THE ROLE OF JOINTS OF LOWER LIMB DURING SHOCK ABSORBING PHASE IN RACE WALKING

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The purpose of this study was to investigate the role of each joint of the lower limb during the shock absorbing phase in race walking (RW) by comparing it with normal walking (NW) and running (RU). Three active race walkers participated in this study. They performed NW, RW and RU (toe-strike) with self-selected speed in a motion capture laboratory. An optical 3D motion capturing system with two force plates was used. The vertical fluctuation of the center of mass in RW was the smallest among the three movements. The negative power at the ankle and knee joint were hardly detected in RW, however, a relatively large negative power was observed at the hip joint. The negative works of both total and individual joint were obtained by integrating the negative power during the shock absorbing phase. The total negative work in NW (0.14 W/kg) was the smallest among the three motions. The ratio of the hip joint was greater (36.7%) than the other joints in RW.

KEY WORDS: shock absorption, joint moment, joint power, negative work

INTRODUCTION: According to the competition rules, the definition of race walking (RW) is a progression of steps so taken that the walker makes contact with the ground, so that no visible (to the human eye) loss of contact occurs. The advancing leg shall be straightened (i.e. not bent at the knee) from the moment of first contact with the ground until the vertical upright position (IAAF competition rule Section VII Rule 230). Hanley et al. (2011, 2013) reported the kinematic characteristics of elite walkers, which showed that the walking speed was associated with both step length and cadence. Men were faster than women because of their greater step lengths but there was no difference in cadence. In the kinetics analysis, there were some reports which measured ground reaction force using force plates and analyzed joint moments and powers in RW (Payne, 1978; White and Winter, 1985; Cairns et al., 1986; Hanley et al., 2014). However, the report that explained the biomechanical mechanism of the shock absorption in detail in RW was not found. The purpose of this study was to investigate the role of each joint of lower limb during the shock absorbing phase in RW by comparing it with normal walking (NW) and running (RU).

METHODS: Three active race walkers participated in this study (1.71±0.6 m in height, 62.0±4.9 kg in weight, 20.3±1.5 yrs, Mean±S.D.). The best records in a 20 km competition for each subject were 1:25'48", 1:31'52" and 1:37'32", respectively. They performed NW, RW and RU (toe-strike) with self-selected speed at the motion analysis laboratory. The walking/running speed were 1.95±0.16 m/s for NW, 2.98±0.31 m/s for RW and 3.07±0.11 m/s for RU. A total of 31 reflective markers based on the HelenHayes marker set were attached to the subject. An optical 3D motion capturing system (MAC3D system; Motion Analysis, USA, 12 cameras, Sampling Freq. 200 Hz) with two force plates (BP6001200; AMTI, USA, Sampling Freq. 1 kHz) were used. A full-body six-degree-of-freedom kinematic model with functional hip joints was applied using Visual3D (C-motion; Germantown, USA). Raw marker positions and ground reaction forces were filtered at 6 Hz and 18 Hz using a fourth-order recursive Butterworth low pass filter, respectively. The model was then used to calculate joint kinematics and kinetics. The displacement of the vertical center of mass (vCoM) and the vertical ground reaction force (vGRF) curves for each motion were calculated. The fluctuation of vCoM (vCoM-fluc) and the peak values of vGRF (peak vGRF) were obtained. Based on the joint power curve of the right lower limb, the negative work was obtained by integrating the negative power during the shock absorbing phase. The time range of shock absorbing phase was defined from the initial contact to the lowest point of CoM.

RESULTS: The displacement of the vCoM and the vGRF curves for each motion were depicted in Fig.1. The vCoM-fluc were 5.5±0.9cm for NW, 2.6±0.9cm for RW and 10.0±0.8cm for RU (Fig.1(a),(c),(e)). The smallest value was shown in RW. The timing of the lowest CoM appeared at a double-limb support phase in NW, but it was at a single-limb support phase in both RW and RU. The peak vGRF of NW, RW and RU were 1.59±0.17N/kg, 1.47±0.12N/kg and 2.83±0.11N/kg, respectively (Fig.1(b),(d),(f)). The hip, knee and ankle joint power curves of each motion were shown in Fig.2. In both NW and RU, the negative power was observed at the ankle joint just after an initial contact (Fig.2(c), (i)), soon after the negative power at the knee and hip joint were confirmed (Fig.2(a),(b),(g),(h)). The negative power at both the ankle and knee joint were hardly detected in RW (Fig.2(e),(f)), however, a relatively large positive power was observed just after an initial contact, and relatively large negative power was observed afterwards at the hip joint (Fig.2(d)). The minimum values of the hip joint power were -1.14±0.69 W/kg for NW, -1.76±0.68 W/kg for RW and -1.46±0.63 W/kg for RU (Fig.2(a),(d),(g)).

