INTRODUCTION
When we walk, we prefer a particular step width, and execute this preference with remarkably small variability [1]. In arriving at this preference, the nervous system may consider objectives such as metabolic energy, stability, and maneuverability. These objectives may have different weightings or be treated as constraints depending on the walking context. The purpose of our study was to understand how the nervous systems of able-bodied people weigh objectives when determining the preferred width. We hypothesize that during walking, energy is highly weighted and continuously optimized to determine the preferred width.

METHODS
To test this hypothesis, we built a custom device that uses closed-loop control to apply energetic penalties as a function of step width to shift the energy optimal width wider than that initially preferred (Figure 1a, 1b, and 1c). First, in order to design the control function, we established each subject’s preferred step width and step width variability. Next, we turned the controller on and measured whether subjects would adapt their preferred width towards the energy optimal width spontaneously, and then when provided experience with the new cost landscape. Finally, we mapped each subject’s new cost landscape to verify that we had indeed shifted the energy optimal width to a width wider than that initially preferred.

![Figure 1](image)

**Figure 1:** a) We combine a constant energetic reward, achieved by applying a forward horizontal force to a hip-belt worn by the user, with a controllable energetic penalty, achieved by manipulating treadmill incline. b) Our real-time visual feedback allows us to enforce specific step widths during the experiment protocol. c) We add the energetic cost of the control function (red dashed) to the natural cost landscape (grey) to produce the new cost landscape (red).

RESULTS AND DISCUSSION
We tested 8 able-bodied young adults and found that preferred step width in a new cost landscape was determined by continuous energy optimization. When the controller was first turned on, subjects did not spontaneously adapt their width towards the energy optimum (Figure 2b, pre-exploration). Only after a perturbation to a lower cost width did subjects begin to adapt (p=8.0x10^{-5}) (Figure 2b, release 2). With each perturbation after, subjects gradually converged on the energy optimum (Figure 2b, releases 3-7). The final preferred width was 3.5±0.8 standard deviations away from that initially preferred (p=3.7x10^{-5}; mean±SD) (Figure 2b, post-exploration). This width reduced energetic cost, on average, by 14.2±6.1% (mean±SD) relative to the cost at the initially preferred width in the new cost landscape.

![Figure 2](image)

**Figure 2:** Averaged across 8 subjects: a) Experimental protocol with perturbations to different step widths in the new cost landscape. b) Step width when allowed to self-select steps after each perturbation. Error bars represent 1 SD. Asterisks indicate that the value is significantly different from the initially preferred step width. c) New cost landscape. The curve is a third-order polynomial fit, and the shading shows the 95% confidence interval.

Importantly, energy optimization may not be the only objective of the nervous system in determining preferred step width. For example, it may also seek to optimize step width for stability and maneuverability. That people normally prefer to walk at their energy optimum does not rule out contributions from other objectives as their sum may also be optimized at the original preferred step width. Our experiment was designed to only change energy as a function of width, leaving the other contributing objectives unchanged. Our finding that people’s new preferred step width is at the new energy optimum, rather than lying between the original and new energy optima, indicates that the nervous system heavily weights energetic cost in determining preferred step width.

CONCLUSIONS
We conclude that the nervous systems of able-bodied people highly weight energetic cost and continuously optimize it to determine the preferred step width. This builds on our recent finding that continuous energy optimization controls preferred step frequency [2]. These two findings use two different methods of manipulating cost landscapes and study two different gait parameters, suggesting that continuous energy optimization is a dominant and general objective in able-bodied walking.

REFERENCES