram, an exploded view of the hydraulic actuator and servo valve attached to the joint. Movement of the harness joint is transmitted by its shaft to the servo valve atop the actuator. The valve regulates the pressure of hydraulic fluid on each side of the movable vane in the actuator. Movement of the vane is conveyed by its shaft to the structural member, positioning the structure joint so it corresponds to the position of the harness joint. Some pressure is fed back through the valve, so the wearer knows the position of the structure.

Man amplifier
Cornell University's Aeronautical Lab, early 1960s

Exoskeletons - First concepts

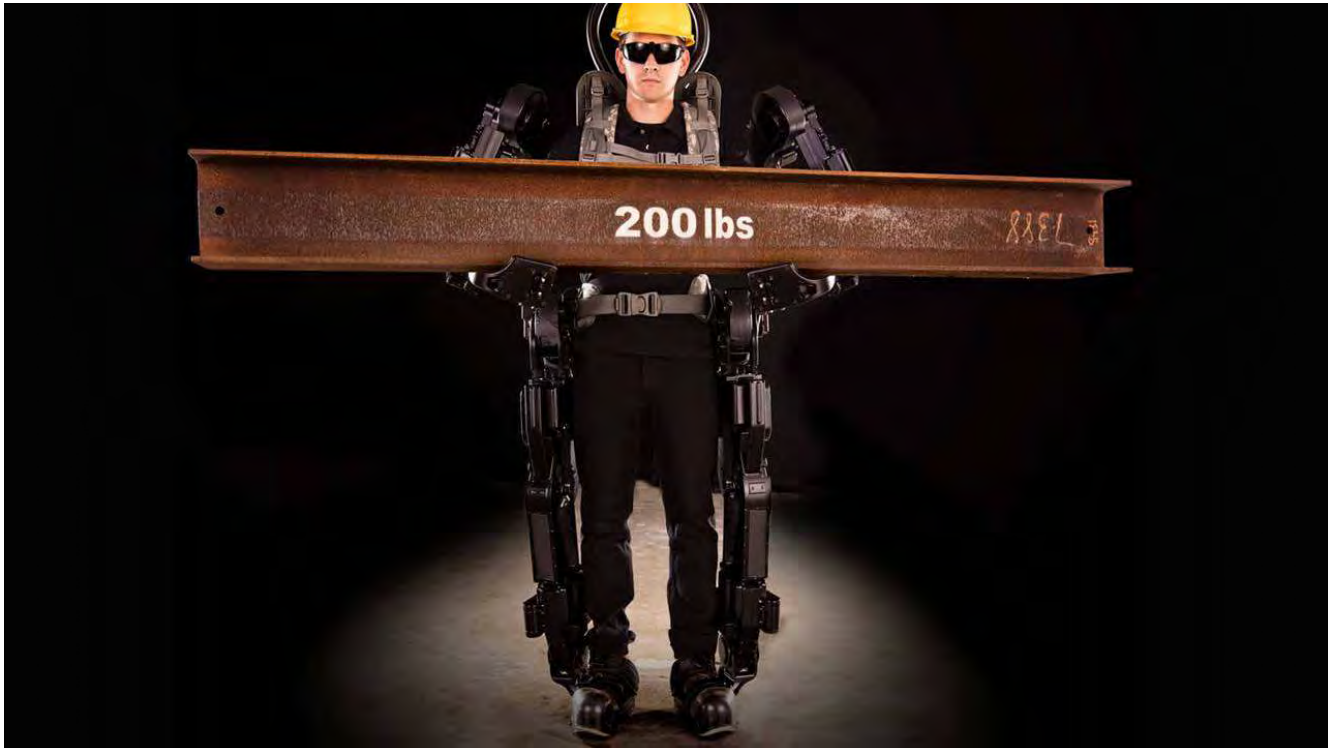


Hardiman, General Electric, 1965

Exoskeletons - Military

Sarcos, XOS 2, 2010

