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Evaluation of Chairless Chair exoskeleton to reduce prolonged standing

Tessy Luger PhD

Dipl.-Ing. Robert Seibt, Dr. Benjamin Steinhilber

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- Prolonged standing work is a risk factor for developing musculoskeletal disorders
  (Werner et al. 2010; Gregory & Callaghan 2008)

- **Exoskeletons** are wearable, external mechanical structures enhancing the person's power or supporting the person
  (De Looze et al. 2015)

Hardiman® *from General Electric, USA; this was a non-successful project of a "practical" powered exoskeleton. Picture can be found on the following website: https://en.wikipedia.org/wiki/Hardiman*

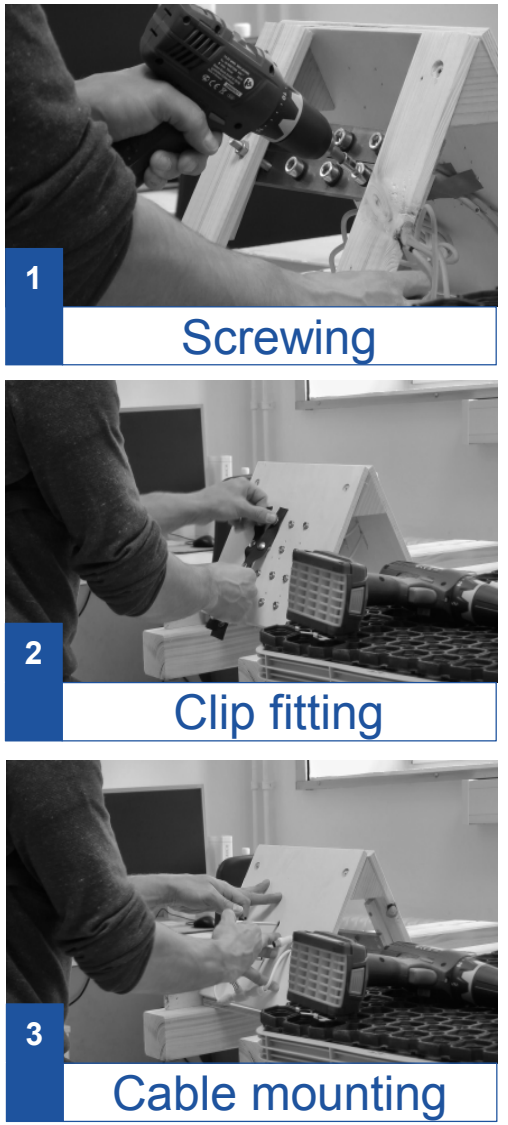
Aim

- To assess **physical load, kinematics, postural control and discomfort** when wearing a passive lower-limb exoskeleton while performing simulated assembly tasks in different **working positions** and different frontal **working distances**.

Chairless Chair: pictures can be found at the homepage of noonee AG (https://www.noonee.com/)

- **Population**
  - N = 45 45♂ (6 left-handed)
  - Age 24.8 ± 2.9 years
  - Height 182.6 ± 5.5 cm
  - Weight 78.1 ± 8.7 kg

- **Design**
  - 21-min simulations of 3 assembly tasks (see Figure)
  - ~30-min familiarization trial on day 1

