IS THE ASSUMPTION OF SYMMETRY FOR POWER CALCULATIONS IN RUNNING VALID?

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In many gait studies, a variety of algorithms have been used to calculate internal mechanical work or power from data obtained using a single side sagittal view (Quanbury, Winter, & Reimer, 1975; Winter, Quanbury & Reirner, 1976; Winter, 1979a; Pierrynowski, Winter, & Norman, 1980). This technique is based on the assumption of bilateral symmetry. The assumption implies that the movement patterns of the right and left sides of the body are similar. The derivation of whole body parameters is accomplished by shifting the kinematic data for one side of the body by 180 degrees, or one-half of a gait cycle, yielding the correct phasic relationship for the opposite side of the body. Figure 1 is a conceptual representation of right side data, that suitably displaced in time, doubles as data for the left side. The combined displacement data are then used to calculate whole body parameters. Methodological advantages of this technique include a simplified experimental setup requiring only one camera and reduced digitizing time. To the best of our knowledge, evidence supporting the assumption of bilateral symmetry in calculations of mechanical work and power has not been verified in the literature. Therefore, the purpose of the present study was to test the assumption of bilateral symmetry by using three combinations of right and left side displacement data to calculate mechanical power over one stride.

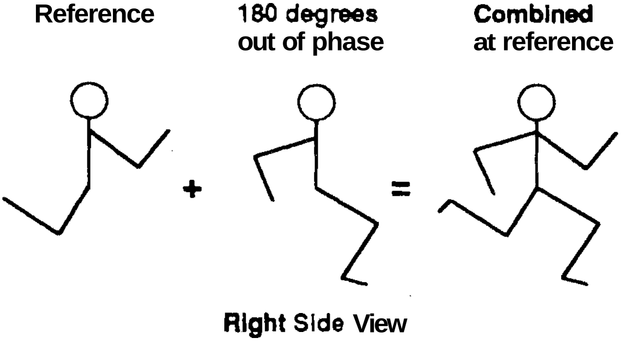

Figure 1. Kinematic data from the right side is shifted 180 degrees out of phase and combined with the reference to form whole body displacement data

THEORY

Energy can be described as the capacity to do work The mechanical energy of an object consists of kinetic energy due to motion and potential energy by virtue of its position. The internal mechanical work of the body is the amount of work necessary to move the segments through their patterns of motion (Winter, 1979a). As equation 1 indicates, mechanical work (W) is equal to the change in total body energy (Eb), which in turn is equal to the sum of the changes in potential energy (PE), translational kinetic energy (TKE), and rotational kinetic energy (RKE) components.

$$W = \Delta Eb = \Delta PE + \Delta TKE + \Delta RKE \quad (1)$$

Analysis of energy changes in linked segment models are useful to determine the behavior of the system without knowing the details of the motion. Results of such analyses are frequently expressed in units of power, the rate of doing work. The power per stride provides a relative quantity that can be used for comparisons in running or walking.

Differences in existing work algorithms depend on whether passive energy transfers are permitted to occur between or within segments, and the constraints placed on the energy flow. The three common work algorithms used in the present study assumed either no transfer of energy within segments (NT; Norman, 1976). transfer of energy within segments (WT; Pierrynowski et al., 1980). or transfer within and between segments (WBT; Winter, 1976).

METHODOLOGY

Fourteen male distance runners (age = 24.8 ± 6.1 y, stature = 1.83 ± 0.09 m, mass = 69.4 ± 9.3 kg) of competitive and recreational ability ran on a treadmill at 4.13 $m \cdot s^{-1}$ for a minimum of 5 minutes. All subjects were free of any functional limitations or musculoskeletal injuries. Reflective markers were placed on eight anatomical landmarks (lateral epicondyle and greater tubercle of the humerus, styloid process, greater trochanter, lateral femoral condyle, lateral malleolus, calcaneous, and the lateral head of the fifth metatarsal) to derive an eleven segment model for calculating power. Kinematic data were obtained using two Hi Speed NAC video cameras and recorders operating at 200 Hz. The cameras were placed 5-7 meters from the plane of motion and aligned to obtain right and left side sagittal views of the runners. Six complete strides of right and left side views of each subject were digitized from video tape and processed using a Motion Analysis VP110 microprocessor interfaced to a SUN minicomputer. The data were digitally filtered using a fourth-order recursive, low pass Butterworth filter. Optimal cut-off frequencies for both x and y coordinates of the individual marker paths were determined using procedures outlined by Jackson (1979).

