# ELITE II – Enhancement LITe Exoskeleton

## Design and Development of an Exoskeleton to Support Human Movement


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TÉCNICO LISBOA
Laeta
laboratório associado

# ELITE II – Enhancement LITe Exoskeleton

## Motivation


Helmet and eye protection

+

Ballistic protection, water,…

+

Rifle and ammunition

+

Boots and uniform

= >40 kg


> Reaction forces

> Moment forces

> Metabolic costs

> Risk of injury

[3] Quinto, L., Gonçalves, S. and Silva, M., "Exoesqueletos para membros inferiores: Estado da arte", Congresso Nacional de Biomecânica, Guimarães, 2017

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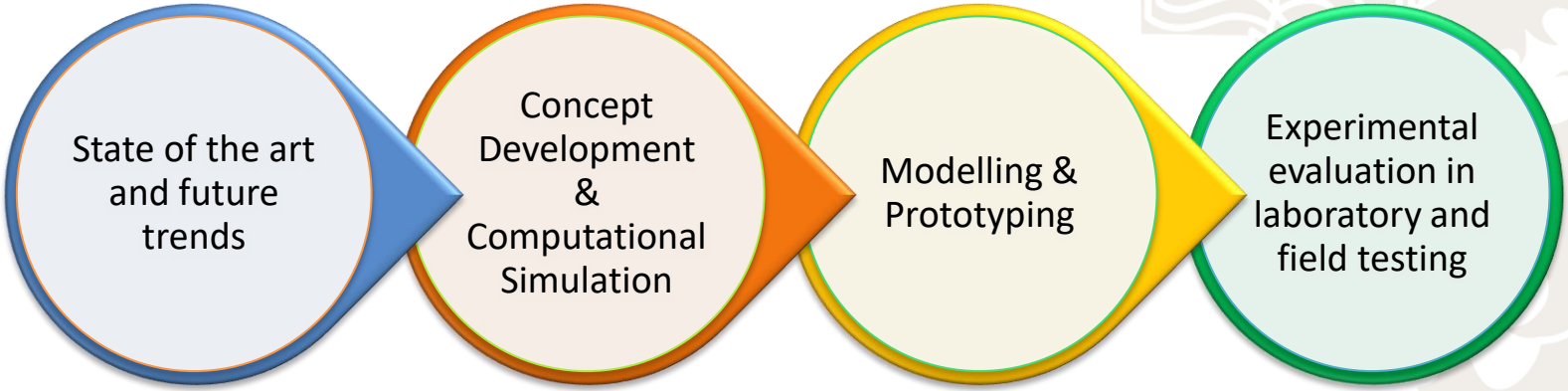
# ELITE II – Enhancement LITe Exoskeleton

## Objetive

The main goal of this project is to develop a dual-purpose passive exoskeleton for human enhancement in industrial, military or daily life activities and for physical rehabilitation

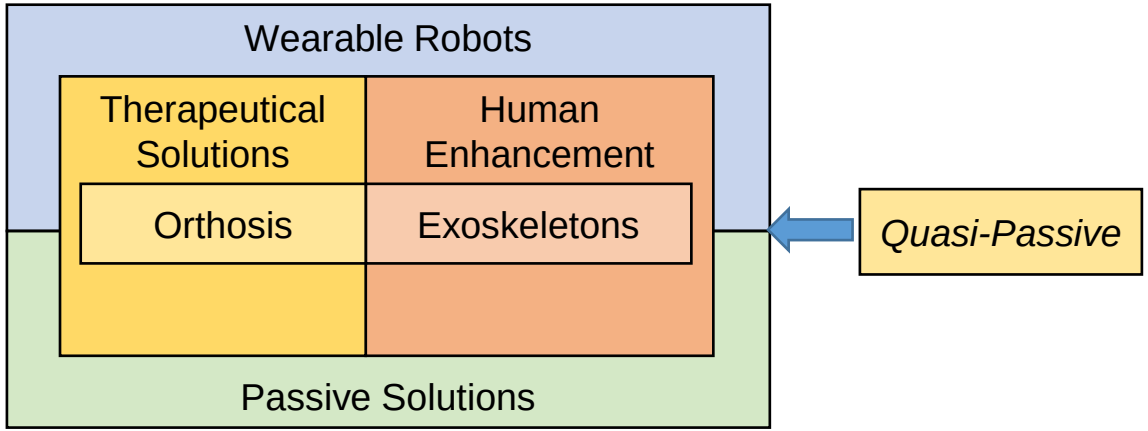



[3] Quinto, L., Gonçalves, S. and Silva, M., "Exoesqueletos para membros inferiores: Estado da arte", Congresso Nacional de Biomecânica, Guimarães, 2017

