PRELIMINARY STUDY OF THE MECHANICAL OUTPUT WORK OF BODY SEGMENTS DURING MEN'S 1500M RUNNING

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The rational energy allocation, energy transfer and the effective use of physiological energy of body segments during exercise were studied. Four distance runners served as objects were analyzed from films taken during a simulated test and their physiological energy costs (PEC) were estimated based on oxygen consumption (VO_2). The results has revealed the proportion of the mechanical output work (MOW) of different body segments during 1500m running and indicated that the work of the swinging leg was the highest (34.57%), followed by that of the supporting leg (28.08%). The percentage of the upper limbs' work was equal to that of the trunk (about 17% respectively), and the output work of the head was only the lowest (2.73%). Energy transfer took place both within and between segments during running and energy transferred between segments was the major part.

KEY WORDS: mechanical output work, energy transfer, energy expenditure, running

INTRODUCTION: “Efficiency of movement” has been studied for a long time and lots of results of mechanical efficiency were yielded. But the problem of energy allocation among body segments is unsolved if we only obtained the data of mechanical efficiency, and the rational expenditure of metabolic energy is also unrecognized. Then in this paper, the rational energy allocation, energy transfer and the effective use of physiological energy of body segments during exercise were studied.

MEHOD: Film was taken of four distance-runners from Beijing University of Physical Education as they ran in the average velocity with which they got the best achievements of their own in the 1500m race. The height of the camera was one meter, and the camera worked at 80 samples per sec. The treadmill experiment was made in National Research Institute of Sports Science. The treadmill speeds were controlled in the speeds which obtained from the film. They were shown in Table1.

Table 1 **Runners and Treadmill Speeds**

Name	Age	Height (cm)	Body Weight(kg)	Speed (m/s)
WYX	20	170	53	6.43
YC	20	173	65	6.25
CYL	22	175	63	6.19
ZSY	21	178	65	5.67

Supposed the human body was a multi-rigid-body including head, trunk, upper arms, forearms, hands, thighs, legs and feet. The potential (PE), rotational kinetic (RE) and translational kinetic (KE) energy components of each segment of a model of a runner can be calculated at each instant during a half movement cycle, for example, from touch-down of the supporting leg to touch-down of the swinging leg. The sum of the energy components is the instantaneous energy level of the segments, and the sum of the segments energy produces a total body energy.

$$TE_{ij}=KE_{ij}+PE_{ij}+RE_{ij} \qquad (1)$$

$$TE_{ij}=\frac{1}{2}M_iV_{ij}^{\ 2}+M_igH_{ij}+\frac{1}{2}I_i\,\omega_{ij}^{2} \qquad (2)$$

Where i and j =segment and time (film frame); TE = total segments energy; M = segment mass; I = segment moment of inertia about its own center of gravity; g = gravitational constant 9.81m/s^2; h = vertical position above an arbitrary datum; V = absolute translational velocity of center of gravity; ω= absolutely angular velocity of segment.

If we assume there are energy transfers both within and between segments, the total mechanical work output was calculated through equation 4.

$$TEB_j=\sum_{i=1}^{s}TE_{ij} \qquad (3)$$

$$W_{wb}=\sum_{j=2}^{n}\left|TEB_j-TEB_{j-1}\right| \qquad (4)$$

Where TEB_j = total energy for whole body; i and s = body segments; j and n = time samples (frames); W_{wb} = work output assuming transfers of energy both within (w) and between (b) body segments.

Also, an estimate can be made by calculating work output from relationships that assume no energy transfers (W_N), transfers only within segments (W_w), and their differences to yield how much energy was transferred somewhere in the system.

$$W_N = \sum_{i=1}^{s}\sum_{j=2}^{n}\left(\left|KE_{ij}-KE_{ij-1}\right|+\left|PE_{ij}-PE_{ij-1}\right|+\left|RE_{ij}-RE_{ij-1}\right|\right) \qquad (5)$$

$$W_w=\sum_{i=1}^{s}\sum_{j=2}^{n}\left|TE_{ij}-TE_{ij-1}\right| \qquad (6)$$

$$T_{wb} = W_N - W_{wb} \qquad (7)$$

$$T_b = W_w - W_{wb} \qquad (8)$$

$$T_w = W_N - W_w = T_{wb} - T_b \qquad (9)$$

Where W_N = work output assuming no energy transfers; W_w = work output assuming transfers within segments only; T_{wb} = amount of energy transferred both within and between segments; T_w = amount of energy transferred within segments; T_b = amount of energy transferred between segments.