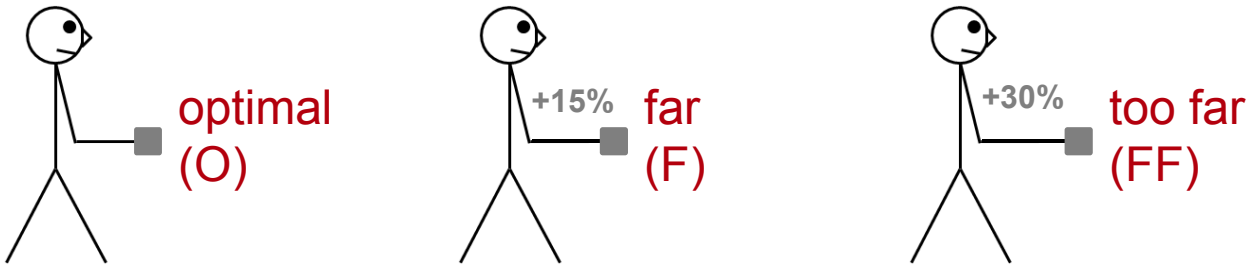


- **Design**: 2 independent variables
  - Working posture / exoskeleton status

  - Working distance

$$WD_{optimal} = length_{grasping\ arm} + \left(\sin(\beta) \cdot length_{upper\ arm}\right)$$

β is the elbow angle of 105°

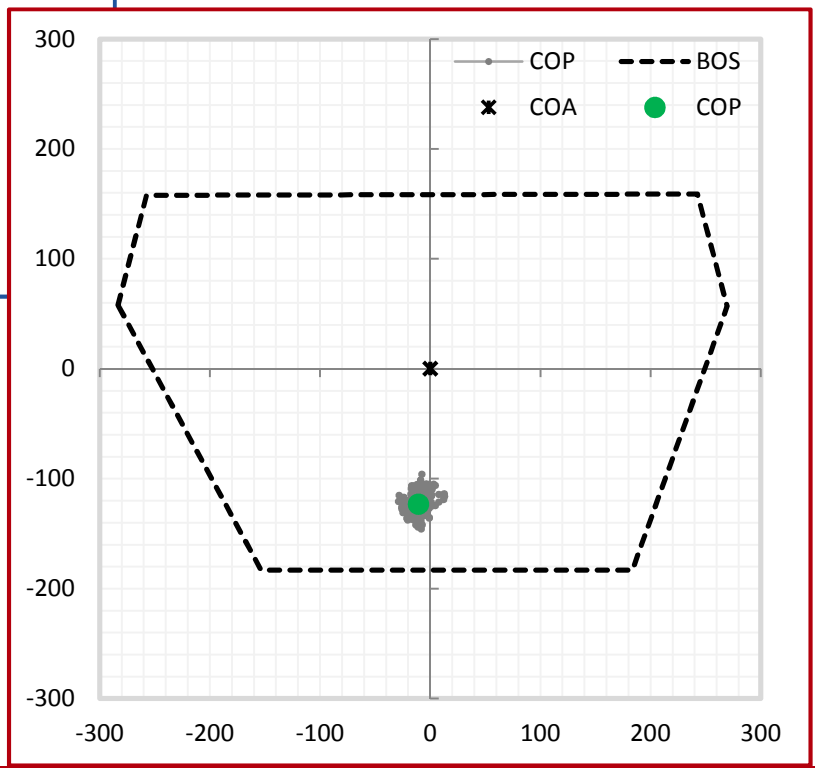


Measurements

- Kinetics — Force plate
  - *Centre of pressure [mm]*
  - *Relative standing stability [%]*
  - *Absolute standing stability [cm]*
  - *Velocity [mm/s]*
  - *Weight distribution [kg]*
- Kinematics — Position sensors
  - *Neck & trunk flexion [°]*

$$SS_{REL} = \frac{|s_{COP} - s_{BOS}|}{|s_{COA} - s_{BOS}|} \cdot 100\%$$

COP is the centre of pressure
BOS is the base of support
COA is the centroid of activity