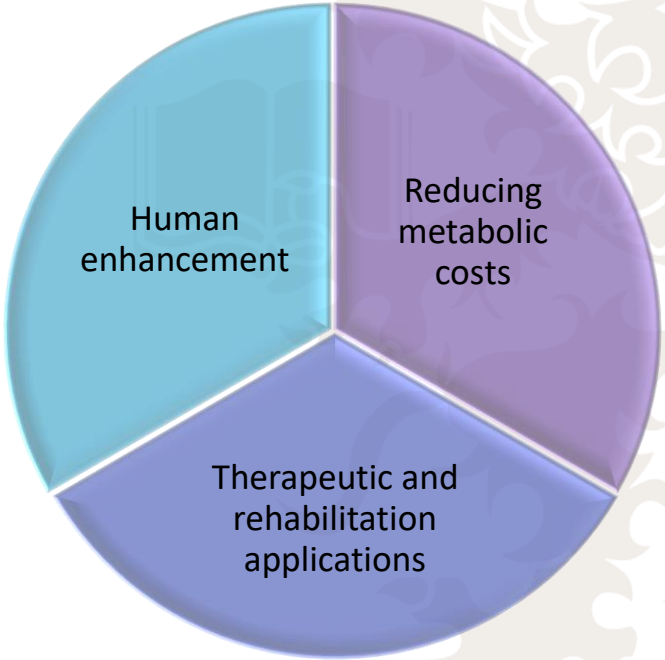
# ELITE II – Enhancement LITe Exoskeleton

## State of the art

**Interaction between orthosis, exoskeletons, wearable robots and passive solutions**




**Exoskeleton Categories**




[3] Quinto, L., Gonçalves, S. and Silva, M., "Exoesqueletos para membros inferiores: Estado da arte", Congresso Nacional de Biomecânica, Guimarães, 2017

# ELITE II – Enhancement LITe Exoskeleton

## State of the art

### Human Enhancement


BLEEX

HULC



FORTIS

### Reducing metabolic costs


XPED 2

Asbeck *et al.*

Mooney e Herr

Collins *et al.*

[3] Quinto, L., Gonçalves, S. and Silva, M., "Exoesqueletos para membros inferiores: Estado da arte", Congresso Nacional de Biomecânica, Guimarães, 2017
[6] Quinto, L., Gonçalves, S. and Silva, M., "Revisão sistemática de exoesqueletos para membros inferiores", Jornadas das Engenharias, Lisboa, 2017

# ELITE II – Enhancement LITe Exoskeleton

## State of the art and future trends

**Exoskeleton reference model:**

- **Rigid Frame**
- **Degrees of Freedom:**
  - Hip – 3
  - Knee – 1
  - Ankle – 3
- **Actuation:** Electric actuators
- **Control:** Force sensors
  - Inertial sensors
  - EMG

source: www.123rf.com

***Key challenges:***

- Safety, autonomy, human-machine interface, reliability and affordability
- Ergonomics (degrees of freedom, mass and volume)
- Customization (tailored/adjustable solutions)

