A PERFORMANCE INDEX IN NORMAL GAIT

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ABSTRACT -- The authors investigated three performance functions, used commonly in computerized gait synthesis and prediction of the magnitude of muscle forces of the locomotor system during gait, by comparing the behaviour of these functions with the behaviour of the metabolic energy expenditure.

The performance functions were determined by measuring the moments about the lower limbs joints and the joints angular velocities. The behaviour of the performance functions was defined by calculating them for different points in the cadence - stride length domain.

It was found that none of the performance functions demonstrated the expected behaviour, i.e., a behaviour similar to that of the metabolic energy consumption.

INTRODUCTION

Prediction of the magnitude of muscle forces of the locomotor system during gait, requires the definition of a reliable performance function which is expressed in terms of the moments acting about the joints of the system, and in terms of the kinematics of its joints. Such a performance function, may also be useful in computerized gait synthesis for the determination of the moments required in the joints to achieve a so-called "optimal gait" (Chow, C.K. & Jacobson, D.H., 1971; Frank A.A., 1970; Crowninshield, R.D. & Brand, R.A., 1981).

The aim of the present work was to define a performance function which demonstrates a behaviour in the cadence-stride length domain similar to that of the metabolic energy (see figure 1), i.e., a monotonic continuous function with minimum at the point of "natural" gait.

The performance functions investigated were:

$$J_1 = \frac{\int (\sum_i M_i \times \omega_i)\,dt}{L} \qquad (1)$$

$$J_2 = \frac{\sqrt{\int (\sum_i M_i^2)\,dt}}{L} \qquad (2)$$

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$$J_3 = \frac{\int\limits_i ((\Sigma META)_i)dt}{L} \quad \text{where} \quad \begin{array}{lll} META = M \times \omega & \text{for} & M \times \omega > 0 \\ META = 0.3 \cdot M \times \omega & \text{for} & M \times \omega < 0 \end{array} \qquad (3)$$

where M_i is the moment about the joint i, ω_i is the angular velocity of the joint i, and L is the stride length.

METHODS

The first stage of the work was devoted to measurement system development. The system included a computer linked television system for body segment displacement analysis, a force-plate for the measurement of ground reactions, an instrumented walkway for stride length and cadence measurement and a metronome for cadence dictation (see figure 2).

The television system comprehended a T.V. camera, a camera control unit and a video location monitor. The T.V. camera was placed at a distance of 5.2 meters from the walking pathway, where the width of the viewing field of 2.5 meters, was chosen by the necessity of viewing one complete stride.

On the body of the test subject were glued reflective markers, which were brighter than the background. The function of the video location monitor was to identify points with a high contrast in relation to the background and to send their coordinates to the PDP-11/55 computer through the use of its direct memory access.

The sampling frequency was 50 T.V. fields per second, each field containing 256 horizontal lines and 256 vertical lines.

The kistler force plate comprises a rigid plate of 600 milimeters length and 400 milimeters width, rigidly connected to the ground through 4 stands, within each one 3 piezo-eletric force transducers.

A system of charge amplifiers translates the charges at the 12 transducers to 8 D.C. voltages, in the range of -5V to + 5V, which are proportional to the load in the plate. These voltages were sent to the computer through the use of a multiplexer.

The instrumented walkway consisted of a resistance wire walkway and a electronic unit. Thin brass shim strips 6 m x 10 mm (0.4 mm thick) and 6m lengths of resistance wire (resistivity 8.9 Ohm/meter) are alternately glued longitudinally to a linoleum walkway. The brass strips are spaced 37.5 mm apart (edge to edge) giving a 6 m x 150 mm sensitized portion for each foot. Conducting adhesive strips fastened to the subject's soles shunt a resistance wire/brass strip pair as the subject walks along the pathway.

The electronic unit measures the voltage developed across each resistance wire, through its respective buffer amplifier and produces the sum of these voltages. The 2 output D.C. voltages, in the range of -5V to +5V, are proportional to the distance of the shunt to the end of the walkway. These 2 output voltages are sent to the computer through the use of the same multiplexer mentioned above.

