Shod vs. Barefoot Walking: Why do humans change their step frequency?

Matthew B. Yandell & Karl E. Zelik

Mechanical Engineering, Vanderbilt University, Nashville, TN, USA

Background

People seem to:

1) Choose a step frequency that minimizes metabolic cost during shod walking [Zarrugh 1974]
2) Increase step frequency when barefoot as compared to shod [Grieve 1966, Lythgo 2009]

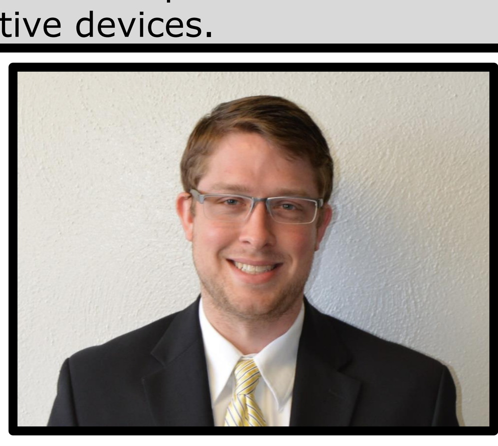
Open Questions

1) Do people increase their step frequency when barefoot to reduce/minimize metabolic cost?
2) If not, what factor(s) account for the change in step frequency?

Methods Phase I:
We studied 10 subjects (mean ± SD, 21.5 ± 3.2 years old, 67.8 ± 9.4 kg, 171.8 ± 9.7 cm height) during level walking on an instrumented split-belt treadmill. At the beginning of each experiment subjects performed treadmill acclimation/training trials at 1.4 m/s. These trials were used to determine each subject's baseline self-selected (SS) step frequency while both shod and barefoot. We then tested subjects walking barefoot at their barefoot vs. shod SS step frequencies, using an ABBA experimental design. Each subject was also asked to walk while matching the frequency of a metronome for 6 randomized conditions, from 85% to 110% of their barefoot SS step frequency. A metabolic system was used to measure the subject's oxygen uptake and carbon dioxide production rates for about 7 minutes, until a steady state period of sufficient length was achieved. Net metabolic data were averaged over the last 2.5 minutes of the trial and used to calculate metabolic power. The metabolic results were used to determine if the energy consumed during barefoot walking was reduced at the barefoot self-selected frequency. Ground reaction force (GRF) data were also collected and will be analyzed in future work. Statistical analysis was performed using ANOVA with significance level of 0.05.

Methods Phase II:
We studied 4 subjects (mean ± SD, 33.0 ± 12.8 years old, 89.4 ± 8.9 kg, 180.2 ± 2.0 cm height) during level walking on an instrumented split-belt treadmill. At the beginning of each experiment subjects performed treadmill acclimation/training trials. Next, each subject was asked to walk at 1.4 m/s while performing 15 different conditions to estimate changes due to shoe parameters (mass, length, and height). Ground reaction force (GRF) data were collected and used to compute step frequency. Individual limb COM power analysis will be performed in future work.