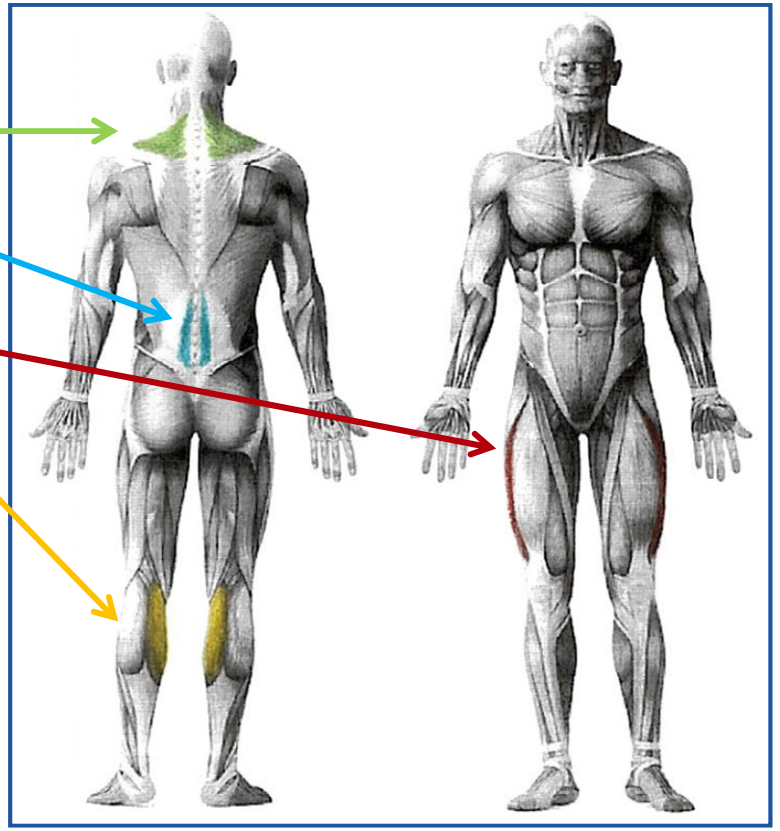


Measurements

- Muscular activity — Electromyography
  Relative activity [%RVE]

Normalization to the electrical activity of the reference voluntary contractions

- M. trapezius descendens
- M. erector spinae
- M. vastis lateralis
- M. gastrocnemius medialis



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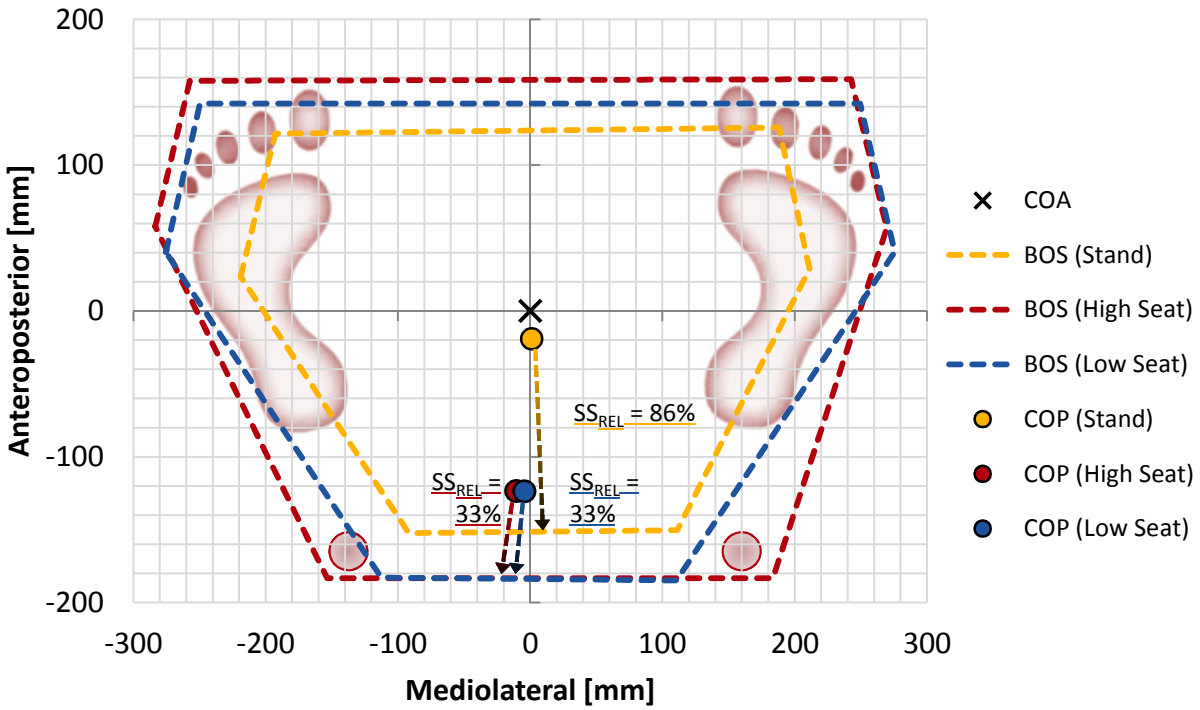
- Discomfort — 11-point Likert scale

