DISINTEGRATING THE METABOLIC COST OF HUMAN RUNNING: WEIGHT SUPPORT, FORWARD PROPULSION, AND LEG SWING

Erin M. Warddrip and Rodger Kram

Locomotion Lab, Integrative Physiology Dept. University of Colorado, Boulder, CO USA
E-mail: erin.warddrip@colorado.edu Web: www.colorado.edu/intphys/research/locomotion.html

INTRODUCTION

Running is a natural, intuitive motion. Analytically however, running is a composite of specific tasks including weight support, forward propulsion, leg swing, braking, arm swing, and balance. Our previous studies have inferred the metabolic cost of separate tasks by using assistive devices to reduce the metabolic cost (Chang and Kram 1999, Moed and Kram 2005, Teunessen et al. in review). However, we have not accounted for synergies between the tasks.

The purpose of this study was to ascertain the energetic costs of three individual tasks that comprise running, i.e. weight support, forward propulsion, and leg swing. We applied combinations of assistive devices to runners, measured the subsequent decreases in metabolic rate and deduced the cost of normally performing each task.

METHODS

Five healthy, fit, adult runners (3M, 2F) volunteered. We measured metabolic rate via expired gas analysis during standing, running at 3.0 m/s normally, and with combinations of assistive devices. We calculated net metabolic rate as (running – standing). The first assistive device provided weight support (WS) via a waist harness (Figure 1A). To assist with forward propulsion, a device pulled with an aiding horizontal force (AHF) at the waist (Figure 1B). A third device provided leg swing assist (LSA), by applying a forward pulling force to the feet during the first half of the swing phase (Figure 1C). We tested 12 combinations of these assistive devices over two sessions. Guided by previous experiments, these trials consisted of 4 levels of body weight (100, 75, 50 and 25%) combined with AHF values of 10% of effective weight and LSA of 2% of normal body weight.

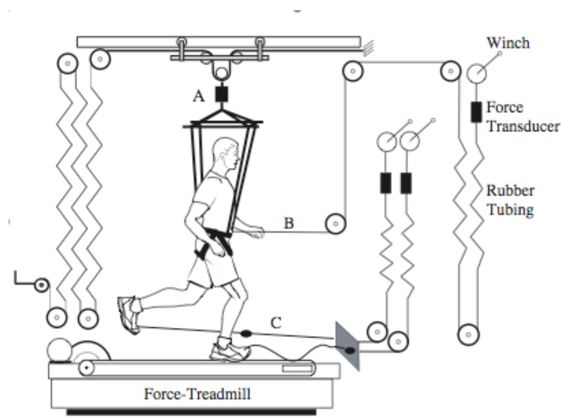

Figure 1: Schematic of Setup

RESULTS AND DISCUSSION

We calculated mean net metabolic rates for each trial (Table 1). We then normalized metabolic rates as a percentage of the metabolic rate of the normal running trial.

With weight support, we found a linear decrease in metabolic rate that was less than directly proportional to body weight (Figure 2). Extrapolating the WS line in Figure 2 to 0% body weight, the intercept is 69% lower than the value for the normal weight running trial. We therefore deduce that weight support comprises 69% of the net cost of running, consistent with Teunissen et al.

Providing AHF further reduced the metabolic rate during running (Figure 2, middle line). We calculated the difference between the WS line and the (WS + AHF) line in Figure 2 expressed as a % of the WS only value. We averaged these values for each level of WS. This calculation suggests that forward propulsion comprises 29% of net running cost. That value is slightly lower than our previous estimates of the cost of forward propulsion (Chang and Kram 1999), perhaps due to synergies.

Providing LSA caused a fairly consistent absolute decrease in the metabolic rate at each WS level (Figure 2, bottom line). At 100% of normal weight, the difference between the (WS + AHF) and the (WS + AHF + LSA) lines in Figure 2 was 0.66 W/kg which is ~7% of the net cost of normal running (9.76 W/kg). That value is also a bit lower than our previous estimates of the cost of leg swing (Moed and Kram 2005), again possibly due to synergies.

Our assistive devices did not completely eliminate the cost of running. Extrapolating the (WS + AHF + LSA) line to 0% body weight reveals an intercept of 0.97 W/kg which is 10% of the normal running net cost. That remaining value may reflect the metabolic costs of arm swing, balance, increased ventilation and cardiac work.

By another method of accounting, WS comprises 69% of the net cost of normal running, forward propulsion 29% and leg swing 7%. The sum of those values is 105% which indicates that our methods were able to nearly disintegrate the costs of running.

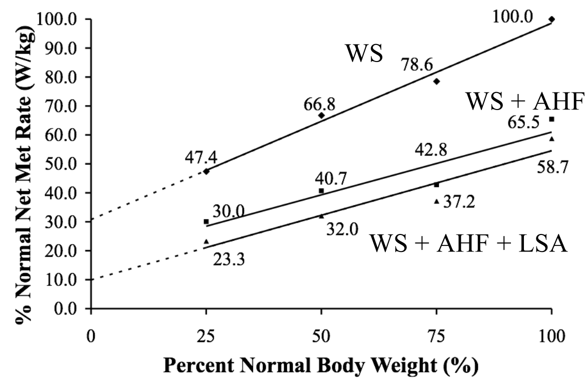

Figure 2: Percent normal net metabolic rate versus percent normal body weight for combinations of running assistive devices at 3.0m/s

SUMMARY/CONCLUSIONS

The energetic costs of running can be inferred by combining assistive devices and measuring the corresponding reductions in metabolic cost. Weight support, forward propulsion, and leg swing are the major energy consuming processes.

REFERENCES

Chang, Y. H., Kram, R. (1999). *J. of Appl. Physiol.*, **86**, 1657-1662.
Moed, B. and Kram R. (2005) Proceedings of XXIX ISB Congress, Cleveland, OH.
Teunissen L.P.J., Grabowski A., Kram R. In review *J. Exp. Biol.*

Table 1: *Mean Net Metabolic Rate (W/kg) (SEM)*

%BW	**25**	**50**	**75**	**100**
WS only	4.63 (0.34)	6.52 (0.55)	7.67 (0.54)	9.76 (0.31)
WS + AHF	2.93 (0.39)	3.97 (0.63)	4.18 (0.55)	6.39 (0.60)
WS + AHF + LSA	2.27 (0.39)	3.13 (0.43)	3.63 (0.39)	5.73 (0.62)