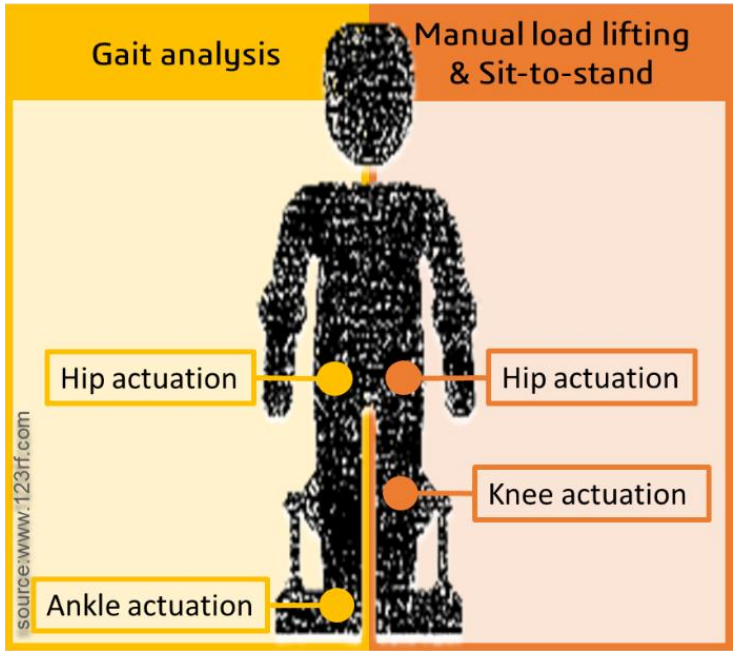
***Future Trends:***

- Compliant solutions
- Passive solutions
- Passive/actuated synergies

[3] Quinto, L., Gonçalves, S. and Silva, M., "Exoesqueletos para membros inferiores: Estado da arte", Congresso Nacional de Biomecânica, Guimarães, 2017
[6] Quinto, L., Gonçalves, S. and Silva, M., "Revisão sistemática de exoesqueletos para membros inferiores", Jornadas das Engenharias, Lisboa, 2017

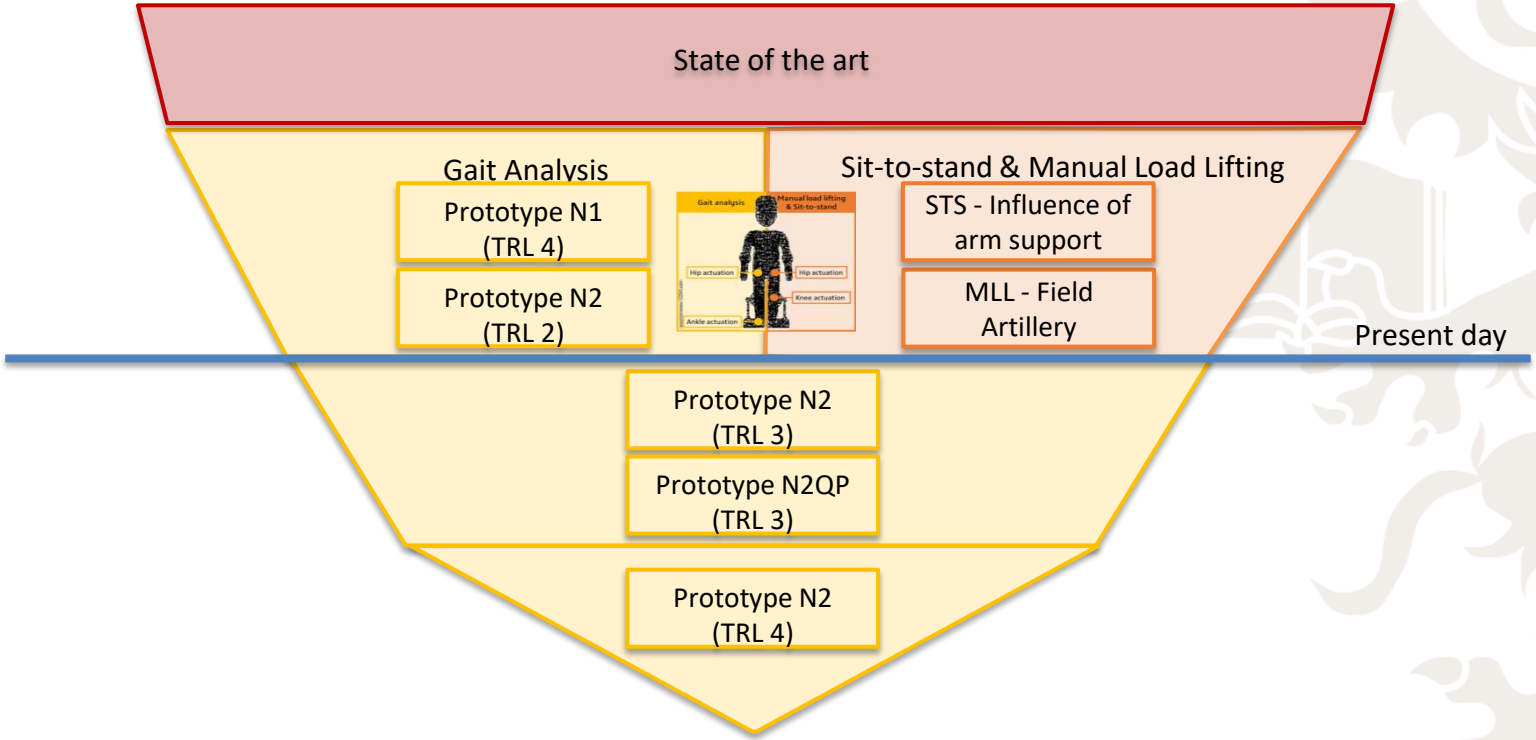
# ELITE II – Enhancement LITe Exoskeleton