Statistical analysis

- Two-factor repeated measures ANOVA
- Post hoc: Tukey HSD
- $p < 0.05$ *(JMP® 13.1.0)*

(1) Exoskeleton status & (2) Working distance

- **Kinetics** (force plate)

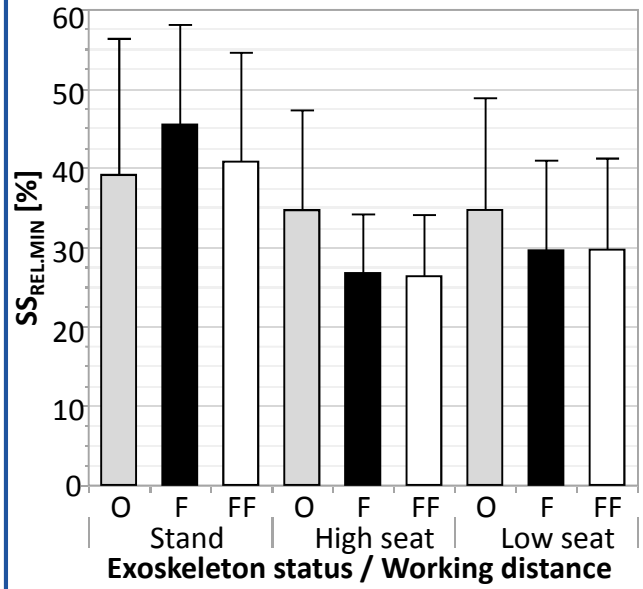


Typical example of a subject in *Stand*, *High Seat* and *Low Seat* on the Chairless Chair with optimal working distance

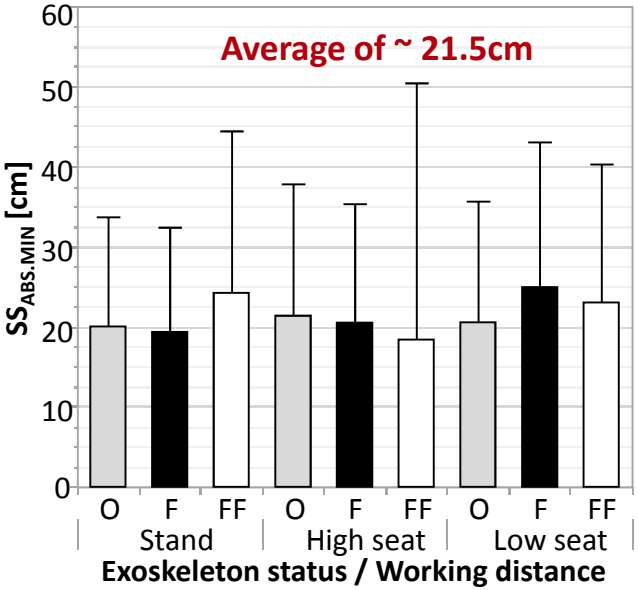
- Sitting on the Chairless Chair:
  - more posterior COP
  - smaller SS_{REL} *(min.: 27%)*
  - lower V_{COP}
- Working further to the front:
  - slightly higher SS_{REL}
  - more anterior COP
  - slightly higher V_{COP}

- **Kinetics** (force plate)