Exoskeletons - Construction



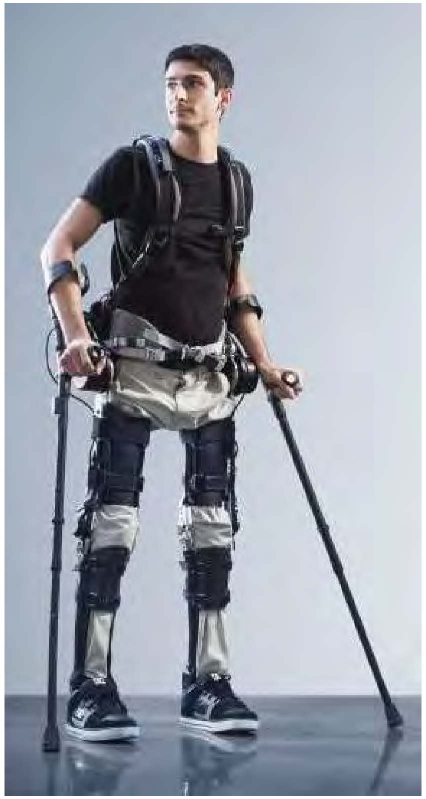
Sarcos, Guardian XO, 2019

Exoskeletons - Rehabilitation

Ekso GT
Ekso Bionics, 2016

ReWalk Personal 6.0
ReWalk, 2016

REX
REX Bionics, 2016



PhoeniX
SuiX, 2016

Exoskeletons - Characteristics

Full powered exoskeletons
(rehabilitation, military, augmentation, …)

- Provide full support/power
- Follow body kinematics
- Actuate all/most of the joints
- High energy requirements (battery)

Exoskeletons - Characteristics

Passive exoskeletons
(prevention)

- ~~Provide full support/power~~ → Provide only partial support
- ~~Follow body kinematics~~ → Non anthropomorphic design
- ~~Actuate all/most of the joints~~ → Actuate only a few joints
- ~~High energy requirements (battery)~~ → Passive actuation

