Passive Lower Back Moment Support in a Wearable Lifting Aid: Counterweight Versus Springs

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Abstract Passive wearable lifting aids support workers by applying gravity force compensation at the arms. In this study we investigated the feasibility of a compensatory lower back moment, generated by a practically constant spring force (38.5 Nm), extending the lower back by pushing on the upper leg. This design is proposed as a light-weight solution to generate lower back moments. The method is compared to using counterweights at a different distances. We recorded EMG activity of the erector spinae longissimus (ES) muscle, the perceived workload (NASA TLX) and the preference of 12 subjects. Results showed no significant difference in ES peak EMG activity during the task, and no significant difference between perceived workload between conditions, as we expected. However, 10 out of 12 subjects indicated preferring the spring mechanism over both counterweights. The main reason of preference was the reduction of weight and inertia of the system. Therefore, the proposed constant spring force mechanism is a feasible alternative to counterweights.

1 Introduction

Heavy lifting is a strong contributor to low back injuries, in part due to the spinal loading [4]. Part of this load stems from trunk muscles with a short moment arm that need to provide high forces to stabilize the spine.

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Passive wearble lifting devices to reduce this burden on its user can therefore be very valuable for the health of the user. The passive FORTIS (Lockheed Martin Corporation, Bethesda, MD, USA) uses a counterweight to balance the moment induced by the supported load carried by the user. Devices that use a spring mechanism only provide a supportive force when the user is flexing their trunk (much like a torsion spring) such as the Personal Lift Assist Device (Queen's University, Kingston, ON, Canada) [1, 3] or the Laevo (Laevo B.V., Delft, Netherlands). This is a major difference compared to using a counterweight, which continuously provides compensation, but also makes the device heavier.

In this study we investigated if springs are a feasible alternative to counterweights, when providing an almost *constant* moment compensation, which different from torsion spring behavior. We measured electromyography (EMG) activity on the lower back, specifically the erector spinae longissimus (ES), during a lifting and lowering task. This study also investigated subject preference for the various moment compensation methods using a questionnaire and the NASA Task Load Index (TLX).

2 Materials and Methods

A balanced repeated measures design was used where subjects performed a symmetric lifting task in three varying conditions. Subjects were asked to lift an 11.2 kg load while being assisted in gravity compensation force for 50 % by a passive lifting assistive device (SaeboMAS Mini, Saebo, Charlotte-NC, USA). During lifting, subjects were supported and the lower back with a counter moment of 38.5 Nm.

In this experiment three different 'moment compensation' conditions were compared: a constant spring force mechanism, a light counterweight of 6 kg at a distance of 0.54 m, and a heavy counterweight of 12 kg at a distance of 0.27 m. The lifting aids are shown schematically in Fig. 1 and the real setup is shown in Fig. 2.

Subjects were instructed to lift once per minute the load from a table onto a plateau and after 30 s lower the load back onto the table, for a total of 10 repetitions per condition. The table had a height of 79.5 cm and the plateau had a height of 120.7 cm; both measured from the ground.

Twelve healthy subjects (11 male, 1 female) were recruited from the university population. Average subject characteristics were 23.3 ± 1.8 years of age and 185 ± 7 cm in length. Subjects were aware of the goal of the study and blinding was not possible. We met institutional requirements and informed consent was obtained from all subjects.

EMG of the ES was measured using the Delsys Trigno wireless EMG system (Delsys Inc., Boston, MA). Electrodes were placed 3 cm lateral from the spinous process of the L3 [2]. An online tool was used to fill in the NASA-TLX. Subjects were asked after the experiment which compensation method they preferred, and why.

From the EMG data, peak muscle activity was investigated, because this would relate to peak spinal compression. The envelope of the EMG signal was calculated by phase-lag free (Matlab filter `filtfilt`) high-pass filtering (10 Hz 4th order

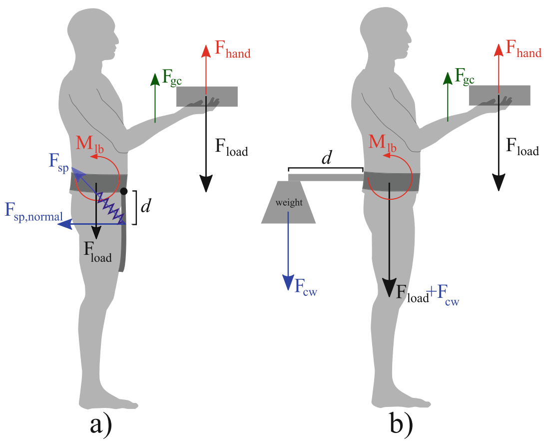
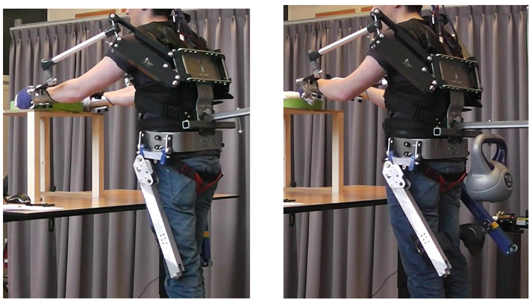