In the experiments, the test subject was asked to walk freely in his "natural" speed, to walk faster and slower at different speeds, and to walk at frequencies which were dictated by the metronome. The frequency dictated trials included tests where stride length was chosen freely by the test subject and tests with larger and smaller strides.

For each one of the walking tests a bi-dimensional seven segments model (trunk, two legs, two thighs and two feets) was employed for calculating ankle, knee and hip moments, as well as the angular velocities at these joints, and subsequently the three performance functions were determined.

RESULTS AND CONCLUSIONS

It was found that none of the performance functions demonstrated the expected behaviour in the cadence-stride length domain (see figure 3 and table 1). The large scattering of performance function values for various test trials at similar cadence and stride length, was found to be related to differences in mechanical work at the first part of the walking cycle, prior to the push-off stage. During the latter part of the cycle, total mechanical work was found to be the same for different trials. The dispersion at the earlier part of the cycle is thought to be related to stabilizing the body over the leg, prior to double support stage (see figure 4).

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Table 1 - Normalized values of J_1, J_2 and J_3

		A_1	C_1	B_2	C_2	D_2	A_2	B_3	C_3	D_3	A_3	B_4	C_4	D_4	C_5	A_4
J_1	B			72				101				88				
	A,C	92	51		57		103		114		128		87		55	137
	D					38				122				94		
J_2	B			139				107				84				
	A,C	151	113		97		110		109		100		87		79	87
	D					76				100				89		
J_3	B			106				96				87				
	A,C	103	77		73		99		111		107		93		92	117
	D					66				110				109		

