RACE WALKING GROUND REACTION FORCES

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Race walking is an athletic event which is contested in most major international track and field competitions, including the Olympics. It is also slowly growing in popularity as a form of exercise and recreation. The rules of race walking state that it is "progression by steps so taken that unbroken contact with the ground is maintained". Further, "during the period of each step when a foot is on the ground, the leg must be straightened (i.e., not bent at the knee) at least for one moment... in the vertical upright position" (I.A.A.F., 1982).

Thus, the advancing foot of the athlete must contact the ground before the rear foot leaves the ground, and the leg must be straight as it passes beneath the body. The first of these rules is a statement of the visually obvious difference between walking and running. The second is a result of the evolution of the sport over time.

Very little study of race walking is reported in the literature. Most information is in the form of books for the serious coach or athlete (i.e., Rudow, 1975; Laird, 1972 and Hopkins, 1976) or general information for the individual interested in race walking for fitness (Jacobson, 1980). These are fundamentally based on the experience of successful athletes and general coaching principles, as opposed to rigorous scientific study of the event. Race walking does merit such study, however, as it appears both recreational and competitive walkers tend to suffer fewer injuries than runners of similar ability, while enjoying comparable cardiovascular conditioning (Pugh, 1968). Thus, information concerning the range of motion of, and forces on the body while race walking is quite relevant.

This study is an initial investigation into the ground reaction forces experienced in race walking at various speeds. The goal is to determine significant characteristics of the ground reaction forces in race walking, and the possible use of such force information in the analysis of the race walker's technique. The specific use of ground reaction force data as a technical aid to elite race walkers is considered.

BACKGROUND

Only one study of race walking kinematics was found in the literature. Murray (1983) analyzed the kinematic and electromyographic patterns of two Olympic-caliber race walkers. Previous study by Murray (1966, 1967) included examination of normal walking patterns for men, at free and fast speeds. Noteworthy differences in changing from normal walking to race walking include increased transverse rotation of the pelvis, increased plantar flexion at the ankle of the rearward extremity, decreased knee flexion throughout the walking cycle, and even slight hyperextension of the knee at midstance. Dorsiflexion at the ankle of the swing leg projected the calcaneus forward, augmenting the stride length, as did narrowing the stride width and placing the feet closer to the line of progression. The armswing was much more vigorous in race walking, accompanied by a transverse rotation of the thorax opposite that of the pelvis. The race walkers exhibited greater pelvic tilt in the frontal plane, as the pelvis rose above the straightened stance leg, and dropped on the side of the swing leg.

Perhaps most importantly, the vertical motion of the center of mass was signficantly less in race walking than in fast normal walking. Thus, the motions of the hips, pelvis, thorax, pectoral girdle and arms successfully replace knee flexion in the role of minimizing vertical motion of the center of mass.

Payne (1978) measured the ground reaction forces for one subject while walking, race walking, and running. Vertical and anterior-posterior forces were only slightly greater in race walking than normal walking, while medial lateral forces were almost four times as great. The race walking speed was 4.69 m/sec (16.9 km/hr), and in running was 7.52 m/sec (27.1 km/hr). This is a rather high velocity in comparison to typical training or competitive race walking speeds, but is the only information on race walking ground reaction forces found in the literature.

APPARATUS AND PROCEDURE

The initial study was carried out in the mobility facility of the Laboratory for Biomechanics and Human Rehabilitation at the Massachussetts Institute of Technology. This is a large, high ceilinged room with 20 meters of unobstructed approach area adjacent to the force platform installation.

The force platform, a Kistler model 9281A, is covered with the same tiles as the surrounding floor and is flush with the surrounding surface. Previous tests indicate that the fundamental natural frequency of the platform in this installation is approximately 700 Hz. The host computer for data collection and reduction is a D.E.C. PDP 11/60. This system was developed by prior students, and is described in great detail by Antonsson (1982).

A sampling frequency of 2.0 kHz was used, primarily because of interest in the peak forces experienced at heel strike. The sampling period was one second.

