Effort-o-Meter: the relationship between effort of walking and amount of walking performed

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1 Introduction

Walking is an effective method for promoting activity among sedentary groups, and people adhere to walking routines more than other, more vigorous exercise regimens [1, 2]. Slightly increasing the metabolic cost of walking could be a simple method of increasing overall physical activity in the overweight or obese. However, while increasing the energy cost per step would increase net metabolic cost if all conditions (distances, velocities, etc.) were kept constant, this benefit could be reduced or eliminated if the subject reduces overall activity due to the higher cost.

In this study, we explored whether a modest increase in energy cost per step affected overall energy consumption from walking over a one week period compared to normal walking energy expenditure. We hypothesized that even a small increase in energy cost per step would cause the amount of walking performed to be reduced so dramatically that the overall energy cost would be decreased. The results of this study not only have implications for prescribing exercise regimens to improve public health and promote weight loss, but also help understand the expected impact of energy-saving prostheses and orthoses on exercise obtained during walking.

2 Methods

Two pairs of flat-soled sneakers were constructed: one pair weighted and one pair unweighted. A foam platform was attached to the sole to house an inertial monitoring unit (Sapphire Inertial Monitor, APDM, Inc.) and weight, if applicable. A steel bar was used to generate the appropriate mass, which was calibrated to equal approximately 2.5% of the user's body weight, or 1.25% of body weight per foot. The total load was expected to correspond to roughly a 25% energy increase per step in the user [3].

Twenty-four able-bodied participants with no cardiovascular, respiratory, metabolic or orthopedic conditions were recruited at Carnegie Mellon University. Five voluntarily withdrew before completion of the protocol due to discomfort while wearing the shoes, especially the weighted shoes. An additional nine had unusable data for a variety of reasons, including not wearing the shoes for more than 12 hours per day, large periods of unexplained time (> 4 hours) spent with the shoes off, and changing environmental conditions between the two weeks. For example, one subject had access to a car one week, but not the next, so changes in walking behavior were compulsory and not due to the shoes.

The remaining subjects (n=10, 7 male, 3 female, 23.60±2.88 years, 22.86±2.52 kg/m^2 body mass index) were asked to wear the shoes all day except when sleeping or bathing. Additional activities that required the use of other shoes or no shoes (running, swimming, etc.) were logged and kept consistent between the two weeks to minimize misrepresentations in total energy costs. Subjects were randomly given one of the two pairs of shoes for one week, and the second pair for an additional week. It was expected that one week would be adequate time for any behavioral changes to surface. Furthermore, subjects were not informed of the exact nature of the data being collected and motivation behind the study to minimize data biases due to conscious decisions to alter walking behavior. Study protocol was approved by the Carnegie Mellon University Institutional Review Board, and written informed consent was obtained from all subjects after the nature and possible consequences of the study were explained.

At the completion of the community-based collection, the participant answered three pairs of qualitative questions regarding the shoes (Fig. 1). Subjects then walked on a treadmill wearing each pair of shoes at five different speeds and grades while oxygen consumption was measured. The order in which the shoes were worn was randomized, as were the conditions for that particular shoe. Whole body oxygen consumption was measured for each condition using an indirect respirometry system (Jaeger Oxycon Mobile).

Data from the inertial monitor was numerically integrated [4] using IMUWalk software (Intelligent Prosthetic Systems, LLC) to estimate foot placement and timestamps for each step, but slope information was ultimately ignored due to drift issues in the monitor. Future versions could use GPS to estimate altitude. Foot velocities, distance walked, and stride lengths were calculated. Velocities less than 0.5 m/s or greater than 2.5 m/s were excluded from analysis to ensure all steps analyzed were due to walking, not running or foot tapping. Stride lengths smaller than 0.15 m or greater than 2 m were also excluded to eliminate "false positives." Subjects' metabolic power data was used in conjunction with the processed monitor data to determine total metabolic cost while wearing the shoes. A paired t-test was used to determine statistical significance at 95% CI.

3 Results

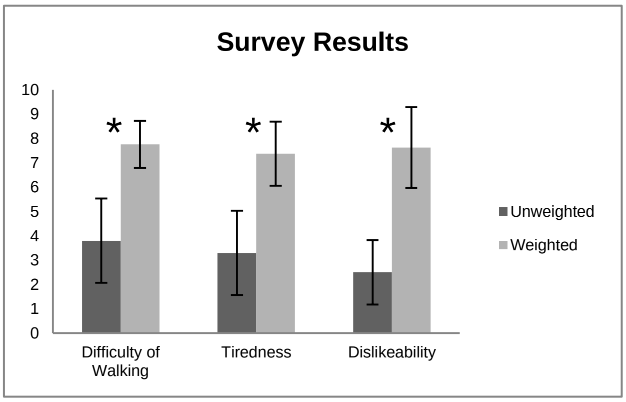

Figure 1: Survey results from all participants showing strong dislike of the heavy shoes. Asterisks denote a significant difference.