The total and ratio of the negative works of the hip, knee and ankle joint during the shock absorbing phase were shown in Fig.3. The smallest total negative work among the three motions was shown in NW (0.14 W/kg). The ratio that the knee joint accounted for was the greatest at 48.1% in NW. The ratio of the hip joint was greater (36.7%) than the other joints in RW. In RU, the ratio of the ankle was the biggest (66.7%), and that of the hip joint remained only 3.9%.

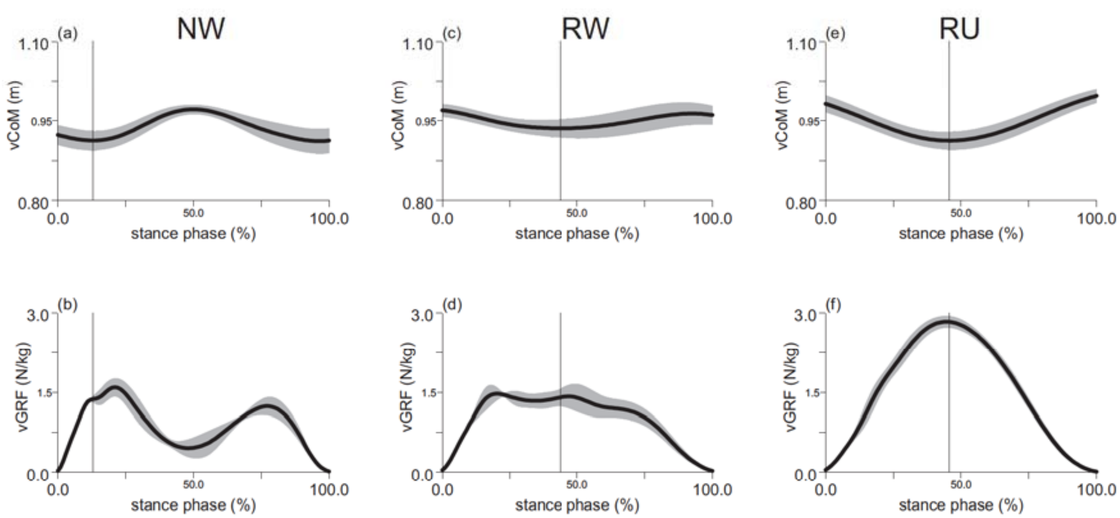

Figure 1: The vertical CoM (Center of Mass) displacements (a,c,e) and vertical GRF (ground reaction force) curve (b,d,f) in the support phase of right leg (mean ± SD, n=3). The vertical line means the timing of the lowest point of vCoM. NW: normal walking, RW: race walking and RU: running.