A simple relay operated clock was applied in conjunction with two light source and phototransistor pairs to measure the time it took the subject to cover a known distance (4 meters) while crossing the force platform. The light sources, 5 milliwatt Hewlett-Packard helium-neon lasers, were mounted on tripods and could be adjusted to the height of the subject's jaw. This minimized the likelihood of the clock being started or stopped by the motion of the subject's limbs, giving a more accurate measure of the average velocity of the subject's center of mass. The phototransistors were set up directly across the walkway from the lasers. The first light beam crossed the walkway 1.5 meters before the center of the force platform, and the second 2.5 meters after.

The subjects for the study were seven competitive race walkers, six men and one woman, from 18 to 45 years old. See Table 1 for details. Four of the subjects (A-D) were nationally competitive athletes at the time of the study. The subjects wore their own competitive footwear for the tests.

Each subject was weighed on the force platform so that data could be normalized to body weight. After adequately warming up, the subject was instructed to walk across the force platform at an even 9 minute per mile pace, while looking at the wall ahead. This was continued with instuctions to adjust the speed given until the subject's velocity was consistently within 5% of the target speed. Data trials were initiated, and the subject's starting position was adjusted until the right foot landed on the platform during a normal stride.

A good trial was one in which the subject's speed was within 5% of the target velocity, the right foot landed fully on the force platform, and the subject did not appear to adjust the gait to strike the platform. If the subject felt their gait was in any way unnatural, or if they appeared to vary their speed in the test area, the data were discarded.

This process of adaptation to desired velocity, and then adjustment of starting position, was repeated at 8, 7 and 6 minute per mile walking speeds. At least four good trials were obtained at each velocity. Nine, eight, seven and six minute per mile paces correspond to approximately 3.0, 3.35, 3.8, 4.5 m/sec, respectively.

RESULTS

The data obtained were examined in graphical form, and hard copy plots of the three force components versus time were obtained on a Hewlett-Packard 9872A plotter. Note that a negative anterior-posterior force indicates a posteriorly directed force exerted on the foot by the platform, a negative medial-lateral force is a medially directed force on the foot, and a positive vertical force is an upward directed force on the foot, as shown in Figure 1. Typical raw data is shown in Figure 2.

Three steps were carried out in the reduction of the data to a generalized form. First, the one second data sample was truncated to include only the contact phase of the measured step. Time was normalized to the duration of contact of the measured foot with the force platform. The peak vertical force and its normalized time of occurrence were also determined.

The second step entailed normalizing the force data to the subjects body weight. This allowed multiple trials, in fully normalized form, to be averaged together for an athlete at a given velocity. Simple point-by-point averaging was used to combine the four trials for a subject at one speed.

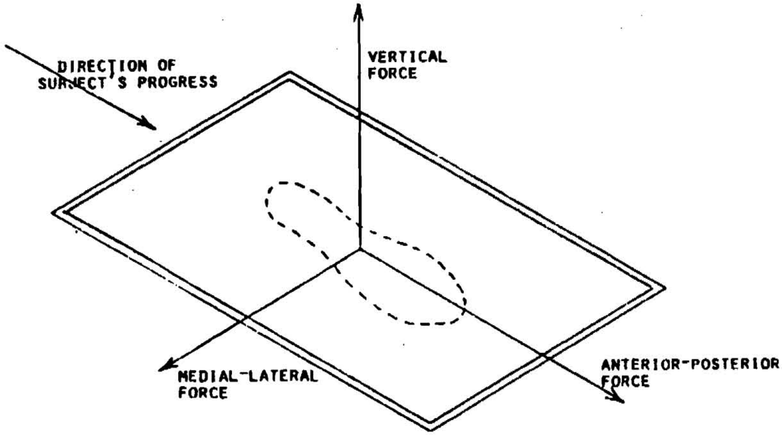

Figure 1. Force platform ground reaction force convention.

