

# Measuring the Just Noticeable Difference of Metabolic Rate with Exoskeleton Assistance

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## I. INTRODUCTION

Researchers have successfully designed wearable exoskeletons that reduced wearers' metabolic expenditures on the order of 10% relative to unassisted walking [1], and the field has converged on this metric as a gold standard by which devices are judged. However, it is not yet clear how well wearers can perceive these changes in metabolic rate; we believe that if the benefits of exoskeleton use are imperceptible, these benefits are unlikely to affect decision making which will hinder translation and public impact. In this work, we quantify this perceptual threshold using the *Just Noticeable Difference* (JND) [2]—the stimulus level above which it can reliably be perceived. Our intent is to provide novel context for how exoskeletons will be perceived by their wearers and to use this information to guide the development of future metrics to quantify the success of these exciting technologies.

## II. METHODS

Ten subjects wearing bilateral ankle exoskeletons (Exo-Boot, Dephy Inc., Maynard, MA), underwent an adapted psychophysical protocol [3] which is robust to the variability of metabolic rate. Subjects experienced different metabolic rates in sequence, which were indirectly controlled by shifting the assistance torque provided by the exoskeleton and measured using indirect calorimetry. Subjects were then prompted to agree or disagree to whether they judged each assistance level to require more metabolic exertion than the level immediately preceding (a *two interval forced choice* test). We aggregated these responses and fit sigmoids that represent the likelihood

of each subject agreeing with the prompt based on the percent change in metabolic rate across profiles; the JND is parametrized by the slope of these response curves.

## III. RESULTS & DISCUSSION

Our results elucidate how changes in metabolic rate are *perceived* by the wearer during exoskeleton-assisted locomotion (Fig. 1). The average inter-subject threshold was 22.7% ( $\pm 17.0\%$ ). This indicates that on average and in the short term, subjects cannot perceive the metabolic benefits from modern exoskeletons. This work also underscores the need to develop new metrics that provide more appropriate and accessible information on exoskeleton success.

## IV. CONCLUSION

We characterized the perception of the metabolic benefits from modern exoskeletons. The perceptual insensitivity to metabolic rate has implications for the field of wearable robots, biomechanics, and physiology, highlighting that metabolic rate alone may not be an ideal metric of success for modern exoskeletons, and future work is needed to discover new metrics that are relevant, informative, and perceivable to their wearers.

## REFERENCES

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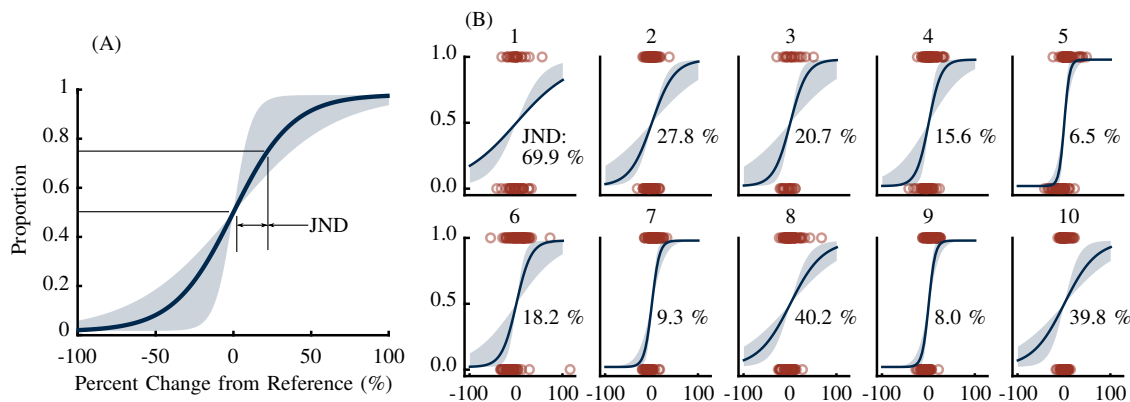


Fig. 1. (A) The psychophysical curve corresponding to the inter-subject average (solid blue, 22.7%) with one inter-subject standard deviation (shaded,  $\pm 17.0\%$ ). (B) Subject-specific data: the likeliest psychophysical curve (solid blue), subject responses (red circles), and the 95% credible interval (shaded blue).