The shoes were worn for at least 12 hours per day with an average time of 14.25±1.32 hours spent in the unweighted shoes and 13.95±0.97 hours spent in the weighted shoes and no significant difference in times ($p = 0.22$). The weighted shoes created a 27.1±16.4% increase in metabolic rate while walking at 1.25 m/s on level ground.

Increasing metabolic cost of walking caused acute discomfort in users. Survey results (Fig. 1) revealed participants strongly disliked wearing the weighted shoes ($p < 0.001$), rating them 6.80±2.62 out of 9, where 9 was strongly dislike, and rating the unweighted shoes 2.50±1.27 out of 9. They also found them much more tiring (7.10±1.37 out of 9 weighted, 3.30±1.77 out of 9 unweighted, where 9 is very tiring, $p < 0.01$).

Despite their dislike of the shoes, participants maintained the same distance walked per day (2.79±2.5 km/day in unweighted, 2.78±2.28 km/day in weighted, $p = 0.91$) and number of strides per day (2,583±1,492 strides/day in unweighted, 2,584±1,378 strides/day in weighted, $p = 0.87$), with no change in average velocity (1.08±0.19 m/s in unweighted, 1.08±0.15 m/s in weighted, $p = 0.98$), resulting in a significant increase in total energy cost when wearing the weighted shoes compared to the unweighted shoes (6,739±5,576 J/kg/day in unweighted, 8,058±6,152 J/kg/day in weighted, $p = 0.002$) (Fig. 2). Indeed, all but one subject had increased energy expenditure in the weighted shoes despite large differences in baseline energy use (Fig. 3).

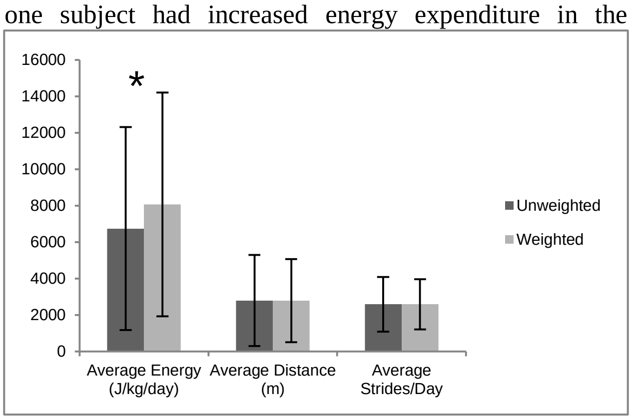

Figure 2: Average values for energy cost, distance traveled, and strides/day. Asterisks denote a significant difference.

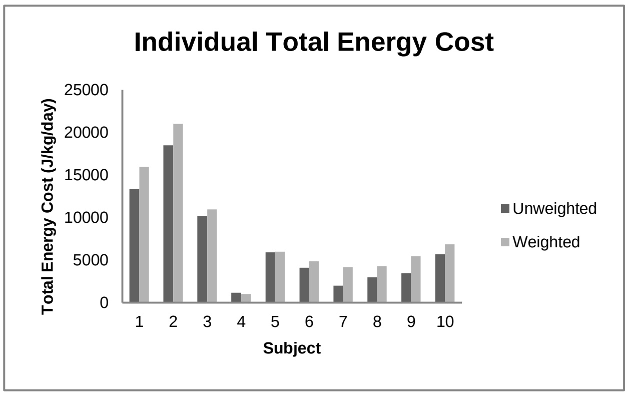

Figure 3: Average energy costs for each subject, showing high variability in baseline energy use between participants.

4 Conclusion

Our hypothesis was incorrect; subjects did not significantly change their behavior when presented with high-effort shoes. As lifestyles become more sedentary and as the number of overweight and obese individuals increase, it may be a viable solution to increase physical activity levels by increasing the metabolic cost per step of walking, since humans already spend a large portion of their time walking. However, more extreme behavioral changes may appear over longer periods of time. Poor protocol adherence was major problem among our subjects, largely due to the discomfort of the weighted shoes, an effect which may be compounded in the long term. Additionally, all subjects in this study were young, healthy university students living in Pittsburgh, where driving to school is relatively uncommon among the student body, so our population is not indicative of the average overweight American. More study is needed among clinically overweight and obese individuals who lead sedentary lifestyles.

Acknowledgements

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