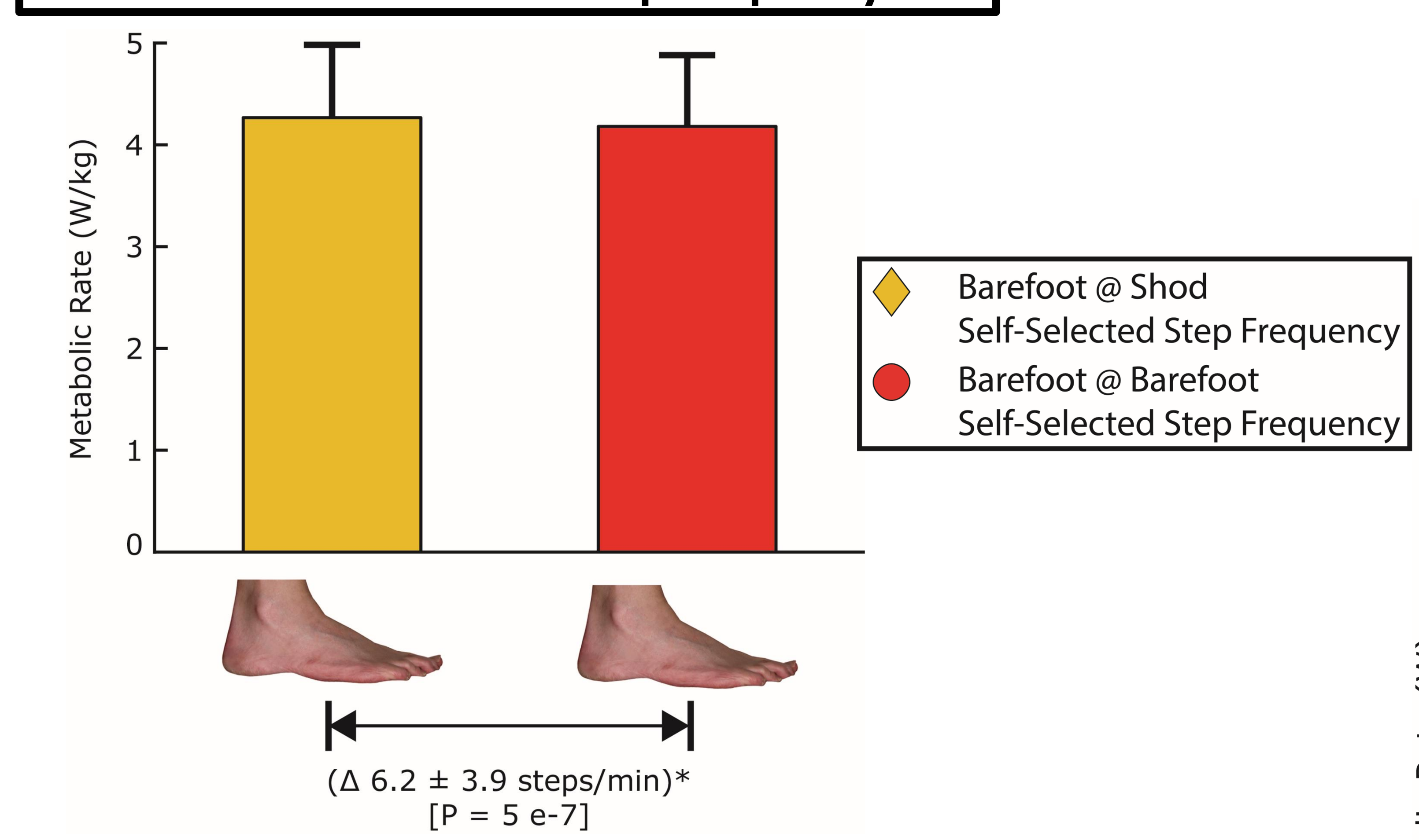
Discussion and Future Work:
Only 50% of individuals tested showed a consistent decrease in metabolic rate at the barefoot SS frequency; meanwhile, 30% of subjects showed the opposite trend. Thus the increase in step frequency from shod to barefoot was not well explained by a desire to reduce metabolic rate. Averaging across subjects may obscure subject-specific trends. The majority of the SS step frequency change between shod and barefoot walking seems to be explained by the shoe mass, length, and height. The remaining change may be explained by shoe cushioning [Tung 2014] and will be tested in upcoming studies. This study may enhance our ability to predict optimal footwear and potentially reduce the metabolic cost of locomotion on an individual basis. Similar methods might be applied to understand and improve other assistive or rehabilitative devices.