Fig. 1 Schematic view of the assistive device with only relevant forces to show the contribution to moments around and forces in the lower back. A load F_{load} is held at distance d_{load}. A gravity compensator (its weight and reaction force omitted for clarity, see Fig. 2) assists with force F_{gc}. The human generates a residual lifting force F_{hand} at the hand and an extension moment M_{lb} at the lower back. The moment in shoulder is omitted for clarity. **a** The spring mechanism provides an almost constant force at the leg-interface $F_{sp,normal}$, over distance d, assisting the extension moment, irrespective of the angle made with the rest of the suit. **b** The counterweight generates a gravity force F_{cw}, at a distance d, assisting the extension moment. The downward force experienced at the hip is higher than in (**a**) due to the counterweright F_{cw}

Fig. 2 The gravity compensation device on the upper back assists in lifting 50 % of the weight. **a** The spring mechanism pushes on the upper legs to generate an assistive moment in the lower back. **b** a heavy counterweight of 12 kg delivers an assistive moment in the lower back



(a) Spring Mechanism (b) Counterweight

Butterworth), full wave rectification and phase-free low-pass filtering (3 Hz 2nd order Butterworth). Peak muscle activity for the left ES was calculated per lift or lowering as the highest peak of the EMG envelope. Due to the lack of space, the right ES data is omitted. EMG data was normalized to a % maximum voluntary isometric contraction (MVIC), which was determined before the experiment. From the 10 task repetitions, the compound mean peak activity was determined. This measure, as well as the overall workload score from the NASA-TLX, were compared in a repeated measures ANOVA.

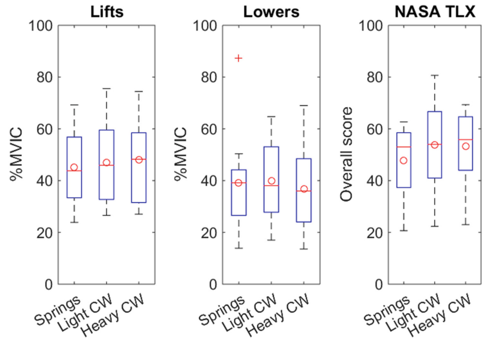


Fig. 3 Peak activity for the left erector spinae longissimus during lifts (**a**) and lowers (**b**) and the overall score for the NASA Task Load Index (TLX) (**c**). The mean is indicated by the *red circle*, the median by the *red line*. No statistical difference was found between the different moment compensation methods for either lifts, lowers, or the workload. CW: Counterweight

3 Results

Repeated measures ANOVA showed that the peak EMG activity was not significantly affected by the type of moment compensation provided. For the left ES during the lifts $F(2, 22) = 2.78$, $p > 0.05$. For the left ES during the lowers $F(2, 22) = 1.21$, $p > 0.05$.

The results show that the overall TLX score was not significantly affected by the type of moment compensation provided, $V = 0.17$, $F(2, 10) = 1.01$, $p > 0.05$.

On the question which of the three methods was most preferred, 10 out of 12 subjects answered the springs mechanism. One subject prefered the heavy, and one prefered the light counterweigt. The main motivation for preferring the spring mechanism was its low weight, compared to the counterweights and its reduced inertia during (especially rotational) movements.

4 Discussion

Results show no obvious differences between the mean peak EMG activity for the type of moment compensation provided; this holds for both the lifts and the lowers. Mean peak EMG activity is somewhat lower for the lowers than for the lifts. This is likely due to subjects first pulling the load towards themselves before lifting the load from the plateau and placing it down on the table. The workload, quantified by the NASA TLX, also shows very little difference between the different moment compensation methods.

There was no significant difference found for the workload. This does not correlate to the subjective preference of the subjects, since 10 out of 12 subjects indicated to prefer the spring mechanism over either of the counterweights. This, and the fact that no statistically significant difference in peak EMG was found, shows that a constant spring force mechanism is a feasible and prefered alternative to heavy counter-weights.

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