Exoskeletons - Passive

Laevo V2
Laevo, 2019

LegX
SuitX, 2019

MATE
Comau, 2019

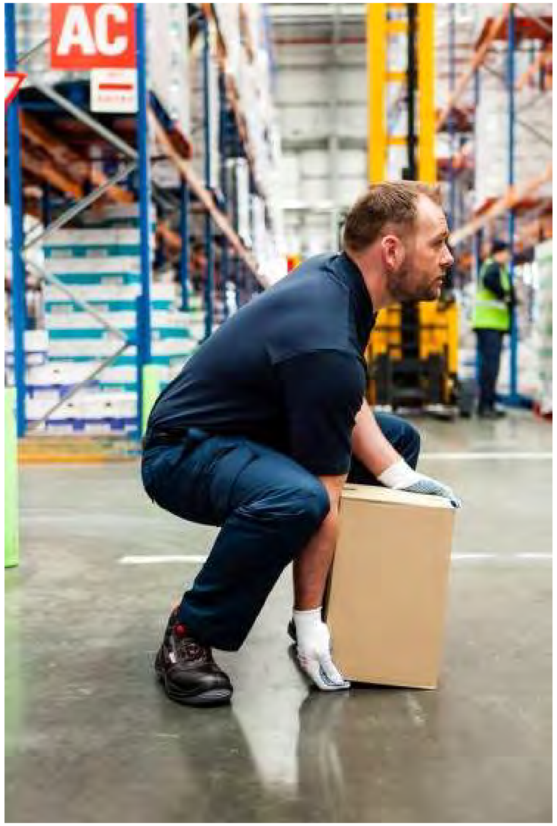
Exoskeleton design

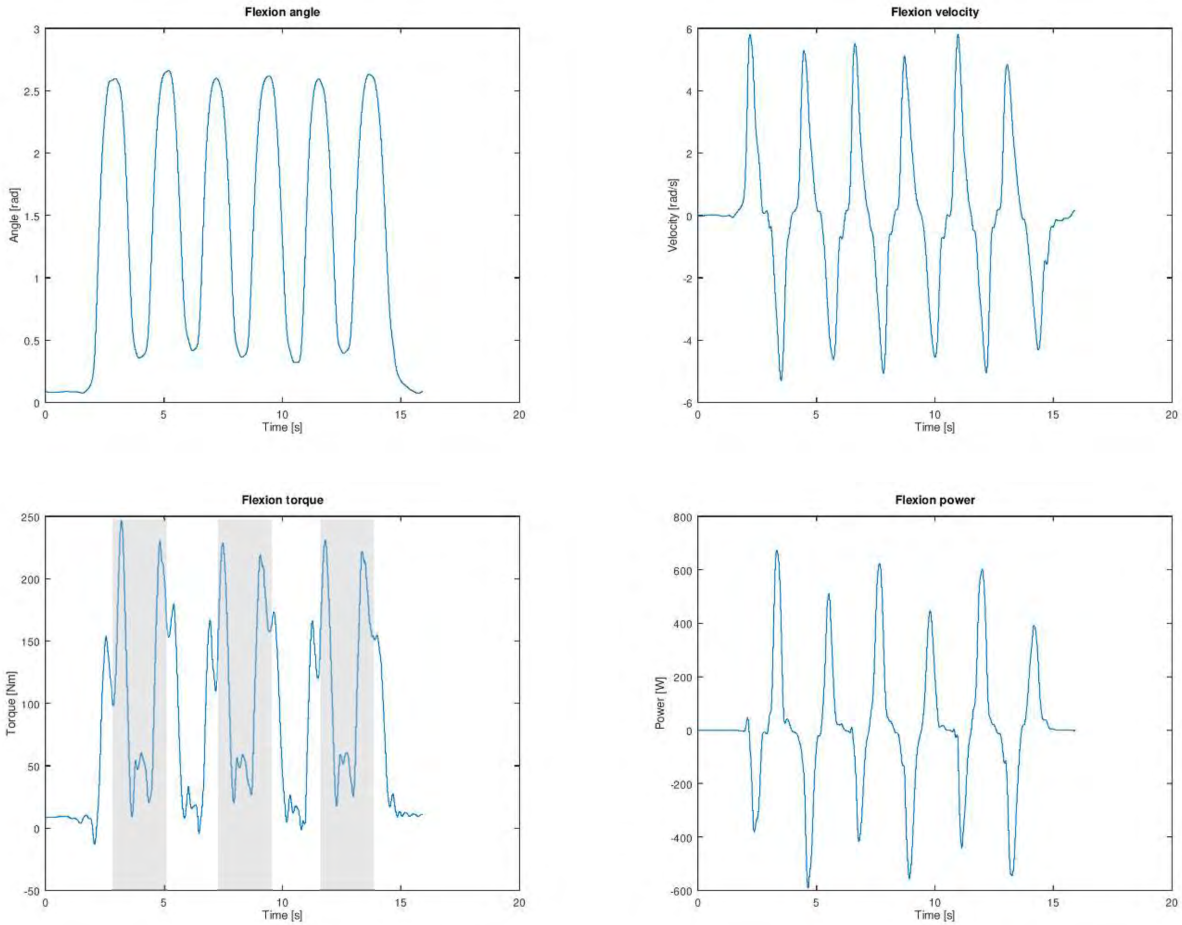
Full powered exoskeletons	Passive exoskeletons
High level of assistance	Low level of assistance
Adaptable	Task specific
High energy requirements	No energy required
Heavy	Lightweight
Bulky	Slim design