The mechanical efficiency was calculated through following equation:

$$\eta=\frac{W}{E}\times 100\% \qquad (10)$$

Where W = total work output, vary with the different assumptions; E = physiological energy cost, calculated from the data of the treadmill experiment. We measured the metabolic energy cost when the body was quiet, when the body was running with a certain velocity and after movement respectively. And E was the sum of the latter two parts subtract the former one.

RESULTS: Mechanical Work Output and Energy Transfers. Mechanical output work of body segments were found in Table 2.The results have revealed the proportion of the mechanical output work of different body segments during 1500m running and indicated that the work of the swinging leg was the highest (34.57%), followed by that of the supporting leg (28.08%). The percentage of the upper limbs' work was equal to that of the trunk (about 17% respectively). But runner ZSY had lower trunk work (9.73%) than the group average work.

Table 2 Mechanical Output Work of Segments (%)

Segments	WYX	YC	CYL	ZSY	Aver
Head	2.08	1.91	3.49	2.04	2.38 �0.75
Trunk	14.91	20.66	21.33	9.73	16.67�5.44
Upper Limb	18.53	16.90	15.35	20.60	17.84�2.25
Swinging Leg	35.97	31.14	34.08	37.66	34.57�3.04
Supporting Leg	28.51	28.07	25.75	29.98	28.08�1.75

Table 3 **Total MOK & Energy Transfer (J/s.kg)**

	WYX	YC	CYL	ZSY	Aver
W_N	60.40	54.71	56.36	40.62	53.02�8.61
W_w	54.56	50.08	51.06	36.42	48.01�7.94
W_{wb}	10.86	16.78	18.42	2.78	12.21�7.08
T_{wb}	49.54	37.93	37.94	37.84	40.80�5.82
T_b	43.61	34.00	32.64	33.64	35.97�5.21
T_w	5.94	3.93	5.30	4.21	4.84�0.94

Total mechanical output work and energy transfers were summarized in Table 3. As noted at the beginning, the total mechanical work output was calculated basing on three different assumptions. Then the results showed W_N>W_w>W_{wb}.This was consistent with that of the theory analysis. Runner ZSY was very low in both type of work output and appeared to have technique problems if these data were typical for him.

Table 3 also showed that there was average 40.80J/s.kg energy transfers within and between segments (T_{wb}), and the major part was from the energy transferred between segments (T_b), which had obvious individual differences. Runner WYX showed the largest transfers, both the within- and between-segments values being far above the group average.

Physiological energy cost (PEC) and mechanical efficiency (ME)

Table 4 **PEC (J/s.kg) & ME (%)**

Runner	PEC	η_{WN}	η_{Ww}	η_{Wwb}
WYX	35.42	1.71	1.54	0.31
YC	36.46	1.50	1.37	0.46
CYL	37.47	1.50	1.36	0.49
ZSY	40.41	1.01	0.90	0.07

Physiological energy cost and mechanical efficiency were found in Table 4. It seemed almost showing that the better achievement of runner was relative to the lower physiological energy cost. Also the different calculating methods of work output result in different mechanical efficiency. And there were $\eta_{WN} > \eta_{Ww} > \eta_{Wwb}$ for all the runners. But the results $\eta_{WN} > 1$ and $\eta_{Ww} > 1$ were not consistent with the facts. We ascribed the results to the fault assumptions. Namely if there were no energy transfers within and between segments, we would estimate the mechanical work output higher than the real values.

DISCUSSION: Divided a single stride into three phases: cushion phase -- from supporting leg strike to midstance; driving phase -- from midstance to swinging leg off; and float phase -- from toe off to swinging leg strike. The curves of the mechanical output work of segments were given.

On cushion phase supporting leg and trunk mechanical energy were decreased and increases in the curves were phase of pushing. But the curves of the swinging limbs were contrary. It could be interpreted that the stimulated muscles contracted actively and the mechanical energy was stored as elastic energy in the elastic tissues and subsequently contributed to the powerful push.

The total mechanical output work curve of runner ZSY showed smoothly. We attributed it to the shorter length of stride (158cm) which leaded to the relative faster stride frequency. And the result was that he had no time to stimulate the muscles which could store elastic energy and subsequently thrust against the ground powerless. The involvement of elastic energy in running was one of the most often cited reasons for unusually high muscular efficiency. Then the problem that we noted as above also could account for the lower mechanical efficiency of runner ZSY.

Checked our data, we found the mechanical output work values during running ranged from 12.21J/s.kg when both within and between segments energy transfer was assumed to 53.02J/s.kg when no segments energy transfer was assumed. This showed that method without considering either within or between segments energy transfers may significantly overestimate the mechanical output work.

CONCLUSION: The study demonstrated that the mechanical output work of the swinging leg was the highest during the men's 1500m running. There were energy transfers both within and between body segments, and the energy transferred between segments was the major part.

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