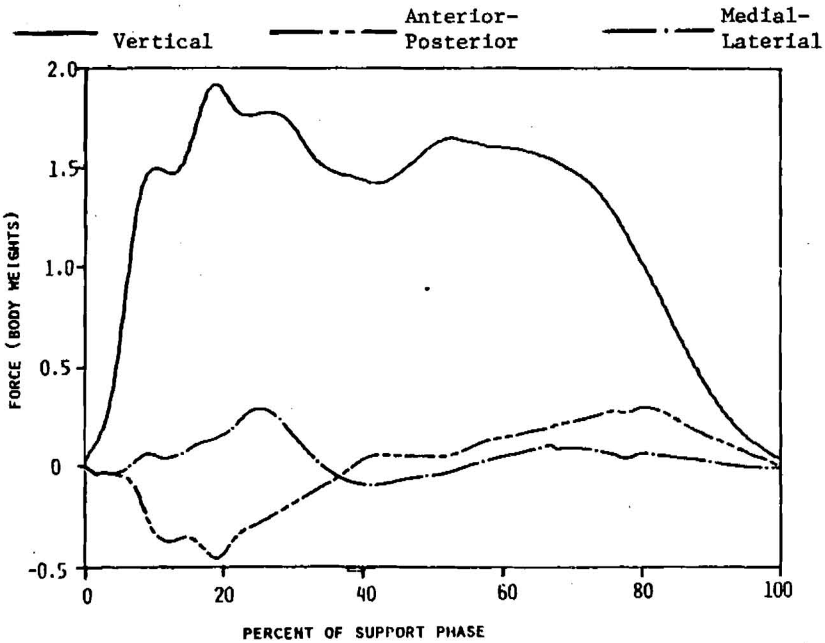

Figure 2. Typical ground reaction forces in race walking, normalized to body weight and contact time. 8 minute per mile pace.

The final step allowed the combination of individual subjects' data into a group average at each velocity. The individuals' averaged data could thus be combined into a group average of normalized force versus percent of support phase. The averaged curve for all seven subjects, at eight minute per mile pace is shown in Figure 3.

The averaging described above was found to be quite effective within one subject, but less so when all seven subjects were combined. Intrasubject averaging effectively smoothed the force curves, without changing the significant characteristics or shape of the curve, thus obviating the need for further data smoothing. This was found to be the case for all of the subjects.

As Figure 3 indicates, however, the averaging of data across all subjects resulted in relatively flat, featureless force curves. In particular, the overall averages do not indicate the full magnitude of the peak vertical forces which occurred within the first 25% of support. This is clearly attributable to variation in the occurrence of significant force characteristics as a percentage of the support phase. These temporal differences between subjects are significant as possible indicators of differing techniques or capabilities.

Based on such differences, the data essentially falls into two groups, using the vertical force component as a guide. Three of the subjects (E, F and G) experience peak vertical force at the first relative maximum, within the first 10-15% of the support phase. Another three subjects, A, B and C, experience the greatest vertical force at the second relative maximum of the curve, at 15 to 25% of stance phase. Subject D does not as clearly fall into either category, as the first two vertical force maxima are often quite similar in magnitude. Subject D, however, is quite appropriately included with subjects A-C. Subject D is similar in age, and weekly training mileage to subjects A-C (see Table 1) and, like A-C, is an elite competitor. Data is considered, therefore, with subjects A-D averaged together, and subjects E-G together. Figures 4 and 5 allow comparison of averaged data for the two groups, at 8 minute per mile pace.

Examination of this data across all velocities allows the following qualitative description of the ground reaction forces in race walking.

The vertical ground reaction forces in race walking are typically found to be similar to, but of slightly greater magnitude than, the reaction forces in normal walking. The vertical force curve can be characterized by three maxima, or peaks. The first peak occurrs within the first 15% of the support phase, with the second peak occurring immediately after and lasting up to 15% of support. The final maximum is in fact a much smoother rise in vertical force, which occurrs during the latter 50% of support, before dropping to zero at toe-off.

A most noteworthy finding is that the vertical ground reaction force in race walking is significantly less than in running. Cavanaugh (1980) found that the peak vertical reaction force in running, at 6 minutes per mile, averages 3.0 BW (body weights). This study indicates that the maximum vertical forces for competitive walkers travelling at the same speed averages 2.1 BW. While the maximum force in running occurs at roughly 50% of the support phase, during propulsion, the peak vertical force in race walking

TABLE 1

CHARACTERISTICS OF THE SEVEN TEST SUBJECTS

Listed in order of competitive ability

SUBJECT	AGE	RACE WALKING EXPERIENCE (YEARS)	TRAINING MILEAGE (MILES/WEEK)
A	23	7½	100–115
B	25	6	50
C	25	10	50
D	21	6	75
E	29	1	50
F	18	4	45
G	45	26	15