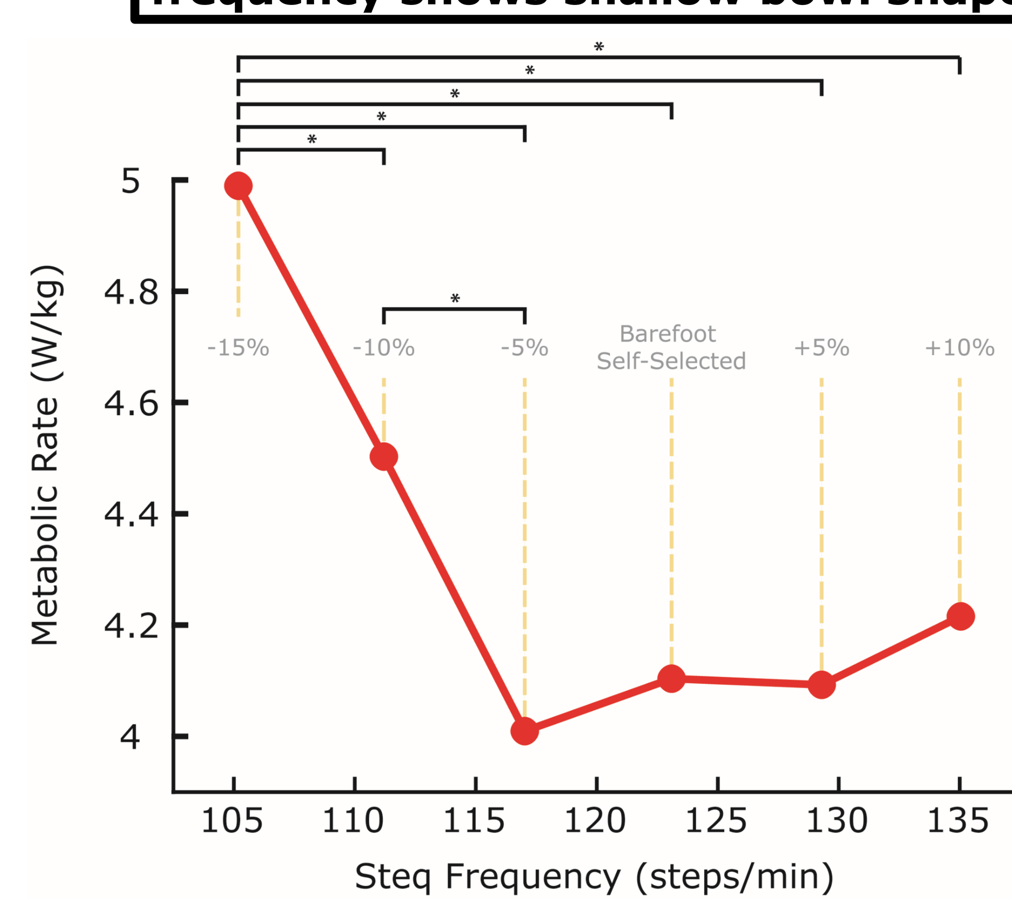
matthew.yandell@vanderbilt.edu
my.vanderbilt.edu/batlab/