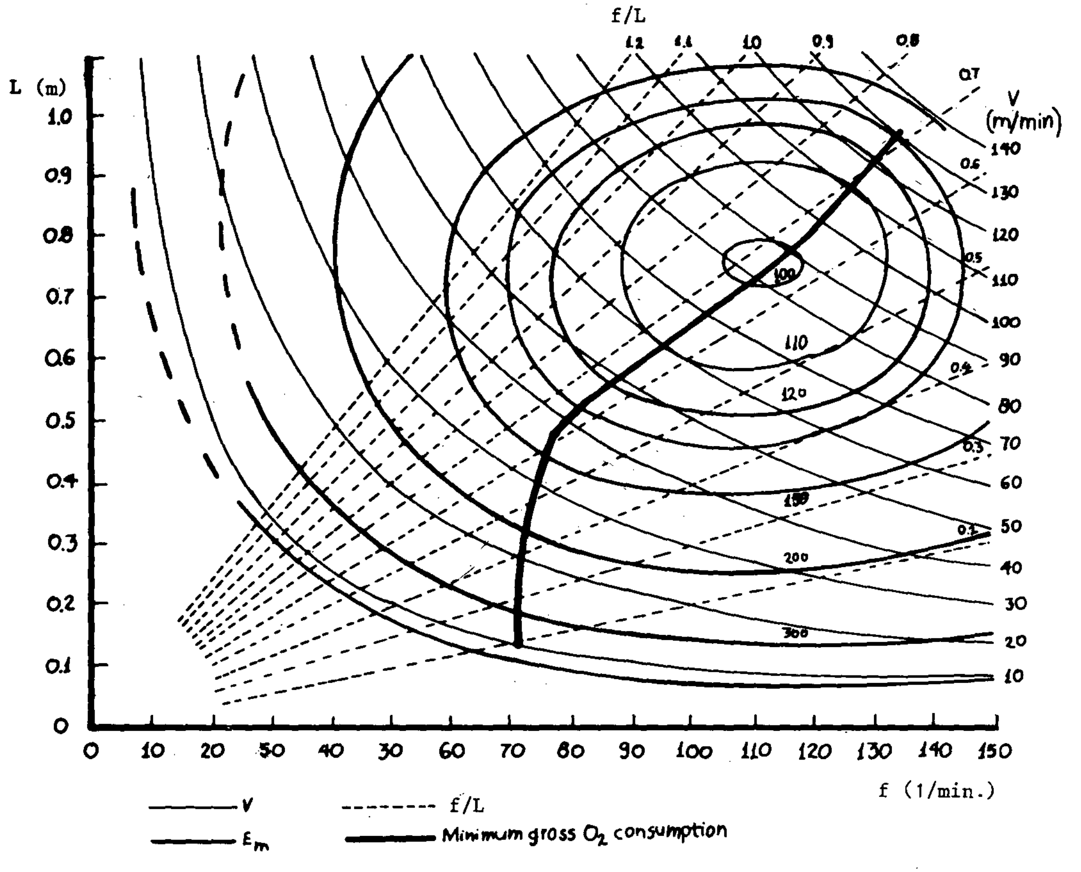


Figure 1 - Metabolic energy consumption for a unit distance, in the f - L plane (f - stride cadence; L - stride length) Reproduced and adapted from Molen N.H. et al - 1972

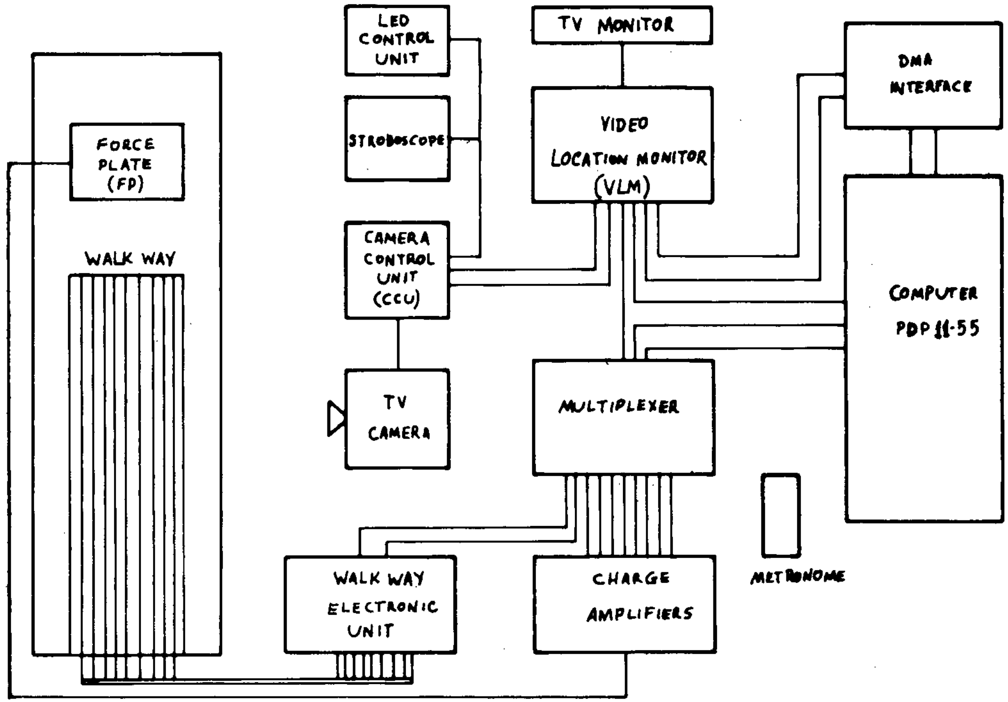
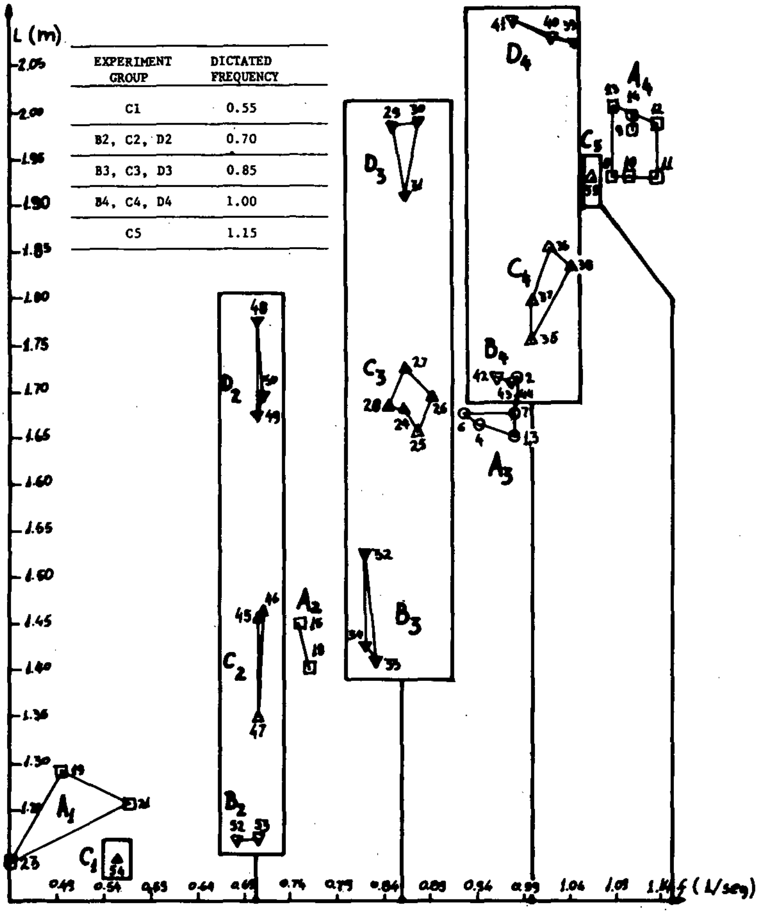