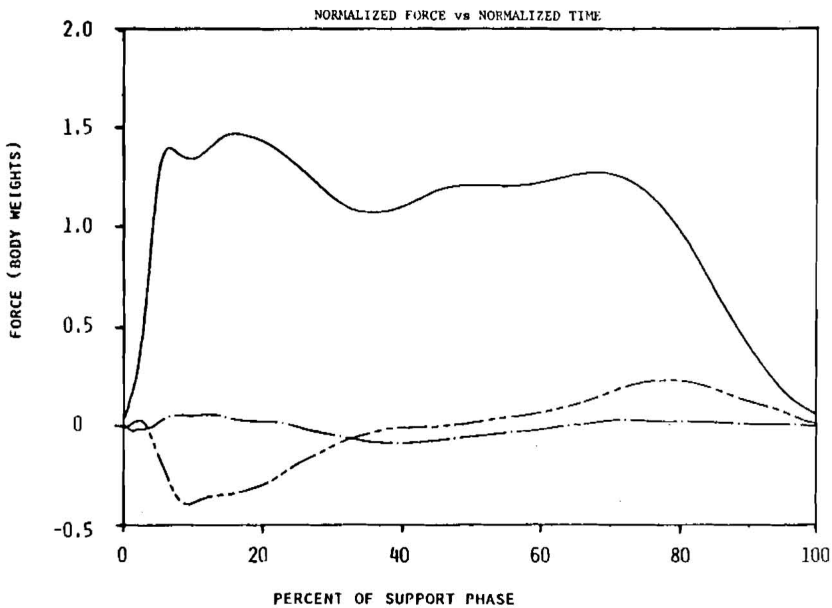

Figure 3. Averaged normalized ground reaction forces for all subjects at 8 minute per mile pace.

Vertical; Anterior-Posterior; Medial-Lateral is seen during the first 30% of support, often immediately at heel strike. This decreased vertical force must be in part related to the decreased vertical motion of the center of gravity in race walking as compared to running.

The foot universally experienced a posteriorly directed force for the first 30% to 40% of support. This shifted to an anteriorly directed force for the remainder of ipsilateral support. These forces in both directions approached, but rarely exceeded, one-half body weight at maximum, even at the highest speed tested. Some athletes experienced an anteriorly directed force, during the first 5% of support, of magnitude less than 0.2 BW (body weights). Such force at heel strike is typical of normal walking curves.

The medial-lateral forces showed the greatest variation, in both direction and magnitude, amongst subjects. Quite generally, the foot experienced a laterally directed force for the first one-third of support, a medial force during mid-support phase, and a lateral force for the final one-third of support. Quite notably, the peak medial-lateral force is similar in magnitude to medial-lateral forces experienced in running, roughly 0.3 BW.

FOLLOW-UP AND CONCLUSIONS

Following the initial work done at Massachusetts Institute of Technology, a force platform has been used with high speed cinematography in technique analysis of competitive race walkers at the U.S. Olympic Committee's Biomechanics Laboratory in Colorado Springs, Colorado. The subjects in this continuing study are elite race walkers training at the U.S. Olympic Training Center in Colorado Springs. Visual examination of the high speed film taken with simultaneous force platform measurement has given a much improved understanding of the athlete's body position during significant occurrences in the ground reaction force pattern.

It is clear that the first relative maximum in the vertical force curve occurs at initial heel strike. The second relative maximum appears concurrent with ground contact of the forefoot of the supporting limb, and full acceptance of the weight bearing role by that limb. As previously discussed, subjects A-D were elite athletes, and as such were expected to have more developed and fluid technique. By comparison, subjects E and F had significantly less race walking experience, and the older subject, G, clearly was losing the flexibility and strength to maintain fluid walking technique, especially at the higher speeds. Clearly, subjects E, F and G exhibited the more abrupt weight transfer onto the supporting limb, and thus the greater force at initial heel strike. This suggests that the nature and magnitude of the vertical ground reaction force is a useful indicator of the smoothness or fluidity of the stride.

In normal walking, knee flexion of the support limb allows the vertical ground reaction force to actually drop below body weight during midstance. The vertical force in race walking similarly drops during mid-support. Knee flexion, however, is replaced by the complex motions of race walking, including pelvic tilt and adduction of the supporting hip, lateral flexion of the torso toward the supporting limb, and a drop of the pectoral girdle above the stance leg. On the whole, the midstance drop in vertical force is not as great in race walking as in normal walking because the vertical excursion of the center of gravity is less in race walking (Murray, 1982).