Relative standing stability

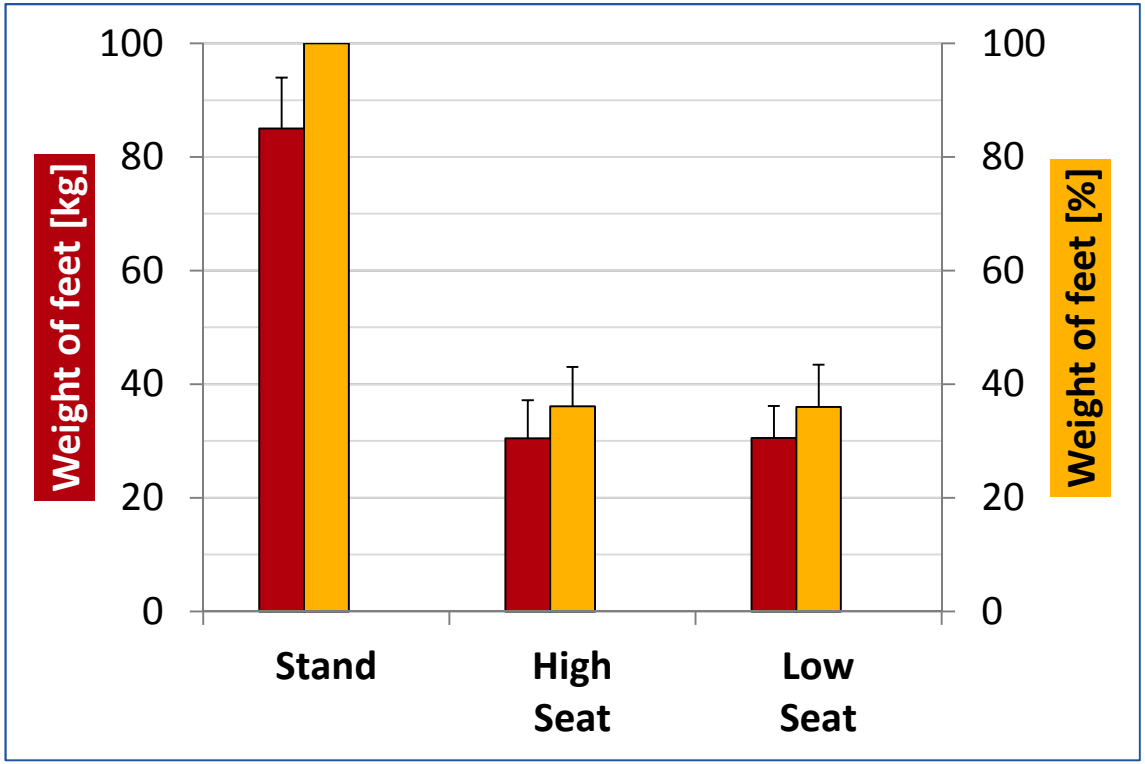


Absolute standing stability



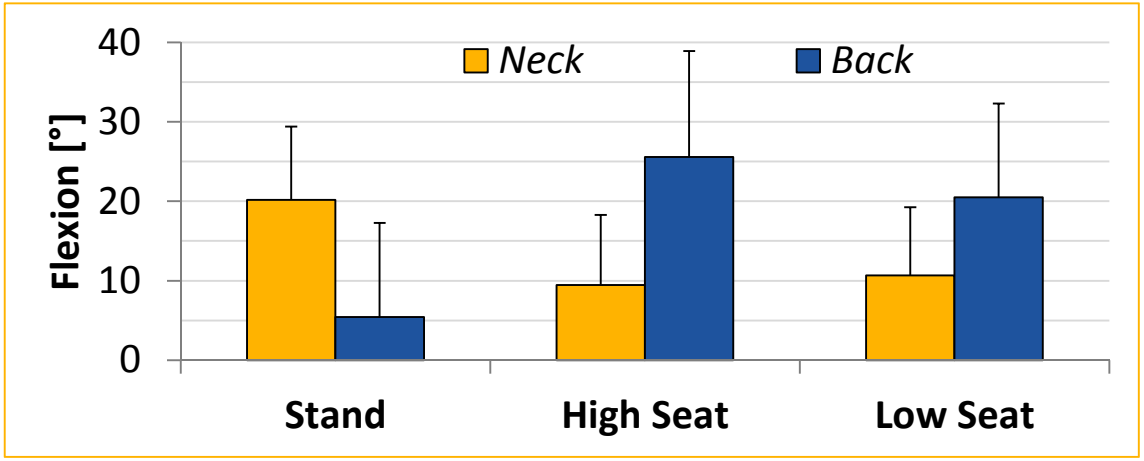
- Sitting on the Chairless Chair:
  - more posterior COP
  - smaller SS_{REL} *(min.: 27%)*
  - lower V_{COP}
  - **unchanged SS_{ABS}**
- Working further to the front:
  - slightly higher SS_{REL}
  - more anterior COP
  - slightly higher V_{COP}
  - **unchanged SS_{ABS}**