Figure 2 - Measurement system - general description



EXPERIMENT GROUP	DICTATED FREQUENCY
C1	0.55
B2, C2, D2	0.70
B3, C3, D3	0.85
B4, C4, D4	1.00
C5	1.15

Figure 3 - Experiments group designation
○freely chosen trials
□freely chosen cadence, slower and faster speeds trials
△dictated cadence, free stride length trials
▽dictated cadence, smaller and larger stride length trials

experiment group - dictated cadence

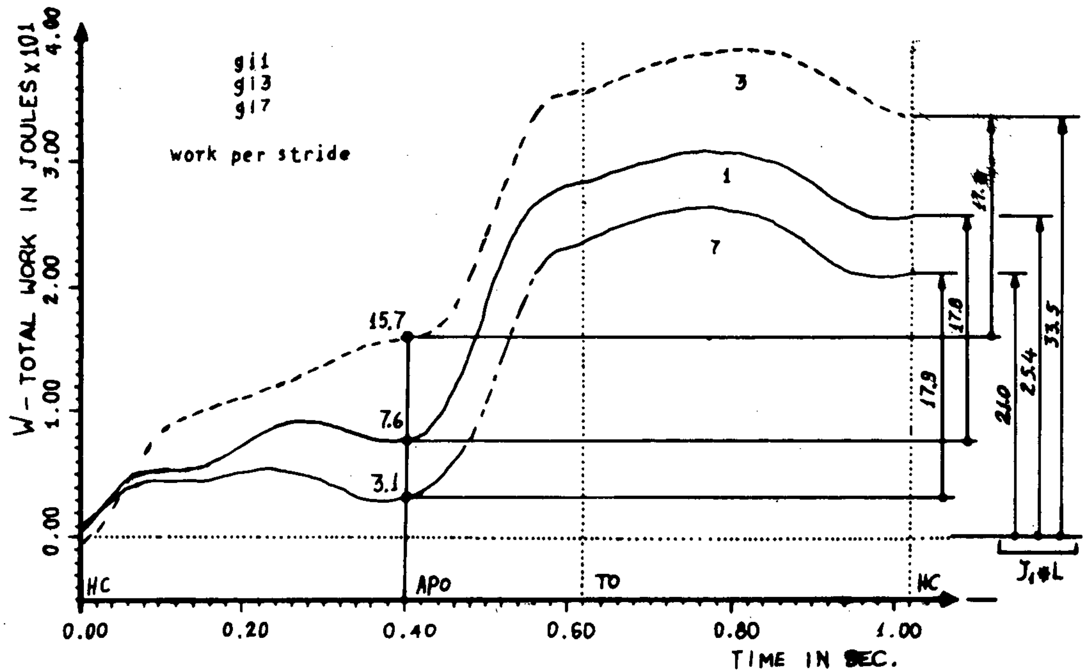


Figure 4 - Total accumulated mechanical work, for experiments 1, 3 and 7