## Methodology



# ELITE II – Enhancement LITe Exoskeleton

## Methodology



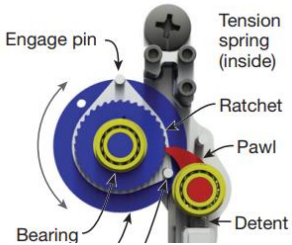
# ELITE II – Enhancement LITe Exoskeleton

## Gait Analysis – Prototype N1

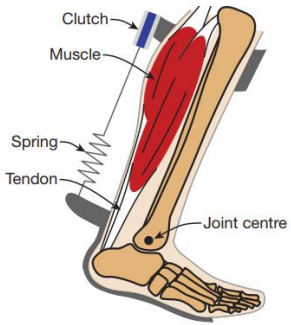
Design and development of a passive exoskeleton to reduce the metabolic cost during walking

Collins *et al.* exoskeleton main features:

- **Rigid structure**
- **Force element**
- **Mechanical clutch**




Taken from [11]

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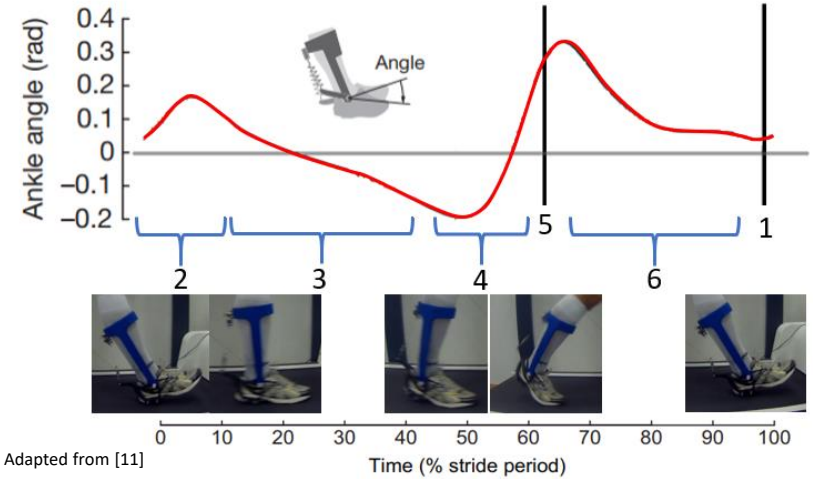


Adapted from [11]


[8] Pinheiro, P., Quinto, L., Gonçalves, S. and Silva, M., "Development and Analysis of a Passive Ankle Exoskeleton for Reduction of Metabolic Costs in Gait", Congresso Nacional de Biomecânica, Covilhã, 2019

[15] Quinto, L., Pinheiro, P., Ferreira, R., Roupa, I., Gonçalves, S. and Silva, M., AM-manufactured passive ankle exoskeleton to reduce the metabolic costs of walking (15NOV19) – Submitted to "Special issue in Journal of Additive Manufacturing"

# ELITE II – Enhancement LITe Exoskeleton

## Gait Analysis – Prototype N1

Design and development of a passive exoskeleton to reduce the metabolic cost during walking

**Concept Development**
Prototype Manufacturing
Experimental Analysis

User requirements:

- Specific requirements from previous and ongoing studies in this field [12]
- Non-structured interviews to military personnel with significant operational experience (n=10)
- Focus groups with members from military, physical training, biomechanics and engineering areas

| A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | Total | % | Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | A3 | A1 | A3 | A3 | A5 | A3 | A3 | A1 | A3 | A3 | A3 | A5 | A3 | A3 | 42 | 19 | 1 |
| | B | C3 | 0 | E1 | B3 | G3 | B1 | I3 | J1 | K3 | L1 | M1 | N1 | O1 | 4 | 2 | 12 |
| | | C | C3 | C3 | C3 | C3 | C3 | I1 | C3 | K1 | C1 | C1 | C3 | C1 | 27 | 12 | 4 |
| | | | D | 0 | D1 | G3 | D1 | I3 | J1 | K3 | D1 | D1 | N1 | O3 | 4 | 2 | 11 |
| | | | | E | E3 | E3 | E3 | I3 | E3 | K3 | L1 | K1 | N1 | O3 | 19 | 9 | 5 |
| | | | | | F | G1 | 0 | I3 | J1 | K3 | L3 | M3 | N3 | O1 | 0 | 0 | 15 |
| | | | | | | G | G3 | I3 | G1 | K3 | G1 | G1 | N3 | O1 | 13 | 6 | 8 |
| | | | | | | | H | I3 | H1 | K3 | L3 | M3 | N3 | O1 | 1 | 0 | 14 |
| | | | | | | | | I | I3 | I1 | I3 | I3 | I1 | I1 | 31 | 14 | 2 |
| | | | | | | | | | J | K3 | L1 | M1 | N1 | O1 | 3 | 1 | 13 |
| | | | | | | | | | | K | K1 | K3 | K1 | K1 | 28 | 13 | 3 |
| | | | | | | | | | | | L | L1 | L1 | O1 | 11 | 5 | 9 |
| | | | | | | | | | | | | M | N1 | O3 | 8 | 4 | 10 |
| | | | | | | | | | | | | | N | O1 | 14 | 6 | 7 |
| | | | | | | | | | | | | | | O | 16 | 7 | 6 |
| | | | | | | | | | | | | | Sum | | 221 | 100 | |

