# Biomechanical effects of using a passive back support exoskeleton during prone-positioning maneuver: A pilot study

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## 1. Introduction

Musculoskeletal disorders associated with patients care and manipulation are frequent among healthcare workers, due to force exertion and sustained awkward postures (EU Commission 2011, Davis 2015). During the COVID-19 pandemic, intensive care units (ICUs) staffs had to perform prone-positioning (PP) of a large number of intubated patients suffering from Acute Respiratory Distress Syndrome (ARDS) many times a day. PP maneuver consists in repositioning a patient from a supine position (on the back) to a prone position (on the front side), which improves oxygenation and ventilatory mechanisms in ARDS patients (Guérin *et al.* 2013). PP is a delicate procedure (risk of extubation) which requires the medical staff to remain bent forward for several minutes (Fig. 1). This posture result in back loading and in the long-term potential injuries in the low-back. Similar postures are common in industrial tasks, and recently occupational exoskeletons have started to be commercialized to help reduce physical load on workers (DeLooze *et al.* 2016). Exoskeletons therefore appear as a promising solution to support healthcare workers, though few studies focused on this sector (e.g. Miura *et al.* 2020; Iishi *et al.* 2015). But while studies overall agree that back-support exoskeletons, and specifically passive devices, have the potential to reduce lumbar muscle activity in tasks involving trunk bending, the exact efficacy and usability of such devices appear largely device- and task-dependent (Theurel *et al.* 2019). A preliminary study of our team (Settembre *et al.* 2020) identified the Laevo passive exoskeleton for lumbar support (Laevo, the Netherlands) as the exoskeleton that best matched the PP maneuver and ICU constraints, among 4 exoskeletons that were available at the time of the test during the COVID-19 first wave. The present study presents a pilot investigation of the biomechanical effects of using the Laevo during PP maneuver.

## 2. Methods

### *2.1 Experimental protocol*


Figure 1: Medical staff equipped with the Laevo exoskeleton performing a PP maneuver on a manikin.

Two healthy volunteers with PP experience performed PP maneuvers both with and without wearing the Laevo, on a patient simulator (manikin) at the Hospital Simulation Center of the University of Lorraine (Fig. 1). Each maneuver lasted about 4 min. In a first experiment, the participants were equipped with the Xsens MVN Link inertial motion capture system (capture rate 240 Hz) to record whole-body kinematics. In a subsequent experiment, the participants were equipped with a Delsys Trigno EKG sensor to measure heart rate, and 12 Delsys Trigno sEMG sensors (sampling rate 4370 sa/sec) placed according to the Seniam recommendations bilaterally on the erector spinae longissimus (ESL), erector spinae iliocostalis (ESI), trapezius ascendens (TA), and biceps femoris long head (BF), and laterally on the right rectus abdominis at T10 level (RA), rectus femoris (RF), gluteus maximus (GM) and tibialis anterior (TAL).

### *2.2 Data analysis*

In order to analyze the kinematics and dynamics of the maneuver, we replayed the recorded motions in a physics-engine based simulation using a 43 degrees of freedom digital human model (DHM). The recorded motions were retargeted on the DHM directly in the Cartesian space by using a quadratic programming controller (QP) typically used for humanoid robots (Maurice *et al.* 2019). The QP control directly estimates the joint torques associated with the motion. This method has the advantage to blend the traditional inverse kinematics and inverse dynamics steps into one faster step, since the computation runs in close to real-time. Since we did not have a direct measurement of the support torque provided by the Laevo, we used the empirical calibration curve published by (Koopman *et al.* 2019) to estimate the lumbar support torque depending on the trunk flexion angle. We used the resulting L5/S1 flexion/extension estimated joint torque as a complement to the physiological measurements obtained with the sEMG.

## 3. Results and discussion

***Kinematic results:*** Using the Laevo did not significantly modify the kinematics of the motion during PP. Specifically, the profile of the lumbar flexion angle remained overall similar (Fig. 2). This result was confirmed by the subjective feedback of the participants who reported that they did not feel the exoskeleton was affecting the way they performed the task.

***Dynamic results:*** The median value of the estimated L5/S1 flexion/extension torque decreased by about 12% when using the Laevo (Fig. 2). This result agrees with the reduced perceived lumbar effort reported by participants, and is aligned with the 15% reduction observed by (Koopman *et al.* 2019) in a similar static forward bending task. Yet those results should be considered cautiously, since only the assistive torque of the exoskeleton was modeled, and not the full effect of the load transfer.

***Physiological results:*** We did not observe any major change in heart rate when using the Laevo. This might be due to the short duration of the experimental task (4 min). The activity of the back extensor muscles (except ESI) and hip extensor muscles overall decreased when using the Laevo (Table 1). The other recorded muscles remained mostly unaffected by the exoskeleton. Those results are consistent with the perceived reduced effort reported by the participants.

## 4. Conclusions

Our pilot study, though limited to a small number of participants, suggests that using the Laevo could help reduce the musculoskeletal load on the low back during PP maneuver, without causing any significant negative side-effect nor modifying the practice. Following this study, 2 Laevos have been successfully deployed in the ICU of CHRU Nancy and have been used there for the past 6 months. Recording quantitative measurements during this field-testing is not possible. However subjective feedback from users is collected through questionnaires and interviews, and will be analyzed in a future study.

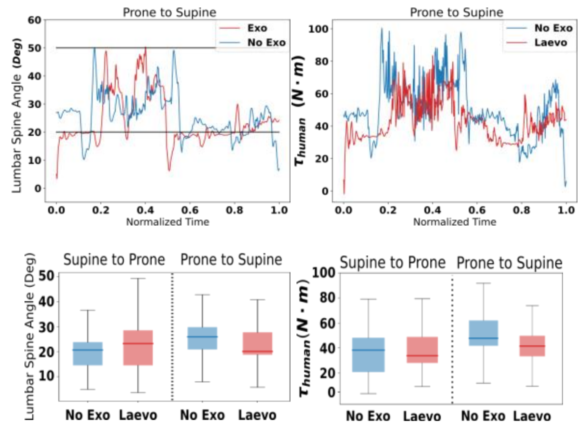


Figure 2: Time-series (top) and distribution across time (bottom) of the L5/S1 flexion angle (left) and torque (right) during PP maneuver with and without using the Laevo.

| | TA | ESL | ESI | GM | RF | BF | RA | TAL |
|---|---|---|---|---|---|---|---|---|
| P1 H | -35 | -12 | -1 | -30 | 0 | -16 | -1 | -2 |
| P2 H | +2 | +5 | 0 | +5 | NA | -20 | 0 | +6 |
| P1 S | -15 | -9 | -1 | -12 | -6 | -53 | 0 | -10 |
| P2 S | -5 | -11 | -2 | +8 | NA | -34 | 0 | -20 |

Table 1: Relative difference (%) in RMS value of the EMG signal with the Laevo vs. without it, for both participants and both PP positions (patient's head (H) and side (S)).

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