INTRODUCTION
In walking, humans maintain lateral balance by varying step width [1] but prefer a moderate step width that minimizes metabolic cost. Walking with step widths that are narrower or wider than the preferred step width is metabolically more expensive [2]. In comparison to walking, humans prefer to run with much narrower step widths which would seem to present a challenge for maintaining lateral balance.

McClay et al. [4] speculated that medio-lateral (M-L) foot placement during running may be important in minimizing the muscular effort needed to maintain lateral balance. This implies that like in walking, there may be a preferred (and energetically optimal) step width in running that minimizes metabolic cost. Swinging the arms is also thought to improve “balance” and possibly reduce the energetic cost of running [3]. We tested these ideas experimentally to gain insight into the energetic cost and balance during running.

To understand the roles of step width and arm swing in human running, we tested 4 specific hypotheses as follows: The rate of $O_2$ consumption will be greater 1) at step widths greater or less than preferred and 2) when arm swing is eliminated. Step width variability will be greater 3) at step widths greater or less than preferred and 4) when arm swing is eliminated.

METHODS
Ten healthy young subjects (5M/5F, 24.4 ± 4.2 yrs, 65.4 ± 11.7 kg, Leg Length (LL) = 93.1 ± 5.6 cm; mean ± SD) ran at 3 m/s on a force measuring treadmill for randomized conditions of target step widths (i.e. 0%, 15%, 20%, and 25% LL), at preferred step width with arm swing (Arms), and at preferred step width without arm swing (No Arms).

During each 7-minute trial, we measured the 3-D motions of the legs (Motion Analysis Corp.), ground reaction forces (AMTI), and rates of $O_2$ consumption ($\dot{V}O_2$) using expired gas analysis (Parvo Medics). During the target step width conditions, we provided real-time visual feedback of foot placement using a computer monitor positioned in front of the subject (Fig. 1). Reflective markers were placed on the heel, mid-foot, and toe of each shoe. Subjects were instructed to place each heel on the respective virtual lines at the instant of heel-contact. The 0% LL trial was achieved by projecting a single virtual line. During the No Arms condition, subjects crossed their arms in front of their chest.
reached a threshold of 10%BW. Step width variability was defined as the standard deviation about the average step width [1]. An increase in step width variability signified a decrease in lateral balance while running.

The net rate of O₂ consumption (ml/kg/min) was calculated by subtracting the average standing rate of O₂ consumption from the total rate of O₂ consumption during the last 3 minutes of each running condition. For each dependent measure, we used repeated measures ANOVA with a priori comparisons between the Arms conditions and the target step width conditions using a Bonferroni correction (α = .0125). To compare between Arms and No Arms, we used paired t-tests with statistical significance set an α level of .05.

RESULTS AND DISCUSSION

Rate of O₂ Consumption: Subjects consumed O₂ more rapidly when running at target step widths greater or less (p < .001) than the preferred step width (Arms). Compared to the Arms condition, the rate of O₂ consumption was 4, 8, 11, and 15% greater at target step widths of 0, 15, 20, and 25% LL, respectively (all p’s < .0125, Fig. 2). When arm swing was eliminated, the rate of O₂ consumption was 8% greater than running with normal arm swing (p < .001, Fig. 2).

Step Width Variability: Step width variability was greater when subjects ran at target step widths greater (p < .001) than the preferred step width. Compared to the Arms condition, step width variability increased by 38, 48, and 69% at target step widths of 15, 20, and 25% LL, respectively (all p’s < .0125, Fig. 3). Mean step width variability at the 0% target step width was 7% greater than the Arms condition but the difference was not statistically significant (p = .09). During No Arms, step width variability was 9% greater (p = .012) than the Arms condition. In general, running with step widths other than preferred or without arm swing decreased lateral balance as indicated by an increase in step width variability.

CONCLUSIONS

While running, humans appear to choose their step width and swing their arms so as to minimize metabolic cost and optimize for lateral balance.

REFERENCES


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