Exoskeleton design

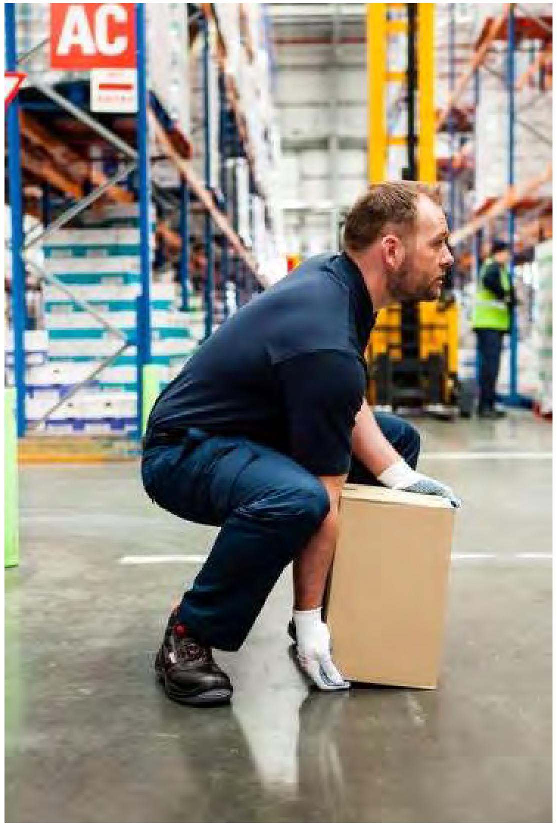
Full powered exoskeletons		Passive exoskeletons
High level of assistance	?	Low level of assistance
Adaptable		Task specific
High energy requirements		No energy required
Heavy		Lightweight
Bulky		Slim design

Lifting example





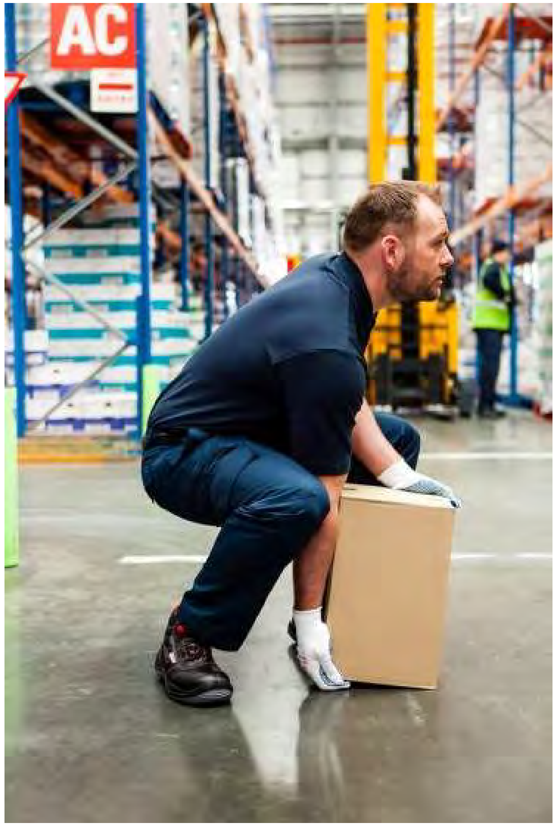
Lifting example



Requirements:

- Maximum velocity = ~6 rad/s
- Maximum torque = ~250 Nm
- Maximum power > 600 W
- Cycle energy (positive power) = ~200 J
- Full freedom of movement
  (6 DoF per segment)