| Relationship | Value |
|---|---|
| Much more important | 5 |
| More important | 3 |
| Somewhat more important | 1 |
| Equal value | 0 |

| Requirements | Designation |
|---|---|
| Do not compromise user safety | A |
| Quick and easy of donning/doffing | B |
| Minimize users' fatigue | C |
| Ease of use | D |
| Reduced weight | E |
| Not having an electromagnetic signature | F |
| Minimize transportation requirements | G |
| Simple maintenance | H |
| Ergonomics | I |
| Not being affected by adverse weather/environmental conditions | J |
| Comfortable during long term use | K |
| Robustness | L |
| Noiseless | M |
| Range of motion | N |
| Autonomy | O |

[8] Pinheiro, P., Quinto, L., Gonçalves, S. and Silva, M., "Development and Analysis of a Passive Ankle Exoskeleton for Reduction of Metabolic Costs in Gait", Congresso Nacional de Biomecânica, Covilhã, 2019
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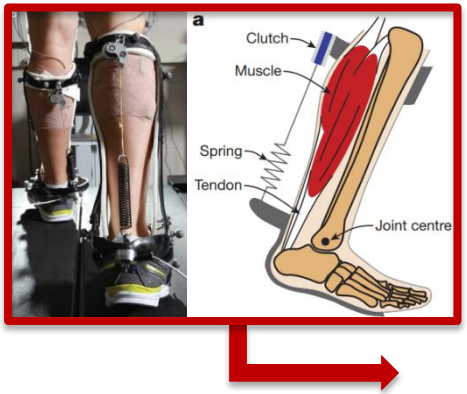
## Gait Analysis – Prototype N1

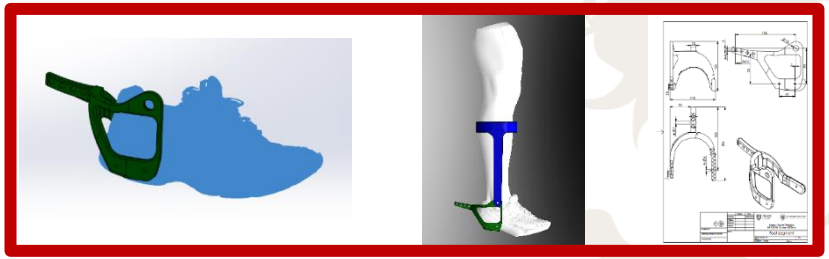
Design and development of a passive exoskeleton to reduce the metabolic cost during walking

**Concept Development**
**Prototype Manufacturing**
Experimental Analysis





Taken from shining3d.com



[8] Pinheiro, P., Quinto, L., Gonçalves, S. and Silva, M., "Development and Analysis of a Passive Ankle Exoskeleton for Reduction of Metabolic Costs in Gait", Congresso Nacional de Biomecânica, Covilhã, 2019
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# ELITE II – Enhancement LITe Exoskeleton

## Gait Analysis – Prototype N1

Design and development of a passive exoskeleton to reduce the metabolic cost during walking

Concept Development
Prototype Manufacturing
**Experimental Analysis**
- **15 subjects**
- **6-minute walk test (6MWT)**
  - Gas analyser
  - Medical purpose treadmill

