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The mass-specific energy cost of human walking is set by stature

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The metabolic and mechanical requirements of walking are considered to be of fundamental importance to the health, physiological function and even the evolution of modern humans. Although walking energy expenditure and gait mechanics are clearly linked, a direct quantitative relationship has not emerged in more than a century of formal investigation. Here, on the basis of previous observations that children and smaller adult walkers expend more energy on a per kilogram basis than larger ones do, and the theory of dynamic similarity, we hypothesized that body length (or stature, L_b) explains the apparent body-size dependency of human walking economy. We measured metabolic rates and gait mechanics at six speeds from 0.4 to 1.9 m s^{-1} in 48 human subjects who varied by a factor of 1.5 in stature and approximately six in both age and body mass. In accordance with theoretical expectation, we found the most economical walking speeds measured (J kg^{-1} m^{-1}) to be dynamically equivalent (i.e. similar U, where U=velocity^2/gravity · leg length) among smaller and larger individuals. At these speeds, stride lengths were directly proportional to stature whereas the metabolic cost per stride was largely invariant (2.74±0.12

J kg^{-1} $stride^{-1}$). The tight coupling of stature, gait mechanics and metabolic energy expenditure resulted in an inverse relationship between mass-specific transport costs and stature ($E_{trans}/M_b \propto L_b^{-0.95}$, J kg^{-1} m^{-1}). We conclude that humans spanning a broad range of ages, statures and masses incur the same mass-specific metabolic cost to walk a horizontal distance equal to their stature.

Key words: metabolism, scaling, locomotion, biomechanics

Abbreviations: $\dot{E}_{metab}$, energy expenditure • $\dot{E}_{metab\text{-}net}$, net energy expenditure • E_{trans}, walking transport cost • $E_{trans\text{-}min}$, minimum transport cost • f_{str}, stride frequency • $\boldsymbol{g}$, gravity • L_b, body length (stature) • L_{leg}, leg length • L_{str}, stride length • M_b, body mass • t_c, foot ground-contact time • t_c/t_{str}, duty factor (ratio of foot ground-contact time to total stride time) • t_{str}, total stride time • U, index of equivalent speed • V, walking speed