CHANGES IN THE MECHANICAL ENERGY OF THE SUPPORT LEG FOR SKILLED RACE WALKERS

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The purpose of this study was to investigate changes in the mechanical energy of the legs of skilled race walkers during the support phase and to identify technical factors that produce high walking speed. Eleven skilled male race walkers walked on a 50 m walkway at the speed which was decided from the 10,000 m race record for each subject. The Ground reaction forces and motion data were collected with force platforms (500 Hz) and a high-speed VTR camera (250 Hz). Inverse dynamics was applied to compute the segmental mechanical energy and the joint kinetics of the support leg. Changes in the mechanical energy of the support leg were dependent upon the joint force power at the support hip. The increase in mechanical energy of the support leg should help the whole body drive forward and produce high walking speed.

KEY WORDS: race walking, mechanical energy, joint force, joint force power, joint torque.

INTRODUCTION: The distance of race walking in international competitions is 20 km and 50 km for men and 20 km for women. Effective use of mechanical energy is needed to produce walking speed and to maintain this walking speed over the race distance. However, there is little information on race walking technique in terms of how to use mechanical energy effectively so as to produce and maintain high walking speed, and achieve high performance. Williams and Cavanagh (1987) suggested that mechanical energy flow between body segments in distance running might enhance the effective use of physiological energy. Hoga et al. (2000) reported that there was a large mechanical energy flow between the recovery leg segments of elite race walkers which was significantly related to walking speed. However, these authors have not investigated the mechanical energy change in the support leg in detail. Information on mechanical energy flow in the support leg during race walking and the effect on walking speed may provide useful suggestions for coaches of race walking. The purpose of this study was therefore to investigate the changes in mechanical energy of the legs of skilled race walkers during the support phase and to identify technical factors which may to produce high walking speed.

METHODS: Eleven skilled male race walkers walked on a 50 m walkway five times at the speed which was decided from the 10,000 m race personal best time for each subject. Personal best times for the 10,000 m race of the subjects ranged from 40 min 52 sec to 45 min 50 sec. The Ground reaction forces (GRF) data were collected by two force platforms (Kistler AG, 500Hz) mounted in the walkway and walking technique was videotaped with a high-speed VTR camera (250Hz). LED signal was used to synchronize the GRF data with the VTR data. Two-dimensional coordinates of the segment endpoints were obtained by digitizing the VTR images of three trials in which the walking speed assigned to each subject was obtained. The location of the centers of mass, masses and the moments of inertia of the body segments were estimated from the body segment parameters following the methods of Ae *et al.* (1992). The step frequency was determined as a reciprocal of one-half of the time elapsed for one cycle, which was defined from the instant of the heel contact to the instant of the next heel contact of the same leg. The step length was determined as one-half of the length that the whole body center of gravity travelled in one cycle. Walking speed was calculated as the mean horizontal velocity of the center of gravity during one cycle. The support phase was divided into two phases: (1) Phase 1, from the heel contact instant until the instant of the mid support (MID) at which the center of mass just passed over the toe of the support foot; and (2) Phase 2, from MID to the instant of the toe-off. An inverse dynamics approach was applied to compute the segmental mechanical energy and the joint kinetics of the support leg. The change in the total mechanical energy of the leg was divided into the mean power of the segment (MSP) by the

time of each phase. Joint force power (JFP) was computed as an inner product of joint force (JF) and joint velocity (JV); and joint torque power (JTP) was computed as an inner product of joint torque (JT) and joint angular velocity. Mechanical work done by JF and JT during each motion phase was calculated by integrating numerically JFP and JTP over the time of each phase. Mean mechanical powers of JFP (MJFP) and JTP (MJTP) were obtained by dividing the mechanical work by the time of each phase. Pearson's product moment correlation coefficient was calculated and a level of significance was set at 5 %. The magnitude of the standardized regression coefficients ( ) of the variables for step analysis were used for the reflection of the strength of the contribution to the walking speed.

RESULTS AND DISCUSSION: Table 1 shows mean walking speed, step length, step frequency and step time with correlation coefficients of these variables to the walking speed.

Table 1. Average walking speed, step length, step frequency and step time of all trials (N=33).

	One step	Support phase	Flight phase
Walking speed (m/s)	3.87		
Step length (m)	1.21 (r = 0.547 **)	1.01 (N.S.)	0.20 (r = 0.554**)
Step frequency (Hz)	3.19 (r = 0.586 **)		
Step time (s)	0.32 (r= -0.589**)	0.27 (r = -0.761**)	0.05 (r = 0.412*)

Correlation coefficient to the walking speed; * p<0.01, ** p<0.001

The Walking speed was found to be significant but only moderately related to step length (r=0.547, p<0.001) and step frequency (r=0.586, p<0.001). Although there was no significant relationship between walking speed and step length in the support phase of race walking, the time of the support phase was significantly related to walking speed (r=-0.761, p<0.001). The step length during the flight phase (r=0.554, p<0.001) and the time in the flight phase (r=0.412, p<0.01) were significantly related to the walking speed, although these correlations were only
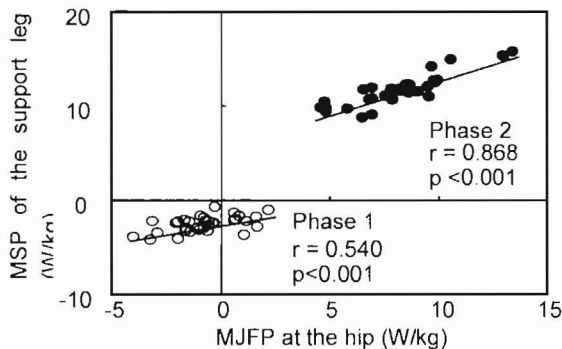