**Experimental Analysis Apparatus**

[8] Pinheiro, P., Quinto, L., Gonçalves, S. and Silva, M., "Development and Analysis of a Passive Ankle Exoskeleton for Reduction of Metabolic Costs in Gait", Congresso Nacional de Biomecânica, Covilhã, 2019
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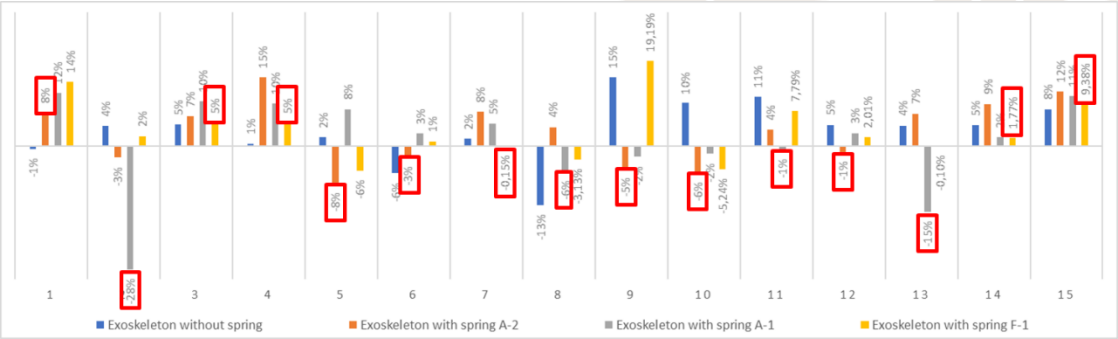
# ELITE II – Enhancement LITe Exoskeleton

## Gait Analysis – Prototype N1

- **10 of the 15 subjects** show a reduction of the metabolic costs between **-27,9% and -0,1%**
- **Average global reduction of -3,1%**
- **Actuation** spring must be **custom fitted**
- **Preserves RoM** and **DoF** of the ankle
- **Addictive manufacturing** customization
- Limitations include:
  - Timing of the clutch
  - Misalignment of the system
  - Weight

Metabolic Costs during 6MWT [MET] - 30





[8] Pinheiro, P., Quinto, L., Gonçalves, S. and Silva, M., "Development and Analysis of a Passive Ankle Exoskeleton for Reduction of Metabolic Costs in Gait", Congresso Nacional de Biomecânica, Covilhã, 2019

[15] Quinto, L., Pinheiro, P., Ferreira, R., Roupa, I., Gonçalves, S. and Silva, M., AM-manufactured passive ankle exoskeleton to reduce the metabolic costs of walking (15NOV19) – Submitted to "Special issue in Journal of Additive Manufacturing"

# ELITE II – Enhancement LITe Exoskeleton

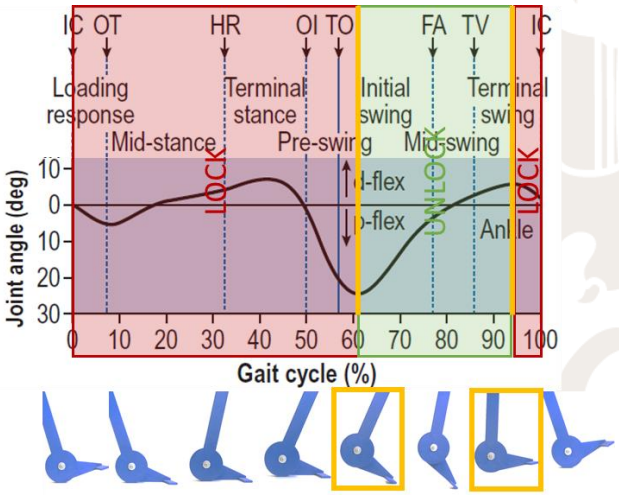
## Gait Analysis - Prototype N2

Design and development of a passive exoskeleton to reduce the metabolic cost during walking

**New Concept**

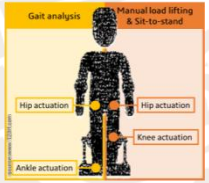
- Military requirements
- Actuation of the ankle
- Aligned with the articulation
- Passive System
- **Adaptable to other joints**

- Quasi-passive version



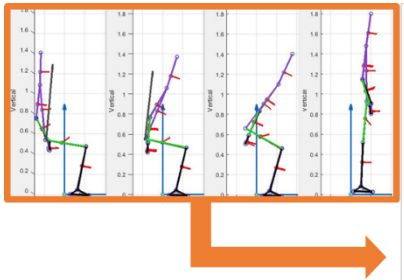
# ELITE II – Enhancement LITe Exoskeleton

