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The effects of step width and arm swing on energetic cost and lateral balance during running

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ABSTRACT

In walking, humans prefer a moderate step width that minimizes energetic cost and vary step width from step-to-step to maintain lateral balance. Arm swing also reduces energetic cost and improves lateral balance. In running, humans prefer a narrow step width that may present a challenge for maintaining lateral balance. However, arm swing in running may improve lateral balance and help reduce energetic cost. To understand the roles of step width and arm swing, we hypothesized that net metabolic power would be greater at step widths greater or less than preferred and when running without arm swing. We further hypothesized that step width variability (indicator of lateral balance) would be greater at step widths greater or less than preferred and when running without arm swing. Ten subjects ran (3 m/s) at four target step widths (0%, 15%, 20%, and 25% leg length (LL)) with arm swing, at their preferred step width with arm swing, and at their preferred step width without arm swing. We measured metabolic power, step width, and step width variability. When subjects ran at target step widths less (0% LL) or greater (15%, 20%, and 25% LL) than preferred, both net metabolic power demand (by 3%, 9%, 12%, and 15%) and step width variability (by 7%, 33%, 46%, and 69%) increased. When running without arm swing, both net metabolic power demand (by 8%) and step width variability (by 9%) increased compared to running with arm swing. It appears that humans prefer to run with a narrow step width and swing their arms so as to minimize energetic cost and improve lateral balance.

1. Introduction

Minimizing energetic cost and maintaining lateral balance are important goals in human locomotion. Humans prefer to walk with a moderate step width (~12 cm) that minimizes energetic cost (Donelan et al., 2001). In contrast, humans run with a step width near zero (Cavanagh, 1987), which would seem to challenge lateral balance and incur a greater energetic cost. Humans also prefer to swing their arms while walking and walking without arm swing increases energetic cost (Collins et al., 2009; Ortega et al., 2008). In running, arm swing may assist with lateral balance and possibly reduce energetic cost. In this study, we investigated if humans not only minimize energetic cost but also optimize for lateral balance while running.

There are many examples of energetic optimization in human locomotion. The energetic cost of walking per unit distance (cost of transport) plotted as a function of speed exhibits a U-shaped curve with a minimum close to the preferred walking speed (Martin et al., 1992; Ralston, 1958; van der Walt and Wyndham, 1973; Workman and Armstrong, 1963; Zarrugh et al., 1974). Similarly, if walking or running speed is fixed and stride frequency is varied, energetic cost also exhibits a U-shaped relationship with a minimum near the preferred stride frequency (Cavanagh and Williams, 1982; Hogberg, 1952; Holt et al., 1991; Umberger and Martin, 2007). The walk–run transition occurs near the speed at which running becomes more economical than walking (Mercier et al., 1994). Thus, the idea that humans prefer to walk or run in a manner that minimizes energetic cost is generally accepted.

Minimizing energetic cost, however, is not the only goal during human locomotion. Maintaining lateral balance is a critical prerequisite that involves active control via sensory feedback (Bauby and Kuo, 2000; Donelan et al., 2004). One way humans demonstrate active control of lateral balance in walking is by varying step width from step-to-step (Bauby and Kuo, 2000) but humans prefer an average step width that minimizes energetic cost. Walking with step widths narrower or wider than preferred is energetically more expensive (Donelan et al., 2001). In contrast, humans run with much narrower step widths (Cavanagh, 1987). Placing the foot along the midline of the body aligns the vertical ground reaction force close to the whole body center of mass (Fig. 1; Cavanagh, 1987; McClay and Cavanagh, 1994). Thus, the

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