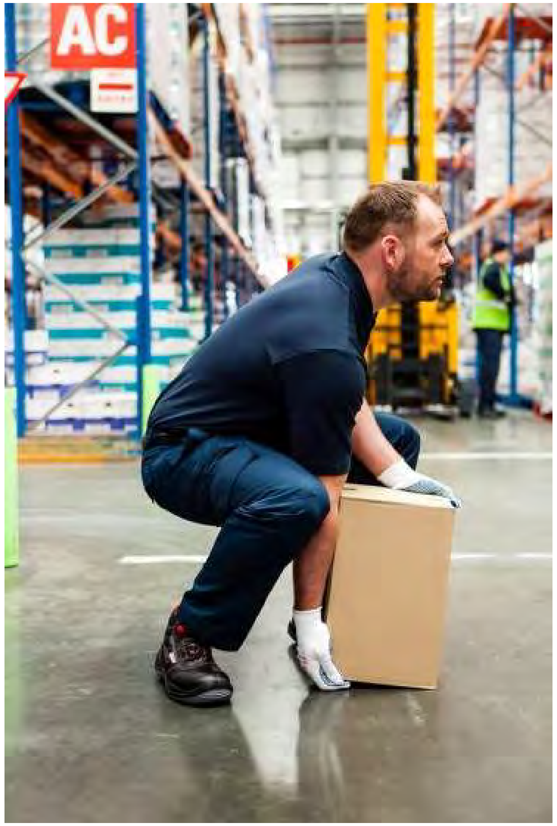
Lifting example



Actuation selection (1 motor per side):

- Motor power = 600 W
- Motor speed = 2080 rpm
- Motor torque = 1.56 Nm
- Gear ratio = 1:80 (1:35)
- Output speed = 2.7 rad/s (6.2 rad/s)
- Output torque = 124.8 Nm (54.6 Nm)
- Motor weight = 1 Kg
- Gears weight = 1.5 Kg
- Unit weight = 3 Kg

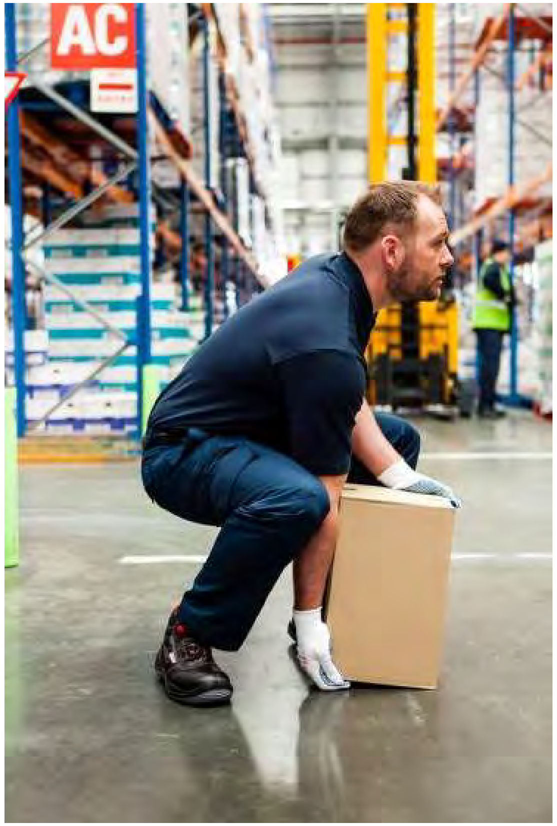
Lifting example



Battery selection:

- Autonomy = 8 hours
- Energy storage = 10 AH
- Energy density = 2.5 AH/Kg
- Weight = 4 Kg

Lifting example



System weight:

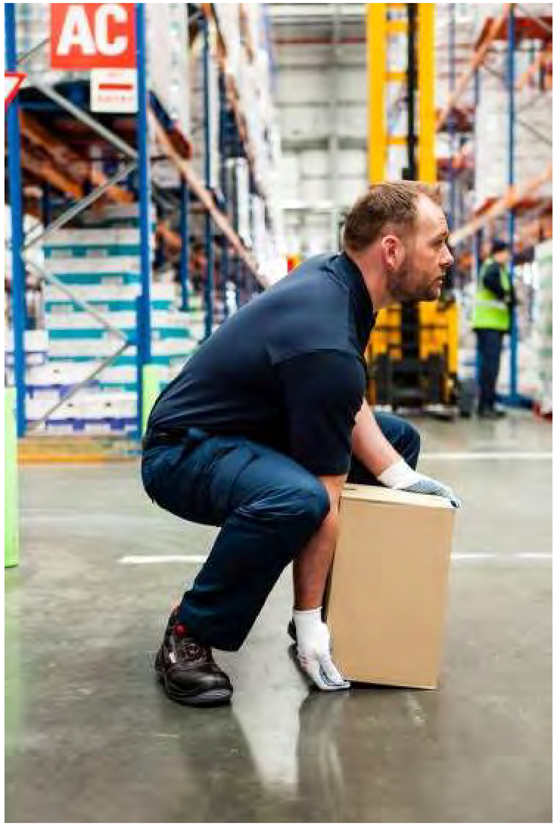
- Actuation = 6 Kg
- Battery = 4 Kg
- Structure = 10 Kg
- Others = 4 Kg
  (electronics, CPU, cables, sensors, garment, attachments, ...)
- Total = 24 Kg!

