

Design of a passive upper-limb exoskeleton and its effects on muscle activity

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Introduction

Although weapons are vital to a soldier's operational effectiveness and survivability, the weight from holding the weapon can quickly result in upper extremity fatigue and loss of aim accuracy, which can negatively affect shooting performance (Haynes et al., 2020).

Soldiers may often experience temporary loss of voluntary force production capacity (localized muscle fatigue) during exertion (Haynes et al., 2020) and sustained operations with target engagement activities. Current upper body exoskeletons are aimed to help individuals in a medical or clinical setting for rehabilitation or occupational assistance (Gopura & Kiguchi, 2009). However, very few upper body exoskeletons have been designed for military application.

One military exoskeleton, developed by the Army Research Laboratory, is the shooter-3-ARM, a body-borne weapon mount system where a passive mechanical arm wraps from behind the body and provides a 'third arm' to the user by supporting the weapon (Haynes et al., 2020). An upper body exoskeleton aimed to assist in holding sustained mass will likely minimize fatigue and prolong muscle endurance which will greatly benefit the soldier during missions. The goals of this study were to (1) design and test an upper body exoskeleton to simulate sustained weapon holding capacity and (2) determine whether the exoskeleton reduced muscle activity compared to no exoskeleton while holding a mass comparable to that of a standard issue military weapon.

Materials and Methods

Exoskeleton (EXO) Design: The EXO was built using repurposed armor, Fusion360, Hypertherm Powermax65, other hardware, and power tools. The development stage consisted of making each part of the full prototype individually to ensure proper function, then putting all the pieces together to make the final product (Figures 1 and 2). Adjustability and strength were two issues that often arose.

Test Procedure: Instructions were given to participants to stand with their dominant arm straight out (90° shoulder flexion) while holding the 8 lb mass.

Figure 1 (right): EXO on a mannequin.



Materials and Methods (continued)

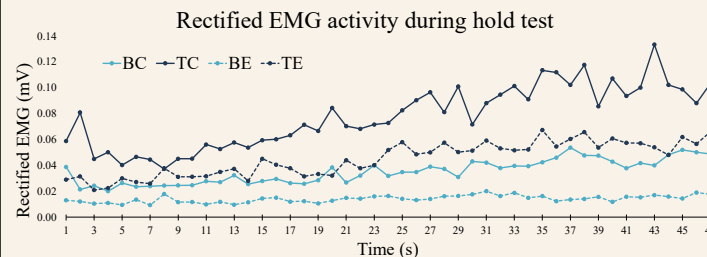
Participants were asked to hold the mass as long as possible without moving or adjusting the arm. A trial ended when the participant either shifted arm position or could no longer hold the weight in the start position. Time from the start to end of a trial was recorded. Three trials were completed without the exoskeleton (control) then with the exoskeleton (EXO). Results from a trial from each condition is shown in Graph 1.

Electromyography (EMG) sensors were placed on the upper trapezius and biceps brachii of the arm. EMG activity (mV) was recorded for each trial. Age ($M = 16.8$, $SD = 1.0$), height ($M = 71.4$, $SD = 22.4$), weight (lb), upper and lower arm measurement (cm), dominant hand, and sport participation were also collected.



Figure 2 (left): Attachment piece that connects the belt to the arm

Results

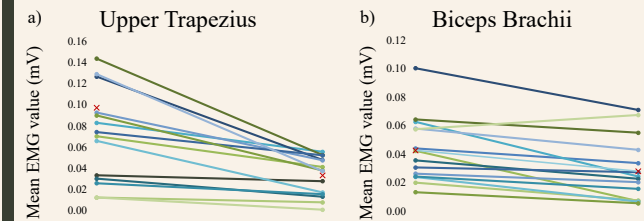


Graph 1 (above): EMG activity for biceps brachii (B) and upper trapezius (T) are shown above for both control (C, solid lines) and EXO (E, dashed lines) conditions of a single trial for one participant. Each point represents the average EMG value over the previous second. The higher the EMG value, the higher the level of effort of the muscle.

EMG activity for the biceps brachii and upper trapezius were significantly lower when the participant used the EXO to hold the mass compared to no EXO (Graph 1).

A paired t -test was conducted on average hold time for the EXO ($M = 37.86$, $SD = 12.82$) and control ($M = 26.92$, $SD = 14.23$). With a 95% CI, a significant difference was found with $p < .001$. Factors, such as prior fatigue, may have impacted results, giving a lower time and a quicker development of muscle fatigue. Age, height, weight, dominant hand, and sports participation did not seem to have a significant effect on the EMG results.

Results (continued)



Graphs 2a and 2b (above): The data displayed is the average mean value from the control condition (left point) and the EXO condition (right point) from each participant. A paired t -test was run on each data set. From the paired t -tests ($n = 14$) with a 95% CI, a significant difference was found between the control and the EXO for the upper trapezius ($M = 0.064$, $SD = 0.027$) (a) and the biceps brachii ($M = 0.015$, $SD = 0.013$) (b) with the p -values $p = .001$ and $p < .001$, respectively. The red \times represents the mean for each data set.

Discussion

Participants were able to hold a mass longer with less upper body muscle activation while using the EXO prototype. These results align with previous studies (Haynes et al., 202; Kong et al., 2023) and further support that upper-limb exoskeletons can be an effective assistive device in reducing physical load, thus reducing upper body muscle activity.

Other factors that weren't collected, such as grip strength, may have impacted the results and should be investigated in the future. Refining the EXO with more robust materials and modifying parts of the design based on findings from this study would be helpful to investigate in the future. Caution should be taken in applying these findings to field performance, where there are less controlled and more dynamic scenarios for holding a mass, like a weapon. Results from this study highlight the benefits of an upper body exoskeleton that could provide aid in load carriage for a military environment.

References

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