ENERGY EXCHANGE DURING WALKING

Paul Webb
Yellow Springs, Ohio

INTRODUCTION

While the energy cost of walking is known from VO, and VCO_2, energy exchange has not **been** measured by direct calorimetry, probably because placing a treadmill in a Calorimeter room would overwhelm the heat loss from a subject. That problem is avoided with my suit calorimeter, which separates the subject from a treadmill and its heat. During exercise, the terms of interest are work (W), heat (ΣQ) and fuel, or energy cost (M). The heat balance equation relates these terms:

$$M = CQ \pm W \pm S$$

When W is measured with a cycle ergometer, the equation has been verified repeatedly since the first reliable human calorimetry at the beginning of this century. But early work with water cooling garments for controlled cooling during walking (1) suggested that there was external work (mechanical work delivered, useful work, concentric work) in level walking, since M **seemed** consistently to exceed heat loss. This was disturbing because biomechanical analysis of level walking traditionally **assumes** that all work is internal and appears as heat. **Summarized** here are two studies (2,3) that were designed to examine this matter with current methods of direct and indirect calorimetry.

METHOD

Ten fit subjects **(5 women, 5 men)** walked on a level treadmill at 3 ***speeds* -- 2.5, 4.6** and **6.7 km/h --** for long enough that skin and rectal temperatures became stable, hence rate of heat storage **(S)** became negligibly small and could be dropped from the heat balance equation. M was measured with a respiration chamber and ΣQ with the suit calorimeter. We also studied level walking when the subjects carried a weighted backpack and when they walked against a horizontal load. In addition, they pedalled a cycle ergometer at 2 loads that had nearly the metabolic cost of the two faster walking **speeds.**

In a second study 10 fit men walked uphill at 5 and 10% grades, downhill at -5 and -10% and on the level, all at the single speed of **5.4 km/h.** They walked long **enough** that body temperatures stabilized, thus minimizing S. M was **measured** with a Gould 2900 system operating in the dilution mode; ΣQ was again measured with the suit calorimeter.

RESULTS

Metabolic cost and heat loss increased with walking speed, with positive vertical grade and with added weight. M decreased and CQ increased with negative vertical grade, which is a power input that becomes heat internally.

Measurable external work during grade walking, during level walking against horizontal load and during cycling fitted quantitatively into the heat balance equation.

However, only during cycling and downhill walking was the **heat** balance equation correct as written. In 10 of 12 walking conditions (-5 and -10% were exceptions) M **was** greater than CQ by 6 to 12%, the difference being highly significant ($p < 0.01$ to 0.001). If we assume that there is external work in (level) walking, labeled W_{walk}, the data can be summarized as follows (numerical values in watts):

	M	=	ΣQ	+	W_{vert}	+	$W_{horiz\ load}$	+	W_{walk}
level walking, 2.5 km/h	239	=	225	+	0	+	0	+	14
4.6 km/h	364	=	335	+	0	+	0	+	29
4.6 km/h with loaded pack	435	=	407	+	0	+	0	+	28
5.4 km/h	414	=	390	+	0	+	0	+	24
6.7 km/h	601	=	538	+	0	+	0	+	63
4.7 km/h with horizontal load	610	=	491	+	0	+	80	+	39
Walking up 5% grade, 5.4 km/h	598	=	516	+	61	+	0	+	21
10% grade, 5.4 km/h	867	=	650	+	122	+	0	+	95

The values for W_{walk} ranged from 14 to 95 watts and were significantly different from *zero.*

DISCUSSION

These arduous experiments showed the need for a nonthermal energy term on the "Energy Out" side of the equation. It is possibly: (1) experimental error, which seems unlikely because cycle exercise verified the accuracy of the equipment, as does close agreement between M and ΣQ at rest; (2) due to incorrectly assuming that direct and indirect calorimetry are always equivalent (a thoroughly heretical notion!); and (3) that there is external work in (level) walking, that is, that energy is transferred to an external object but not as heat. Explanation (3) is provocative.

To date we have suggested that W_{walk} might be the result of interaction between the foot and the ground, as in compressing the heel of the shoe and bending its sole, since the term increases with speed. hence step frequency. But W_{walk} varied with grade at a constant walking speed, which led us to say that during the positive part of the step cycle (rise of body mass against gravity) some fraction of the metabolic energy is externalized which is not precisely balanced by energy internalized as heat during the negative part of the step. While this could be true, it is not exactly an explanation.

CONCLUSION

Measuring energy exchange during level and uphill walking indicates that there is unexpected external work whose nature has yet to be established.

REFERENCES

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