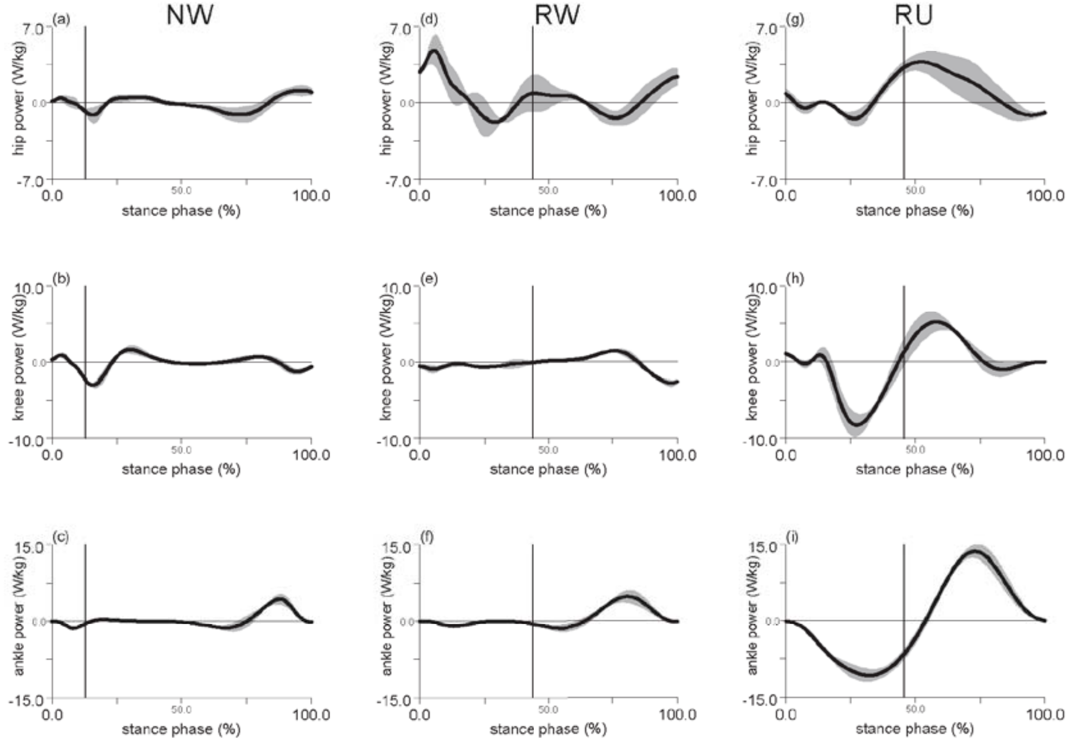

Figure 2: Joint power curve of each joint in the support phase of right leg (mean ± SD, n=3). The vertical line means the timing of the lowest point of vCoM.NW: normal walking, RW: race walking and RU: running.

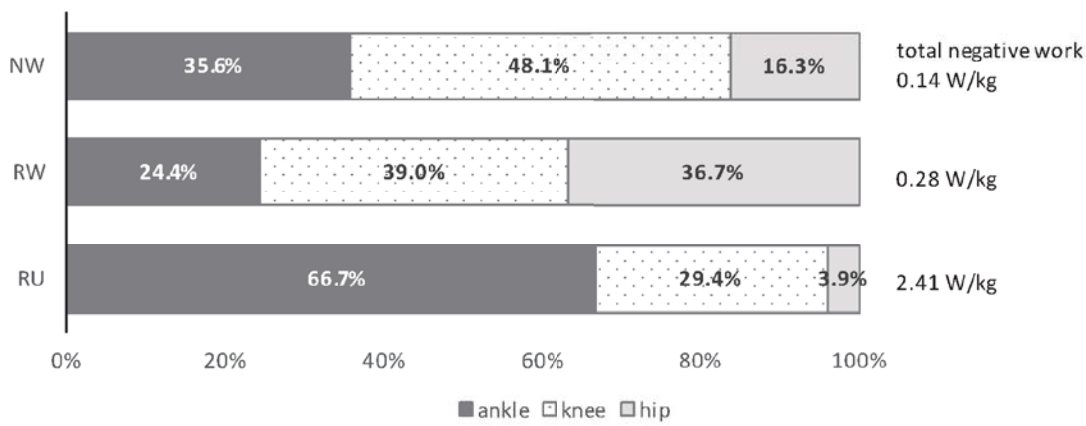

Figure 3: The total and ratio of the negative work for each joint in normal walking (NW), race walking (RW) and running (RU).

DISCUSSION: Because both the vCoM-fluc and the peak vGRF in RW were the smallest among the three motions, the landing shock acted upon a race walker would be smaller. That was regarded as the factor that showed that the total negative work of RW was the smallest in the three motions (Fig.3). Murray et al. (1983) mentioned that it was also because it minimized mechanical energy demands during RW. Pavei et al. (2014) reported that the race walker's CoM has a flat trajectory that does not follow a pendulum-like gait as in NW. On the other hand, in view of the relationship between a motion phase and the fluctuation of vCoM, the movement mechanism of RW is supposed to be similar to RU rather than NW. The shock absorption by the knee joint is limited by rule properties of the RW (not bent at the knee, Fig.2(e)), therefore, it is thought that the hip joint is needed to take a main role in the shock absorption (36.7%) instead of the ankle joint (24.4%) in RW (Fig.3). It was suggested that hamstring muscles having functions of knee flexor and hip extensor activated strongly because flexion moment in the knee joint and extension moment in the hip joint were shown just after an initial contact in RW. Those joint moments probably kept a human trunk straight up and controlled a CoM fall. Then, the shock absorption by the eccentric contraction of the hip abductor muscle was carried out. The limitation of this study was a small sample size.

CONCLUSION:

This study found the following findings:

1) The vCoM and vGRF curves in RW were similar to those in RU rather than those in NW.
2) The total negative work in RW was smallest among the three motions.
3) The hip joint took a main role in the shock absorption in RW instead of a knee or ankle joint.

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