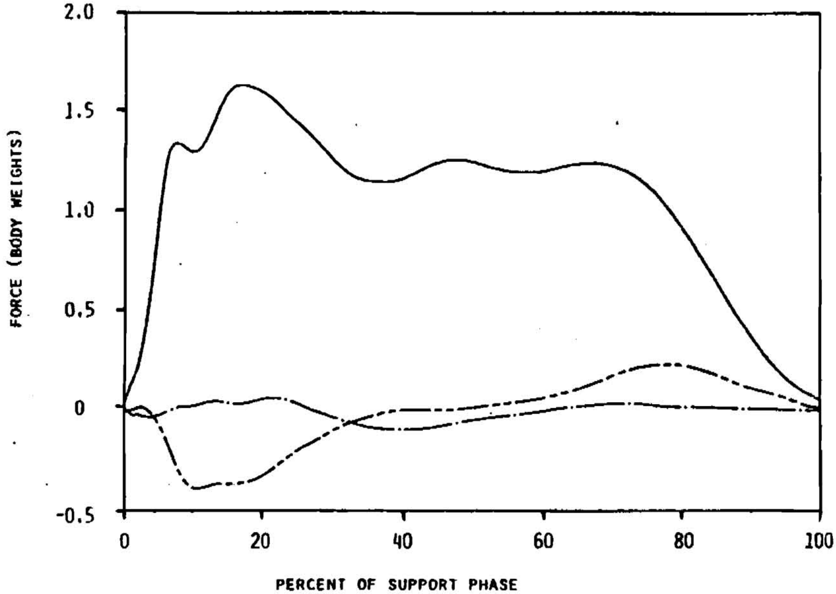

Figure 4. Averaged ground reaction forces for four elite race walkers (subjects A-D) at 8 minute per mile pace.

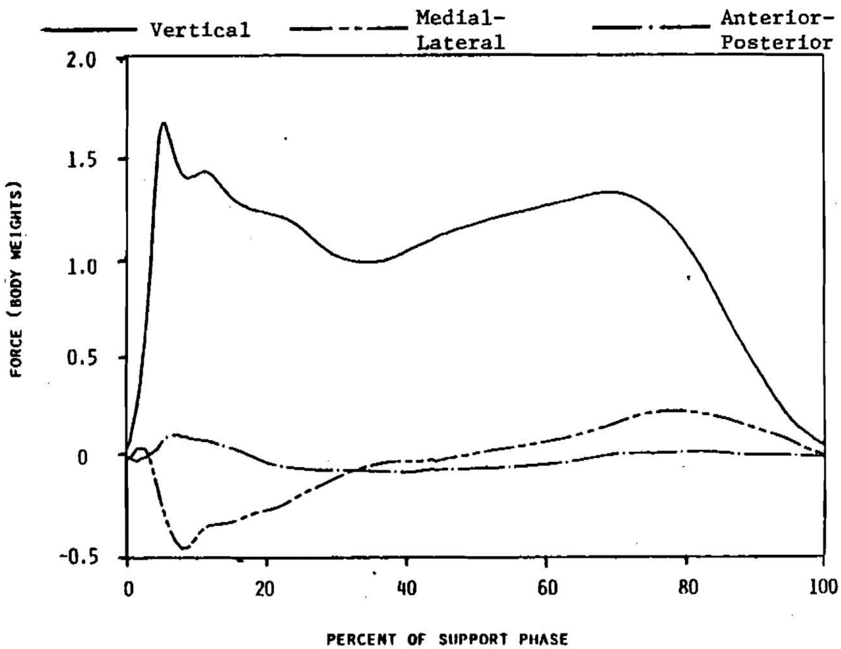

Figure 5. Averaged ground reaction forces for three good race walkers (subjects E-G) at 8 minute per mile pace.

The later rises in vertical force which occur in race walking are about one-half body weight below the maximum vertical force. In normal walking, by contrast, the later propulsive peak is roughly of the same amplitude as the first peak. This is to be expected, as the race walking athlete must minimize the vertical component of forces exerted at toe-off, or vertical motion of the trunk may be increased to the point of disqualifying the athlete for loss of contact with the ground.