Estimated segment weights, centers of mass, and moments of inertia were calculated using values from Winter (1979b). Linear and angular velocities of each segment were calculated from the digitized displacement data using the method of finite differences.

The methodological conditions for obtaining whole body kinematics consisted of three combinations of the right and left side displacement data. In two of the three conditions, symmetry was assumed by doubling the limb values for the right (RS) and left sides (LS), and adding in one-half the energy of the head-neck-tnmk (HNT) segment. The third condition served as the criterion measure and assumed no symmetry by combining the left and right side limb values with the HNT segment (COMB).

The internal mechanical work was calculated over one smde using three algorithms based on the work-energy theorem (NT, WT, WBT). Power was derived from work and expressed relative to body mass. The data were analyzed using a two-way repeated measures ANOVA across conditions (RS, LS, COMB) for each algorithm.

RESULTS & DISCUSSION

Work values (J) across conditions ranged from 1291 to 2195 for NT, 1043 to 1840 for WT, and 453 to 1075 for WBT. Means and standard deviations for the work measures are presented in Table 1. There were no statistically significant differences among conditions, in other words, the LS and RS phase-shifted conditions were no different than the COMB criterion. The greatest mean difference between conditions for all algorithms was 1% of the mean.

Table 1.
Mean and SD (in parenthesis) for mechanical work (J) across conditions (LS, RS, and COMB) for the three algorithms (NT, WT, and WBT).

	LS	RS	COMB
NT	1654	1670	1662
	(205.4)	(231.8)	(212.9)
WT	1372	1381	1377
	(166.8)	(186.2)	(170.8)
WBT	761	768	764
	(128.3)	(123.0)	(116.9)

*$p < .05$

The mean mechanical power results ($W \cdot kg^{-1}$) are summarized in Table 2. Power values across conditions ranged from 25.93 to 38.84 for NT, 20.78 to 31.17 for WT, and 10.24 to 18.32 for WBT. There were no statistically significant differences among the mean power values for LS, RS, and COMB. Since power is simply the rate of work, and expressed here relative to body mass, it is reasonable that the power results are consistent with the work values. The mean values are approximately 4-6 $W \cdot kg^{-1}$ higher than those of Williams (1980) for the same-three work algorithms. The higher power values are most likely a result of the faster running speed used in this study (4.13 vs. 3.57 $m \cdot s^{-1}$). In general, power decreases from approximately 32 to 15 $W \cdot kg^{-1}$ moving down the rows in Table 2 from the NT to WBT algorithm. This trend was expected and is inversely proportional to the amount of energy transfer allowed by each algorithm, i.e., as more passive transfer of energy between segments is assumed, less is attributed to muscular sources.

Table 2.
Mean and SD (in parenthesis) for mechanical power ($watts \cdot kg^{-1} \cdot stride^{-1}$) across conditions (LS, RS, & COMB) for the three algorithms (NT, WT, & WBT).

	LS	RS	COMB
NT	32.11	32.26	32.18
	(2.500)	(2.494)	(2.325)
WT	26.65	26.69	26.67
	(2.117)	(1.992)	(1.873)
WBT	14.76	14.80	14.78
	(1.953)	(1.421)	(1.463)

*$p < .05$

CONCLUSION

The purpose of this study was to test the assumption of bilateral symmetry for the calculation of mechanical power over a running stride. Since there were no differences among the conditions it must be concluded that the assumption of symmetry is warranted. From a methodological perspective, this means that it is sufficient to film a single side sagittal view in order to obtain whole body kinematics in runners exhibiting normal gait patterns. However, researchers should exercise caution when applying the assumption of bilateral symmetry to individuals with a gait impairment.

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