Phase I: Barefoot Metabolic Cost

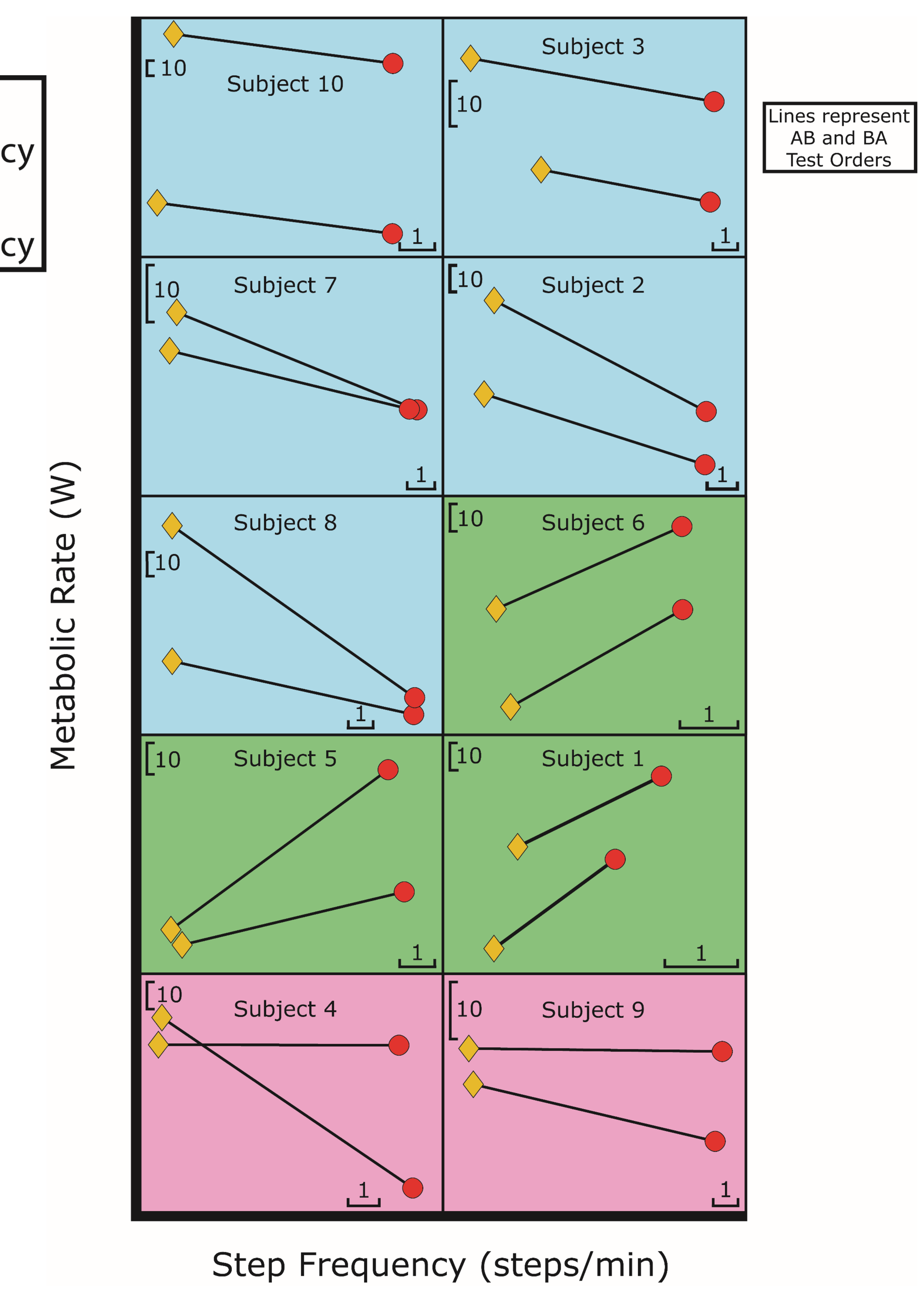
Barefoot self-selected step frequency did not result in reduced metabolic rate compared to shod self-selected step frequency