- **Kinetics** (force plate)

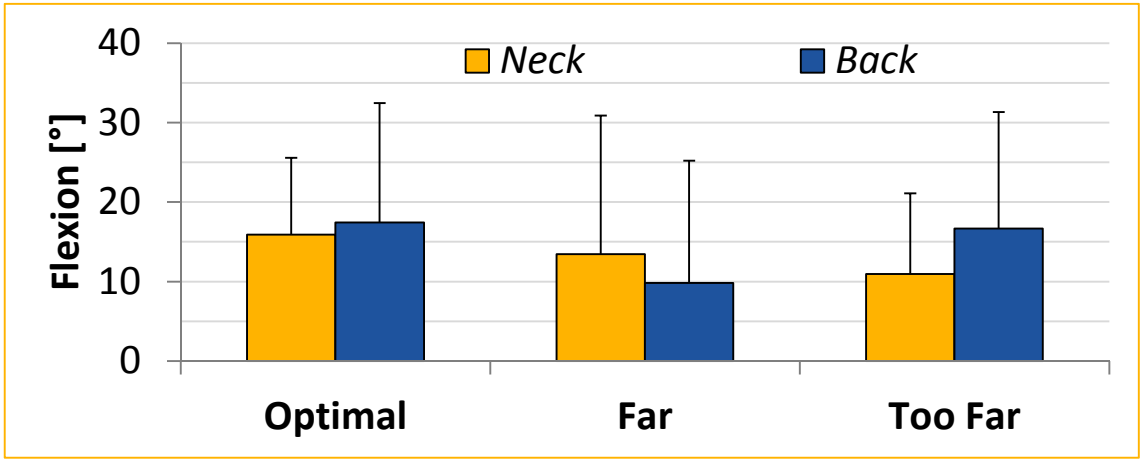


- Sitting on the Chairless Chair:
  - relieves the lower extremities (feet) on average up to *64%*

- **Kinematics** (position sensors)

