

COMPARISON OF MECHANICAL AND PHYSIOLOGICAL ENERGY COSTS OF WALKING

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INTRODUCTION

Two methods of determining internal and external mechanical work have evolved. One uses mechanical energy changes (absolute work) the other integrates the joint moment powers (absolute power). In this study mechanical energy expenditure was measured by two methods for three walking conditions and compared with the physiological costs.

REVIEW

Internal work is defined as the work required to move the segments relative to the body's centre of gravity. **External work** is that done in moving the body's centre of gravity. Not only can measurements now distinguish between two similar types of locomotion (Purkiss, 1996) but the causes of inefficiencies can be isolated to net joint moments of force (Aleshinsky, 1986).

The **absolute work** method is defined:

$$W_{ext} = \sum_{n=1}^{N} \sum_{s=1}^S \Delta E_{s_n} = E_{T_N} - E_{T_1}$$

$$W_{int} = \sum_{n=1}^N \left| \sum_{s=1}^S \Delta E_{s_n} \right| - W_{ext}$$

W_{ext} = external work
 ΔE_s = change in energy of segment s
 W_{int} = internal work

The **absolute power** method is defined:

$$\dot{W}_{int} = \sum_{n=1}^N \sum_{j=1}^J \left| M_{j_n} \omega_{j_n} \Delta t \right| - \dot{W}_{ext}$$

$$\dot{W}_{ext} = \sum_{n=1}^N \sum_{j=1}^J M_{j_n} \omega_{j_n} \Delta t$$

\dot{W}_{ext} = external work
 \dot{W}_{int} = internal work
 M_j = moment of force at joint j
 ω_j = angular velocity of joint j

The causes of these inefficiencies in pathological gait range from co-contractions, isometric contractions, jerky movements and lack of energy conservation (Winter, 1978). Although research seems to indicate that both methods yield values which are quite similar, the moment power method has no arbitrary limitations (e.g., within and between segment energy transfers) and much greater potential for tracing energy costs to their source.

The purpose of this research was twofold. The first objective was to quantify the difference between the absolute power and absolute work methods in measuring gait efficiency and the second to determine whether either method could detect changes in gait efficiency. This was achieved through testing its sensitivity to distinguishing normal gaits from restricted gait patterns, where the modified gaits were presumed to require different amounts of internal work.

PROCEDURES

Eight subjects were recruited to perform three types of gait: normal, splinted knee and splinted ankle. Five normal trials and one trial of each splinted gait were recorded. The splinted trials were individually compared to the normal gait trials for each subject. Each trial was filmed by three video cameras to provide a 3D image. Markers were attached to the upper and lower extremities, bilaterally. Force platform data (2 AMTI at 600 Hz) were combined with video data (60 Hz) for inverse dynamics analysis.

Each subject's oxygen consumption while walking was measured with a TEEM 100. The standing value was subtracted from the walking value to approximate the actual physiological cost of locomotion.

RESULTS

Results showed no significant differences in the mechanical work done for the three walking conditions. Although in many subjects the splinted gaits often produced lower energy costs than the normal gait trials. The table below shows the mean work done as computed by each method for each walking condition and the mechanical efficiency obtained for each type of gait.

	Condition	Total work	Mech. efficiency
power	lock ankle	195 J	n.a.
	lock knee	160 J	n.a.
	normal	193 J	n.a.
work	lock ankle	106 J	n.a.
	lock knee	112 J	n.a.
	normal	117 J	n.a.
O ₂ cost	lock ankle	204 J	14.7%
	lock knee	226 J	15.9%
	normal	233 J	13.6%

Repeated measures ANOVA revealed no significant differences among the work measures for the different methods due to the large between subject variability, as might be expected.

DISCUSSION

Within subject analyses showed that the absolute power method tended to distinguish the modified gaits from the normal trials 11 out of 18 times; while the absolute work method only distinguished 5 out of 18 trials.

Normalized energy expenditures were similar to those reported by Winter (1979) using the absolute work approach of 1.09 J/(kg.m). The absolute work method was 1.75 times larger; while the absolute power method was 2.8 times larger. Not surprisingly the absolute work method yielded the lower work measures since it is known to underestimate internal work cost (Aleshinsky, 1986).

VO₂ work measures were always higher than the mechanical work computed by either method, as expected (Williams, 1985). Based on the conventional definition of efficiency (external work/physiological cost) the mean normal efficiency was 13.6%. This was lower than those obtained by Pierrynowski (1981) which ranged from 20% to 65%.

Contrary to expectations, walking with a splinted joint was less costly in general than walking normally. Although such a gait restriction may only be appropriate for level walking conditions.

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