Barefoot metabolic rate vs. step frequency shows shallow bowl shape



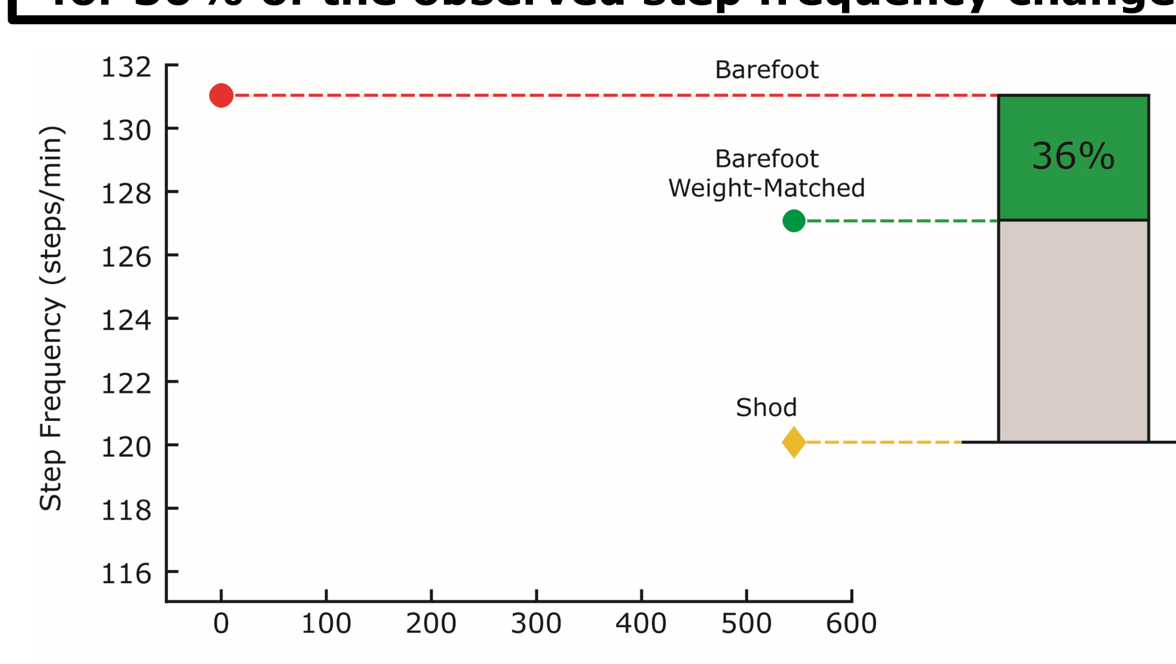
Subject specific trends in metabolic rate were observed



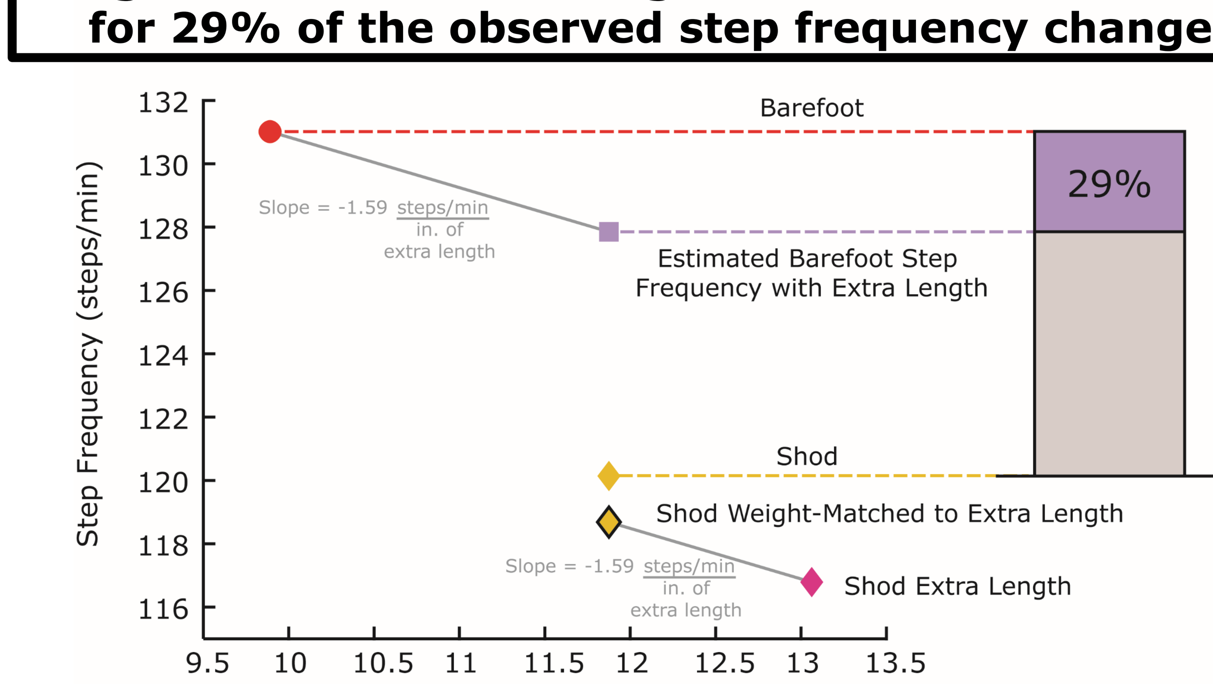
Conclusion:
Barefoot walking metabolic rate at the SS step frequency was not significantly less than walking at the shod SS step frequency, but individual subjects showed distinct directional trends in metabolic rate.