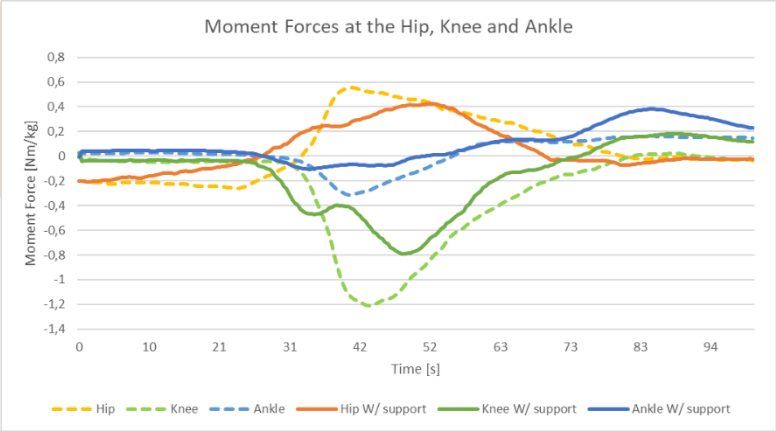
## **Sit-to-stand** and Manual Load Lifting




Sit-to-stand motion analysis – Study the influence of arm support

- Inverse dynamics analysis software developed in-house, APOLLO [12]
  - Motion Capture System
  - 2 force plates
- Angles
- Moment Forces
- Reaction Forces






- 35% maximum moment force reduction at the knee
- 20% maximum moment force reduction at the hip

[11] Quinto, L., Gonçalves, S. and Silva, M., "Design of a Passive Exoskeleton to Support Sit-to-Stand Movement: A 2D Model for the Dynamic Analysis of Motion", 4th International Symposium on Wearable Robotics, Pisa, 2018

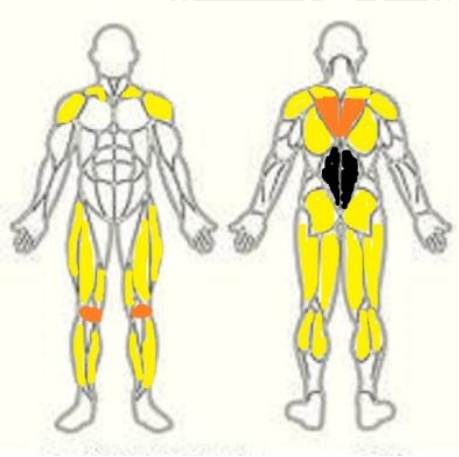
# ELITE II – Enhancement LITe Exoskeleton

## Sit-to-stand and **Manual Load Lifting**

Manual Load Lifting – Field Artillery

- Quantitative analysis
  - Field artillery doctrine analysis
  - Nonparticipant Structured Observation – Military Maneuvers
- Qualitative analysis
  - Inquiry focusing perceived effort and frequency

| | |
|---|---|
| **Howitzer Platform** | **47,5kg > 40kg** |
| **Howitzer Maneuvering** | **36,8kg > 30kg** |
| **Ammunition Case** | **27,3kg*2 > 25kg** |



| |
|---|
| **10 – 25%** |
| **26 - 50%** |
| **51 – 75%** |
| **76 – 100%** |

[14] Ferreira, R., Quinto, L., Gonçalves, S., Silva, M., "A Integração dos Exosqueletos no Campo de Batalha - Estudo da implementação no âmbito da Artilharia de Campanha", Encontro Anual da Investigação & Desenvolvimento em Ciências Militares, 2019

