# Quantifying Perception of Metabolic Changes from Exoskeleton Assistance

Roberto L. Medrano, Gray C. Thomas, Elliott Rouse

## I. Introduction

Exoskeletons and other wearable robots have shown much promise in improving and augmenting the physical performance of their wearer. A key benchmark for the field has become the reduction of the caloric energy needed for a specific activity, usually level ground walking. By reducing this energy, expressed as the user's *metabolic cost*, required for level ground walking [1]–[4], exoskeletons are demonstrating their ability provide assistance by reducing the physical demands of the activity. Percentage reduction of metabolic cost below the baseline rate (task completion without the exoskeleton) is often used as this metric.

While state-of-the-art exoskeletons have been successful in reducing the metabolic rate of their wearer, it is unknown if users can actually *perceive* these energetic benefits. If users are unable to consciously sense reductions in metabolism at the levels achieved by current exoskeleton technologies, adoption outside the laboratory may suffer. Perceivable changes for a stimulus, such as metabolism, are typically quantified using the *Just Noticeable Difference* (JND) [5]—the stimulus level above which humans can reliably perceive a difference has occurred. Our goal is to quantify the ability of exoskeletons to produce perceivable changes in their wearers' energetics by calculating the JND of metabolic cost during exoskeleton-assisted locomotion.

## II. Methods

We conducted a pilot study using a single subject (female, 25 years old) to obtain a metabolic cost JND. The metabolic cost changes were indirectly imposed by an ankle exoskeleton (ExoBoot, Dephy Inc., Maynard, MA). We applied a parametrized torque profile to the user via this exoskeleton in which we controlled the onset timing of the profile to produce either positive or negative energetic changes [6]. We used the indirect calorimetry (COSMED K5, Rome IT) to measure measure subject energetics [7].

The subject walked at each onset timing for two minutes, which yielded a first-order dynamic response in her metabolic cost [8]. We estimated the steady state cost by the two minute walking plus first order fit method described in [9]. To fit the psychometric function that described the subject's perception, we implemented a modified two-interval forced-choice [5] approach. However, instead of structuring the trials such that each featured one reference and one comparison, as is common in psychophysical protocols, we used every two minute section as a comparison against the one immediately preceding it. This allowed us to not only double the number of responses given over the same time period, but also mitigated the effect of imprecise control of subject energetics through the exoskeleton on the fit of the psychometric function. Using this approach, we recharacterized the input stimulus from metabolic cost to percent metabolic cost change, which allowed us to estimate the Weber Fraction [10] as equivalent to JND.

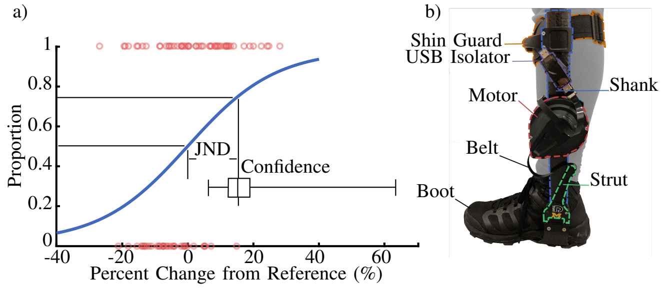


Fig. 1. The pilot results using the proposed SP plan (a). Subject responded (red) to changes in metabolic cost. We then fit a logistic function (blue) and calculated JND to be 15.4% of reference. A box-whiskers plot shows the estimates confidence quartiles which were obtained using bootstrapping. The exoskeleton hardware (b): a motor affixed to a shank structure applies plantarflexive torque via tension belt transmission to a foot-mounted strut.

## III. Results

The resulting JND for the pilot subject was 15.4% of reference (Fig. 1), with a standard deviation of 6.1% using parametric bootstrapping with 10,000 iterations [11].

## IV. Discussion

The JND for the pilot subject indicates that this subject would not be able to reliably perceive the metabolic benefits from state-of-the-art power autonomous exoskeletons [4], [12] compared to the reference condition of unassisted walking. We are currently conducting a full study using this psychophysical protocol, which will yield JND estimates for a greater number of subjects and will further our understanding about the average sensitivity of humans to metabolic cost.

## References

[1] P. Malcolm *et al.*, *PLoS ONE*, vol. 8, no. 2, pp. 1–7, 2013.
[2] L. M. Mooney *et al.*, *EMBC*, vol. 11, no. 1, pp. 3065–3068, 2014.
[3] S. H. Collins *et al.*, *Nature*, vol. 522, no. 7555, pp. 212–215, 2015.
[4] F. A. Panizzolo *et al.*, *Scientific Reports*, vol. 9, no. 1, pp. 1–10, 2019.
[5] F. Kingdom, N. Prins, *Psychophysics*. Springer, 2010.
[6] R. W. Jackson *et al.*, *J. A. P.*, vol. 119, no. 5, pp. 541–557, 2015.
[7] L. Guidetti *et al.*, *PLoS ONE*, vol. 13, no. 12, pp. 1–12, 2018.
[8] J. C. Selinger *et al.*, *J. A. P.*, vol. 117, no. 11, pp. 1406–1415, 2014.
[9] S. H. Collins *et al.*, *Science*, vol. 356, no. 6344, pp. 1280–1284, 2017.
[10] K. H. Norwich, *Perception & Psychophysics*, vol. 42, no. 3, pp. 286–298, 1987.
[11] F. A. Wichmann *et al.*, *Perception and Psychophysics*, vol. 63, no. 8, pp. 1314–1329, 2001.
[12] L. M. Mooney *et al.*, *J. N.E. & Rehab.*, vol. 11, no. 1, pp. 1–5, 2014.