Phase II: Step Frequency Changes

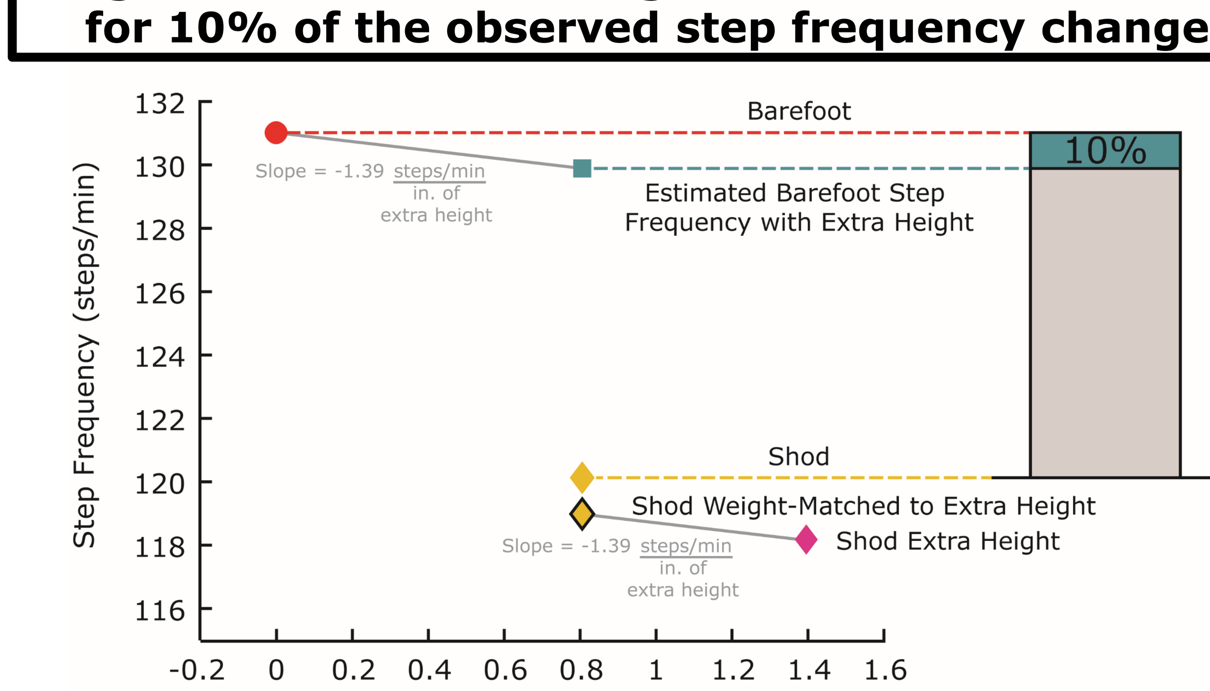
Mass: The additional mass of the shoe accounted for 36% of the observed step frequency change