The decreased vertical component of the propulsive force in race walking appears related to changes in the anterior-posterior force. The transition from posteriorly to anteriorly directed force occurs early in race walking, at 30% to 40% of stance, as opposed to normal walking, at roughly 50% of stance. The curve can essentially be divided into three parts. The posteriorly directed force on the foot is actually a decelerating force on the athlete, which ends when the force becomes positive at 30% to 40% of support. For the next 10% to 20% of support there is a plateau of the anteriorly directed force which is constant or increasing only slightly. During the final 40% to 50% of support, the foot experiences a peak anteriorly directed force, as the athlete pushes himself forward by pushing rearward on the ground.

The more recent force platform/cinematographical study indicates that the maximum decelerative forces occur when the supporting foot is still well in front of the athlete's body, and may be attributable to over striding by the athlete. The midstance plateau in the anterior-posterior force is concurrent with hyperextension of the supporting knee, as the leg passes under the body, and may be relatively shortened by lessening that hyperextension. In both cases, the objective is to relatively minimize the decelerative impulse of each step so that the athlete has to do as little work as possible to maintain a constant velocity. It is also important to attempt to maximize the magnitude of the posteriorly directed force, with powerful rearward drive of the supporting limb,rotation of the pelvis, and plantar flexion at the ankle.

Quantitative analysis may be most useful in pursuing the study of the anterior-posterior force. For example, simple calculation of the negative and positive impulses imparted during the first and second parts of the stance phase will be particularly useful in considering an athlete's efficiency. In any case, it is clear that measurement of the anterior-posterior force is informative in analyzing the athlete's technique.

Examination of the medial-lateral force yields little initial information regarding possible technique modifications, although it does agree well with observed kinematics of the gait. The foot first exerts a medially directed force as the swinging limb, rotating forward and toward the center line of the body, (or the line of progress) contacts the ground. The lateral force during midstance is due to the excursion of the hip and the pelvic tilt, as well as the flexion of the torso over the supporting limb. The medial force as toe-off approaches is due to the medial rotation of the pelvis and contralateral leg about the supporting limb, as the opposite leg approaches the center line at heel strike.

It was noted, again in the more recent study of elite race walkers, that within this general pattern there is noticeable individual variation. Clearly, further study of the medial-lateral forces may prove useful in remedying losses in effeciency, or even injuries, due to poor foot position or excessive lateral motion.

REFERENCES

Antonsson, E.K., A Three-Dimensional Kinematic Acquisition System and Inter-segmented Dynamic Analysis System for Human Motion, A Ph.D. Thesis, Massachusetts Institute of Technology, June 1982.

Cavanaugh, P.R., and LaFortune, M.A., "Ground Reaction Forces in Distance Running", Journal of Biomechanics, 13:397-406, 1980.

Hopkins, Julian, Race Walking. London: British Amateur Athletic Board, 1976.

International Amateur Athletic Federation Official Handbook. London: IAAF Publications, 1977-78.

Jacobson, Howard, Race Walk to Fitness. New York: Simon and Schuster, 1980.

Laird, Ron, Competitive Race Walking. TAF News Press, Los Altos, CA: 1972.

Murray, M.P., Guten, G.N., Mollinger, L.A., and Gardner, G.M., "Kinematic and Electromyographic Patterns of Olympic Race Walkers", The American Journal of Sports Medicine, 11(2); 68-74, 1983.

Murray, M.P., Kory, R.C., Clarkson, B.H., and Sepic, S.B., "Comparison of Free and Fast Speed Walking Patterns of Normal Men", American Journal of Sports Medicine, 45(1);9-24,1966.

Murray, M.P., Sepic, S.B., and Barnard, E.J., "Patterns of Sagittal Rotation of the Upper Limbs in Walking", Physical Therapy, 47:272-284, 1967.

Payne, A.H., "A Comparison of Ground Reaction Forces in Race Walking with Those in Normal Walking and Running". Biomechanics VI-A, Baltimore: University Park Press, 1978, pp. 293-302.

Pugh, L., and Menier, D., "The Relation of Oxygen Intake and Velocity of Walking and Running, in Competition Walkers". Journal of Physiology 197: 717-721, 1968.

Rudow, Martin, Race Walking, Mountain View, CA: World Publication, 1975.