Robo-Mate - First prototype

Problems

- Too much weight (> 20 Kg)
- Too complex mechanism (12 passive joints)
- Too complex construction
- Bad weight distribution (waist)
- Too slow actuation (not for walking)

Requirements review



Requirements:

- Maximum velocity ~~= ~6 rad/s~~ > 6 rad/s
- Maximum torque ~~= ~250 Nm~~ ~60 Nm
- Maximum power ~~> 600 W~~ ~200 W
- Cycle energy (positive power) = ~50 J
- ~~Full~~ freedom of movement
  ~~(6 DoF per segment)~~

Robo-Mate - Final prototype

Improvements

- Lighter
- Simpler mechanism
- Simpler construction
- Good weight distribution
- Good actuation speed
  (walking OK, but not running or jumping)
- Reduction of back muscles activity by ~30%

Problems

- Still too heavy

Beyond Robo-Mate

Improvements

- Better integration
- Reduced further weight
  (no parallel spring mechanism)
- Reduced encumbrance

Problems

- Still too heavy (11 Kg)

Sistemi Cibernetici Collaborativi

Improvements

- Actuation + electronics
- Performance
- Weight (6 Kg)
- Comfort
- Battery support (+1 Kg)

Requirements Vs. Characteristics

Usability	Characteristics
Comfort	Attachments
Total weight	Structure and actuator
Weight distribution	Attachments and kinematics
Transparency	Actuation/low-level control
Intuitiveness	High-level control

Requirements Vs. Characteristics

Industrial compatibility	Characteristics
Standards	Certified components Comformity tests
Task	Kinematics, actuation, control and battery
Space requirements	Actuation and structure shape

Example 1

Manufacturing

- Machines in series
- Lifting 10-15 Kg
- Carrying short distance
- Body rotation
- Walking without load

Example 1 - Characteristics

Manufacturing

- Transparency
- Weight
- Autonomy

Example 2

Warehouse

- Picking (pulling and lifting) 5-15 Kg
- Limited working space
  (inside order-pick)