Figure 1. Relationships between the mean joint force power (MJFP) at the support hip and the mean segment power (MSP) of the support leg during the first half of the support phase (Phase 1) and the second half (Phase 2).

moderate to low. Although the rules of the IAAF define race walking as not losing contact with the ground during a race, flight phases were observed in all trials of the present study. The absolute value of the standardized regression coefficient for the walking speed ( ) of the time of the support phase (-1.15) was the largest of those of other variables (Step length during the support phase, =0.73, p<0.001; Step length during the flight phase, =0.49, p<0.001; The time of the flight phase, =-0.46, p<0.001). This result suggests that the time of the support phase most strongly influenced the walking speed. Figure 1 shows the relationships between MJFP at the support hip and the MSP of the support leg in Phases 1 and 2.The MJFP at the support hip was significantly related to the MSP of the support leg in both phases (Phase 1, r=0.540, p<0.001; Phase 2, r=0.868, p<0.001). There was no significant relationship between the MSP of the support leg and the MJTPs at the support hip, knee or ankle. These results indicate that the change in the mechanical energy of the support leg in race walking was largely dependent on JFP at the support hip. The increase in the mechanical energy of the support leg should help the whole body drive forward in a short time and produce high walking speed. Figure 2 shows the JFP (top), the horizontal component of JF (middle), and the JT (bottom) at the support hip during the support phase in the trials in which the hip JFP was the largest (LF) and the smallest (SF). Although there was no remarkable difference in the JFP of Phase 1 between LF and SF, JFP of LF largely increased from the end of Phase 1. In Phase 2, the magnitude of the JF of LF was larger than that of SF. Although the horizontal component of the JV of LF at the support hip was larger than that of SF during the whole support phase, patterns of the horizontal component of the JV of LF and SF were very similar.
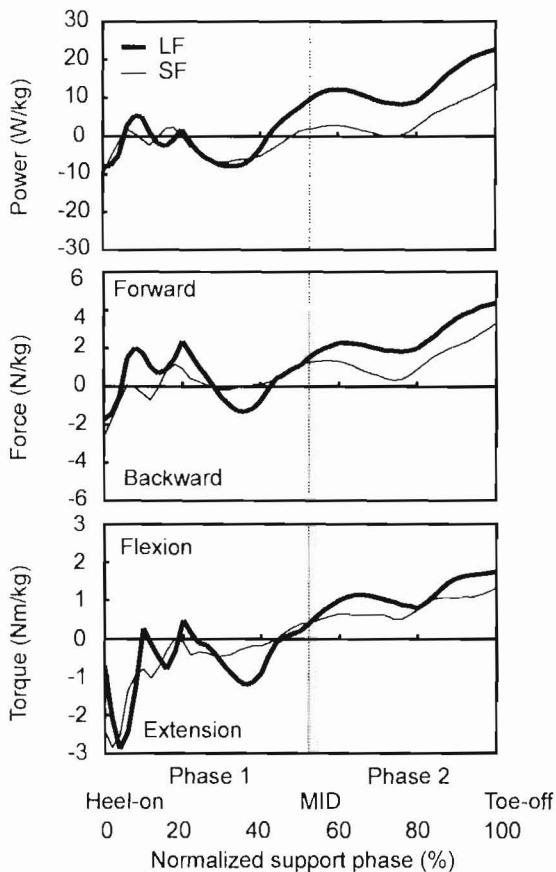

Figure 2. Joint force power (top), horizontal component of joint force (middle), and joint torque (bottom) at the hip during the support phase for the trial of the largest hip joint force power (LF) and the smallest (SF).

There was no remarkable difference in the vertical component of the JF or the JV at the support hip between LF and SF. These results indicate that the increase in the JFP at the support hip in the middle of the support phase resulted from the increase in the horizontal component of the JF at the support hip. A large extensor torque at the hip was exerted at the beginning of Phase 1, and the flexor torque gradually increased to the take-off. The magnitude of the flexor torque of the LF was larger in Phase 2 than that of SF. The fact that the pattern of the change in the hip flexor torque closely corresponded to the JF of the hip suggests that the JT at the support hip would contribute to increase the JF and JFP in Phase 2. The fatigue according to the increase in the distance during the race could decrease the magnitude of the JT and the horizontal component of the JF at the support hip.

CONCLUSION: The results of this investigation revealed that the joint force power at support hip during the second half of the support phase in race walking, which was effected by the joint torque, helped to increase the mechanical energy of the support leg. The increase in the mechanical energy of the support leg may help the whole body travel forward in a short time and, in turn, produce high walking speed.

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