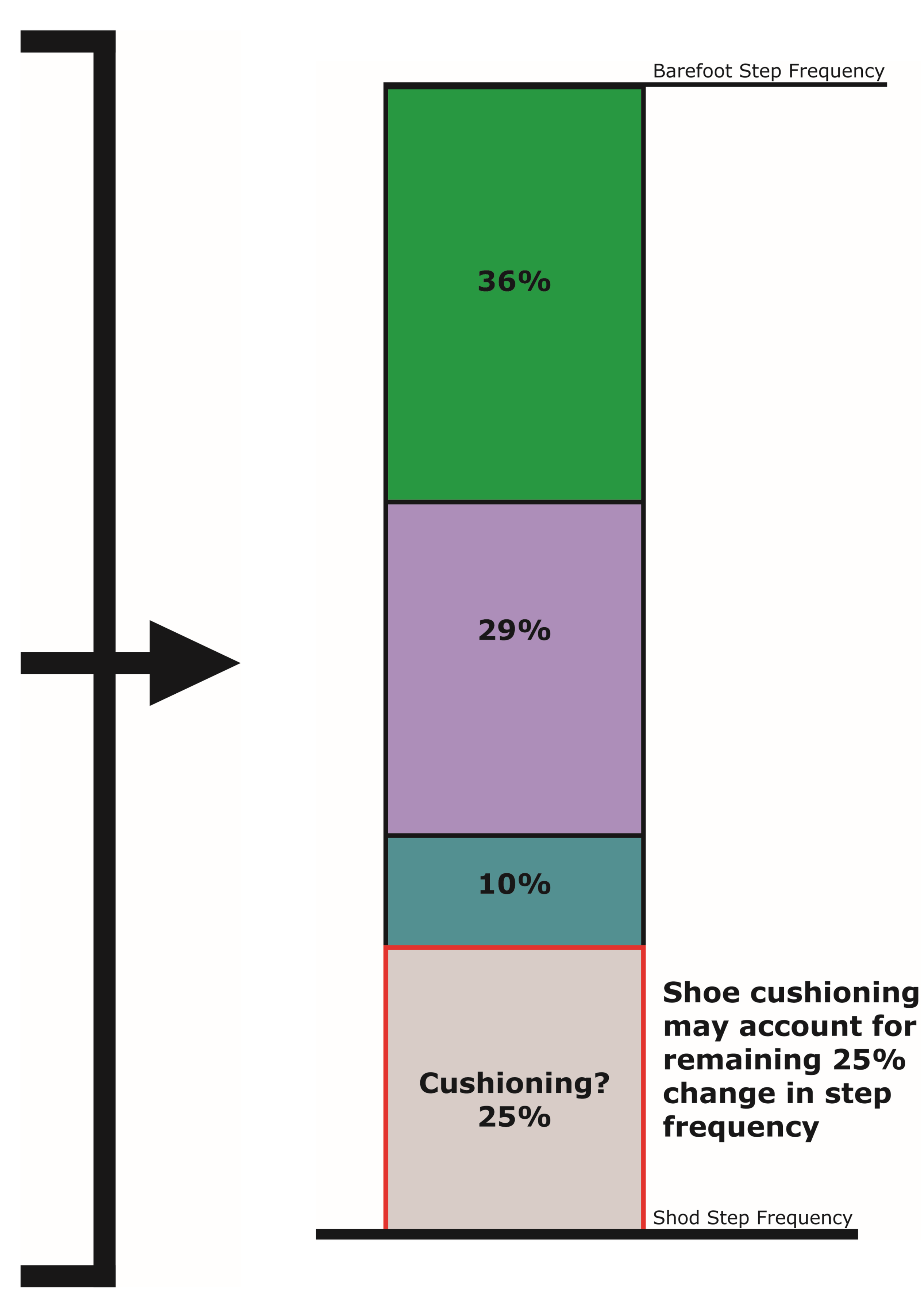


Length: The additional length of the shoe accounted for 29% of the observed step frequency change



Height: The additional height of the shoe accounted for 10% of the observed step frequency change





Conclusion:
Shoe mass, length, and height explained 75% of the observed step frequency change in barefoot vs. shod walking. Shoe cushioning is an untested parameter that may explain the remaining 25%.