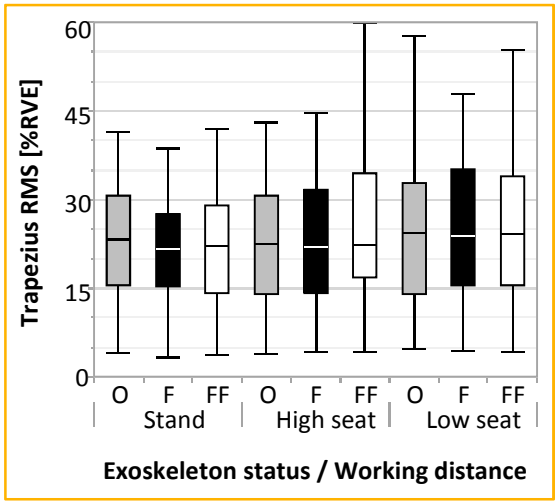


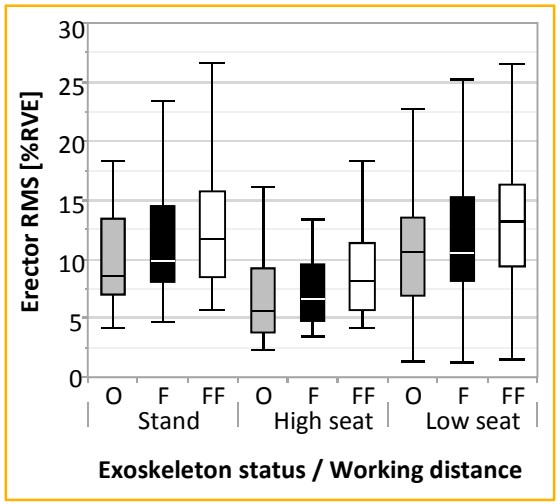
- Sitting on the Chairless Chair:
  - less neck flexion
  - more back flexion

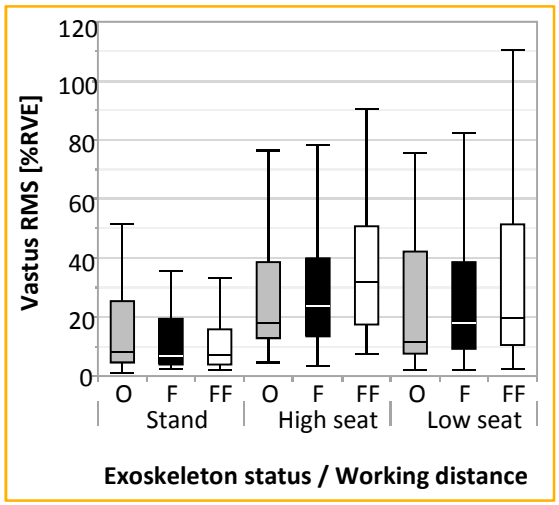


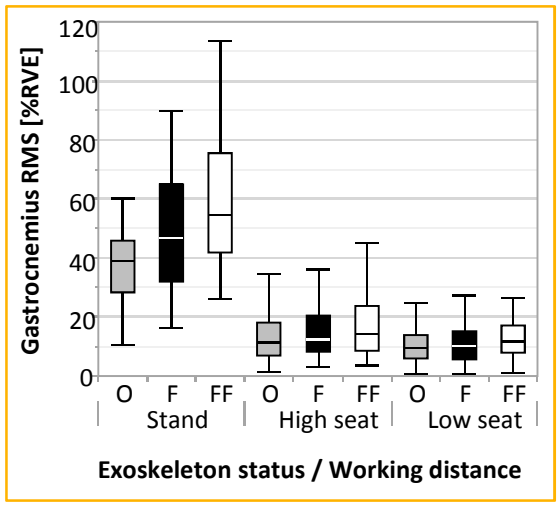
- Working further to the front:
  - less neck flexion

- **EMG** (muscular activity)





