PHYSIOLOGICAL RESPONSES TO THE USE OF UPPER LIMB EXOSKELETON DURING HANDLING TASKS

Consequences on Work Organization?

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Context
Exoskeletons...
Various forms and applications

1968 Hardiman

2017 Gopura et al, 2015

Military applications
Medical/Rehabilitation applications
Occupational applications

03/04/2017
Exoskeletons...
... in order to prevent MSD?

... by reducing biomechanical strains...

Limits of modern technology, automation, and work-related interventions

Awkward postures
Manual handling tasks

03/04/2017
Focus on low back pain and shoulder MSD

Handling tasks

Back exoskeletons

Upper limb exoskeletons

Bos et al., 2014

Available

Cost-effective
Previous studies?
Impact of exoskeletons on physiological workload

Previous studies on handling tasks

- Back exoskeletons
- Upper limb exoskeletons

Benefits

- Lumbar muscles activity
  - Abdoli Eramaki et al., 2006 / 2008
  - Bosch et al., 2016

- Lumbar muscles fatigue
  - Godwin et al., 2009
  - Lotz et al., 2009
  - Bosch et al., 2016

- Lumbar spine internal forces
  - Abdoli Eramaki et al., 2007

Lack of information
About upper limb exoskeleton?

Only during overhead works

Upper limb exoskeletons

Benefits

Disadvantages?

Shoulder muscles activity
Rasheidi et al. 2014

Joints torque
Sylla et al., 2014

Perceived exertion (shoulder)
Rasheidi et al. 2014
Sylla et al., 2014

Lumbar muscles activity
Rasheidi et al. 2014

Postural changes
Sylla et al., 2014

Perceived exertion (back)
Rasheidi et al. 2014
Objective of the present study
During manual handling tasks

Upper limb exoskeletons

HANDLING TASKS

Shoulder flexor and extensor muscles activity?
Postural muscles activity?
Postural balance?
Cardiovascular responses?
Experimental Protocol
Paradigm
EXO versus FREE

8 participants:
- 4 men
- 4 women
- Trained to the use of EXO (4 sessions, ~97 min)

Lifting task (LIFT)
- Sagittal plane
- Imposed rate (10 c/min, during 3min)
- 9 kg (men) / 5 kg (women) = assistance

Unstacking / Stacking task (STACK)
- 90° rotation on longitudinal axe
- Free rate (4 boxes x 8 cycles)
- 15 kg (men) / 8 kg (women) = real work

Load carrying during walking (WALK)
- Toolbox carrying
- 4 x 30 m walking (free chosen speed)
- 15 kg (men) / 8 kg (women) = real work
Measures
Muscular activity and cardiovascular responses

**EMG activity**
- Anterior Deltoid (shoulder flexor muscle)
- Triceps Brachial (shoulder extensor muscle)
- Tibialis anterior (ankle - balance)
- Erector spinae (low back - posture)

**Heart Rate**
- HR rest (5 min)
- HR task (last 30 seconds)

**Cardiac cost (HR task - HR rest)**

**Statistical analyses**
Mixed Linear Model; Subject = random effect; Condition (FREE, EXO) = fixed effect.
* : p<0.05 ; ** : p<0.01; ***p<0.001
Impacts on physiological workload
Muscles activity
EXO versus FREE during lifting and stacking tasks

- **Anterior Deltoid**
- **Triceps Brachial**
- **Tibialis Anterior**
- **Erector Spinae**

**LIFT**

- **FREE**
- **EXO**

**STACK**

- **FREE**
- **EXO**

* p<0.05; **: p<0.01; *** : p<0.001

Shoulder flexor muscle (assisted muscle)
Shoulder extensor muscle (antagonist muscle)
Ankle muscle (postural balance)
Muscles activity
EXO versus FREE, during walking task

Elbow flexor muscles? (decrease of joint torque (elbow))

Lumbar muscles? (trend) – “lever-arm” effect
Cardiovascular responses

**EXO versus FREE**

<table>
<thead>
<tr>
<th></th>
<th>LIFT</th>
<th>WALK</th>
<th>STACK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FREE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration (s)</td>
<td>-</td>
<td>14.0 ± 1.2</td>
<td>36.9 ± 6.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14.7 ± 1.1</td>
<td>47.6 ± 7.1 **</td>
</tr>
<tr>
<td>RPE (a.u.)</td>
<td></td>
<td>13.4 ± 1.1</td>
<td>13.6 ± 1.5</td>
</tr>
</tbody>
</table>
|               |               | 12.9 ± 1.4    | 11.2 ± 2.2    | *
| Cardiac cost (bpm) | 52.1 ± 5.4 | 49.3 ± 9.7    | 66.6 ± 5.2    |
|               | 59.3 ± 8.2    | 46.0 ± 4.5    | 67.0 ± 7.4    |

- **Strong trend** p=0.058

**Productivity** ~30%

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03/04/17
Synthesis
Physiological workload: EXO versus FREE

- No specific joint assistance!
  - Depend on movement kinematic, not on tasks, not on joint
  - Elastic energy storage!
    - Mechanical strains on antagonist muscles

- Additional cardiovascular stress
  - Mass, Kinematic strains, Postural changes

- Mass, inertia or kinematic changes?

- Work task duration

- Cardiac cost

- Lumbar strains

- Postural balance

- Shoulder flexion

- Shoulder extension

- Elbow flexion

- Lengthening of work task duration
Potential consequences on work organization?
Consequences on work organization

Various tasks?

- Shoulder flexion
- Shoulder extension
- Elbow flexion

No specific joint assistance!
Depend on movement kinematic, not on tasks, not on joint

Elastic energy storage!
Mechanical strains on antagonist muscle

Reorganization of the daily tasks (individual or team)?
Tasks with exoskeleton versus those without
Consequences on work organization
Balance and new constrains....

Lumbar strains

Postural balance

Mass, inertia or kinematic changes ?

Rethinking the work environment ?
Avoid the risks of fall, congested space ...

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Consequences on work organization

New constrains, and

Additional cardiovascular stress
Mass, Kinematic strains, Postural changes

Or ...

Lengthening of work task duration

Rethinking the work organization?
Allow operators to regulate the work-intensity with exoskeleton
Our job: making yours safer