Example 2 - Characteristics

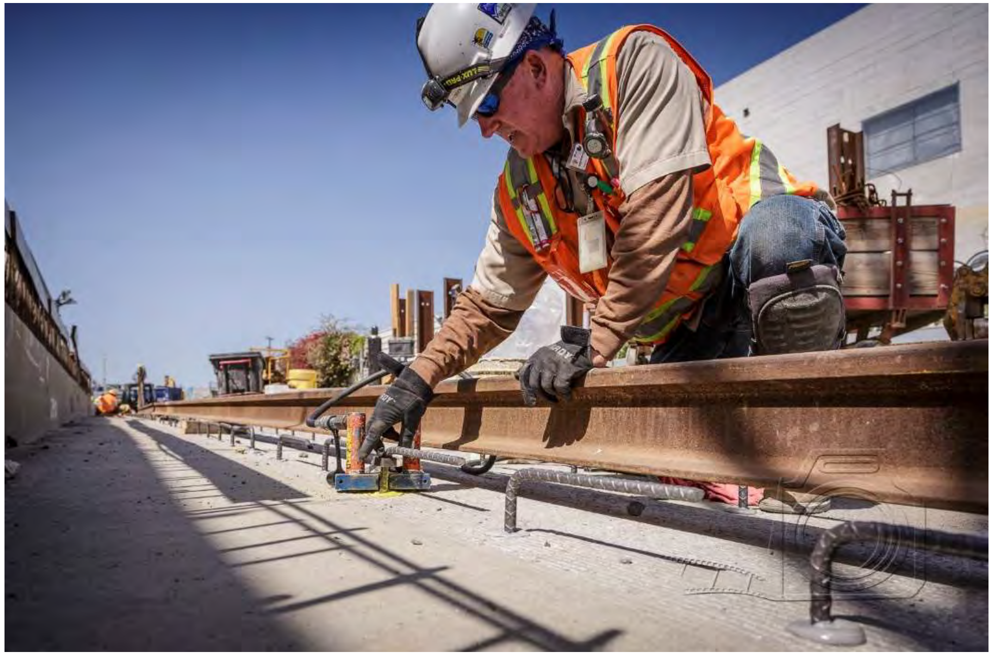
Warehouse

- Dimension limitations
- Modified control system to allow pulling
- No autonomy requirements
- Weight less important

Example 3

Outdoor maintenance/construction

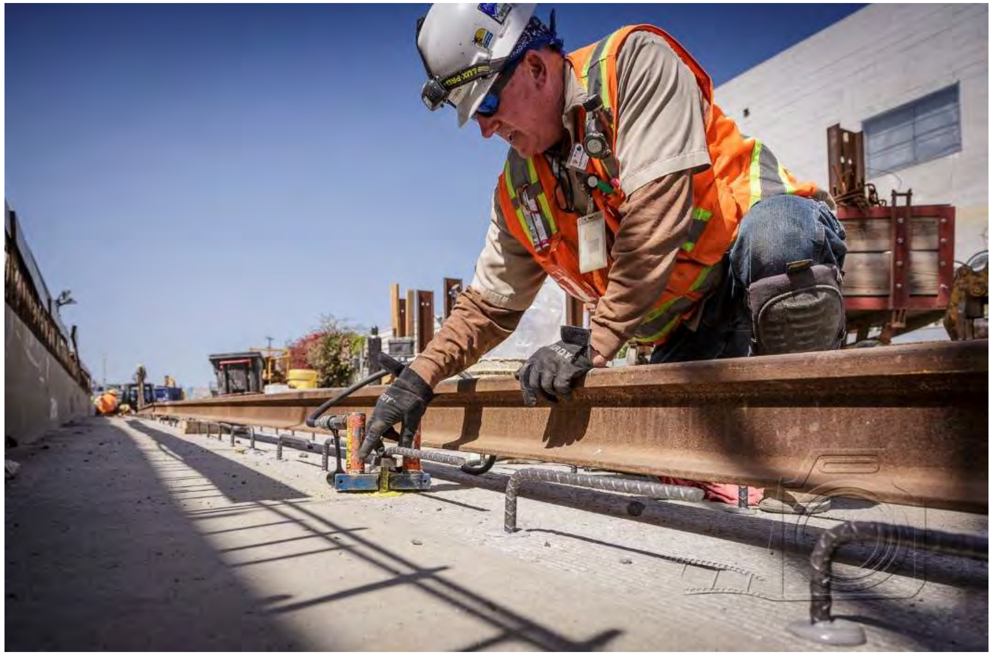
- Lifting
- Postural support
- Walking
- <u>Environment conditions</u>



Example 3 - Characteristics

Outdoor maintenance/construction

- Freedom of movement
- Transparency
- Weight
- Autonomy
- Protection to dust and rain (IP67)



Conclusions

Difficult to design a “one size fits all” exoskeleton

Basic system with modifications

Understand the task

Focus on the requirements

Test/demo as soon as possible with operators

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