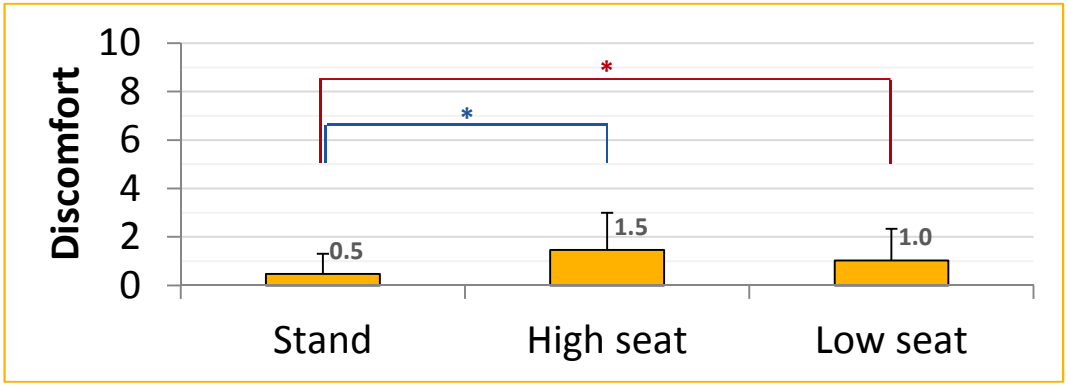




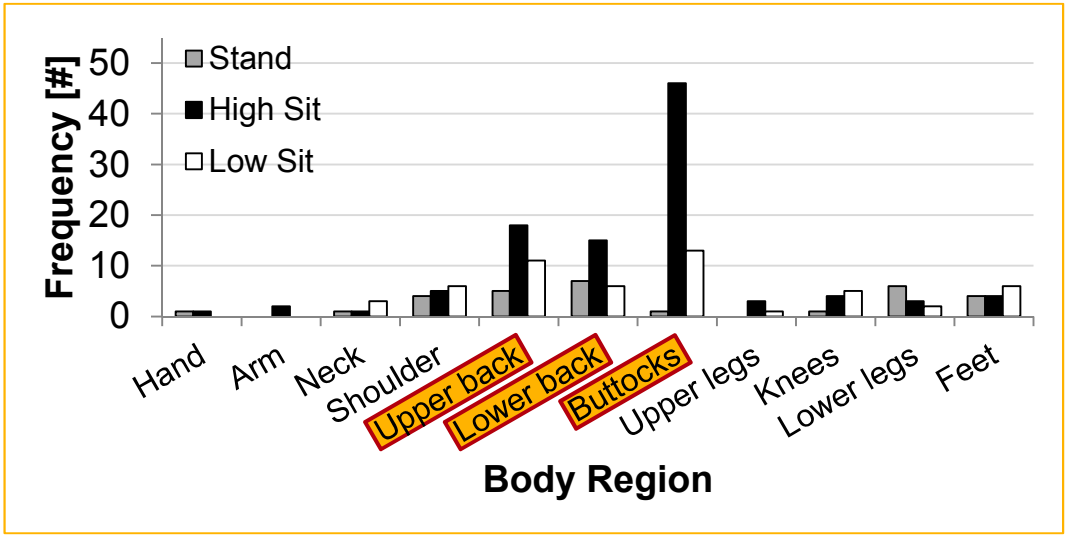
- Sitting on the Chairless Chair:
  - slightly increased trapezius activity
  - increased vastus activity
  - decreased gastrocnemius activity
  - lower erector activity in high seat

- Working further to the front:
  - increased erector & vastus & gastrocnemius activity

- **Discomfort** (local)



- Sitting on the Chairless Chair:
  - higher ratings of discomfort



- Most affected body regions:
  - Buttocks
  - Back

- **Summary, Chairless Chair®…**
  - …reduced relative standing stability without reaching a critical state (≡ 0%)
    - > no *perturbations* (e.g. human-robot collaboration environment)
    - > $SS_{REL.MIN}$ ≥ 27%
    - > **!!!** $SS_{REL.ABS}$ unchanged **!!!** 
  - …relieves loading on lower extremities by ~64%
  - …reduced erector activity by ~22% *only in high sitting (!!!)*
  - …increased trapezius activity by ~6%
  - …increased vastus activity by ~107%
  - …reduced gastrocnemius activity by ~75%
  - …increased feeling of discomfort

- **Practical applications**
  - …*low potential* of decreasing low back physical loading
  - …potential to decrease risks of prolonged standing in **awkward postures** on musculoskeletal disorders
    - > less neck flexion
  - ...**use** the exoskeleton ≤ 21 min
    - > discomfort was higher when using the Chairless Chair®
  - …provide extensive **training** & appropriate **clothing**

- **Future research…**
  - …investigate change of stress in the joints and intervertebral discs
  - …including dynamic working situations with possible *external perturbations*
    - > interaction with machines, e.g. collaborating robots
  - …to effectiveness and usability in the **field**
  - …to effectiveness and usability in the **long-term**

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Thank you!

Contact Tessy Luger

Institute for Occupational and Social Medicine and Health Services Research
Wilhelmstr. 27, DE-72074 Tübingen, Germany

☎ +49 7071 29-84364
✉ Tessy.Luger@med.uni-tuebingen.de