# ELITE II – Enhancement LITe Exoskeleton

## Technology Transfer – Conferences (11 presentation delivered)

- Quinto, L., Gonçalves, S. and Silva, M., "Revisão sistemática de exoesqueletos para membros inferiores", **Jornadas das Engenharias,** Lisboa, 2017
- Quinto, L., Gonçalves, S. and Silva, M., "Exoesqueletos para membros inferiores: Estado da arte", **Congresso Nacional de Biomecânica**, Guimarães, 2017
- Quinto, L., Gonçalves, S. and Silva, M., "Design of a Passive Exoskeleton to Support Sit-to-Stand Movement: A 2D Model for the Dynamic Analysis of Motion", **4th International Symposium on Wearable Robotics**, Pisa, 2018
- Pinheiro, P., Quinto, L., Gonçalves, S. and Silva, M., "Development and Analysis of a Passive Ankle Exoskeleton for Reduction of Metabolic Costs in Gait", **Jornadas das Engenharias**, Lisboa, 2018
- Quinto, L., Gonçalves, S. and Silva, M., "Design of a Passive Exoskeleton to Support Sit-to-Stand Movement: A 2D Model for the Dynamic Analysis of Motion", **Encontro Anual da Investigação & Desenvolvimento em Ciências Militares**, Lisboa, Portugal, 2018
- Pinheiro, P., Quinto, L., Gonçalves, S. and Silva, M., "Development and Analysis of a Passive Ankle Exoskeleton for Reduction of Metabolic Costs in Gait", **Encontro Anual da Investigação & Desenvolvimento em Ciências Militares**, Lisboa, Portugal, 2018
- Pinheiro, P., Quinto, L., Gonçalves, S. and Silva, M., "Development and Analysis of a Passive Ankle Exoskeleton for Reduction of Metabolic Costs in Gait", **Congresso Nacional de Biomecânica**, Covilhã, 2019
- Quinto, L., Gonçalves, S. and Silva, M., "Design of a Passive Exoskeleton to Support Sit-to-Stand Movement: A 2D Model for the Dynamic Analysis of Motion", **Congresso Nacional de Biomecânica**, Covilhã, 2019
- Quinto, L., Lucena, R., Chambel, E., Silva, R., Domingues, M., Pinheiro, P., Ferreira, R., Roupa, I., Gonçalves, S., Quental, C., Silva, M., "ELITE – Enhancement LITe Exoskeleton", **Integration of the Exoskeleton in the Battlefield 5th Workshop**, Trencin, Slovakia, 2019
- Quinto, L., Lucena, R., Chambel, E., Silva, R., Domingues, M., Pinheiro, P., Ferreira, R., Roupa, I., Gonçalves, S., Quental, C., Silva, M., "ELITE – Enhancement LITe Exoskeleton - Projeto e desenvolvimento de um exosqueleto para apoio ao movimento humano", **Encontro Anual da Investigação & Desenvolvimento em Ciências Militares**, 2019
- Ferreira, R., Quinto, L., Gonçalves, S., Silva, M., "A Integração dos Exosqueletos no Campo de Batalha - Estudo da implementação no âmbito da Artilharia de Campanha", **Encontro Anual da Investigação & Desenvolvimento em Ciências Militares**, 2019

# ELITE II – Enhancement LITe Exoskeleton

## Preliminary conclusions

- Results suggest that its possible to reduce the metabolic costs during gait using a passive exoskeleton
- Comfort, ergonomics and range of motion – Main user requirements
- Optimization of the control system is a must – *Actuated and quasi-passive solutions?*
- Development of custom fitted solutions is key
- Aligned with NATO and EDA Research and Development Agenda

# ELITE II – Enhancement LITe Exoskeleton

## Next steps

- Prototype N1 – Understand the influence of user's biomechanical data in the results (force elements, control system tuning)

- Prototype N2
    - Final Design of the exoskeleton solution (new concept)
    - Exoskeleton manufacturing
    - Quasi-passive solution
    - Experimental analysis in the LBL

# ELITE II – Enhancement LITe Exoskeleton

## Expected Results

- Prototyping of an ankle exoskeleton solution (TRL 3)
- Laboratorial trials results (TRL 4)
- Comply with user requirements:
    - Custom fitted/adaptable
    - Lightweight
    - Comfortable
    - Robust
- Reduction of the metabolic costs during walking

# ELITE II – Enhancement LITe Exoskeleton

## Design and Development of an Exoskeleton to Support Human Movement

Rui Lucena[1], Énio Chambel[1], Paula Simões[1], **Luís Quinto *(PI)*** [1,2] Miguel Tavares de Silva[2], Jorge Martins[2], Luís Reis[2], Carlos Quental[2], Sérgio Gonçalves[2], Ivo Roupa[2]

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*[2] LAETA, IDMEC, Lisbon Institute of Technology*
*Lisbon University*
*Lisbon, Portugal*

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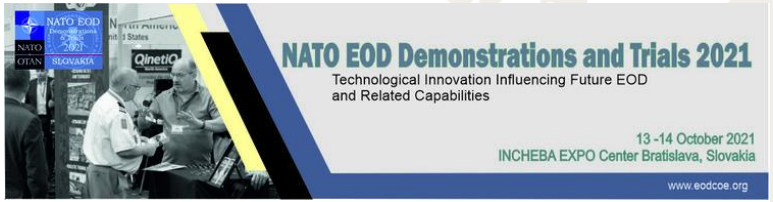
To: CAPTECH CBRN AND HUMAN FACTORS CNCs, CGEs and CnGEs

Copy: R&T PoCs, Central PoCs and Capabilities PoCs

**INVITATION TO EXOSKELETON WORKSHOP**

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