BIOMECHANICAL CHARACTERISTICS OF RACE WALKING: A THEMATIC REVIEW

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ABSTRACT

Race walking, a competitive sport requiring continuous ground contact and strict adherence to technical rules, poses unique biomechanical challenges. This study investigates the lower-limb kinematics, ground reaction forces (GRFs), and flight time in elite race walkers to understand key performance factors. At heel strike, the ankle dorsiflexes, the knee fully extends, and the hip flexes, while the contralateral shoulder and ipsilateral elbow coordinate efficiently. Mid-stance involves knee hyperextension and pelvic adjustments to minimize vertical displacement of the center of mass. Toe-off highlights coordinated plantarflexion, knee flexion, and arm movements. Pelvic rotation and knee straightness play crucial roles in speed and efficiency, though measurement methods yield varying results. Flight time remains minimal, setting race walking apart from running. GRFs display distinct patterns influenced by speed. Insights from this analysis offer valuable information for optimizing performance, refining techniques, and minimizing injury risk in this highly technical and demanding sport.

Keywords: Kinematics, Biomechanics, Race Walking

1. INTRODUCTION

Race walking is a unique form of competitive walking that involves maintaining contact with the ground at all times while striving for an efficient and economical gait. This study aims to provide a comprehensive biomechanical analysis of the lower-limb movements of elite race walkers, with the goal of better understanding the key factors that contribute to their performance and efficiency.

The Olympic and other major sporting championships' athletic programs include race walking. Men's and women's championship events span 20 km, whereas men's competitions span 50 km. Junior men's and women's races (those under 20) span 10 km (Hanley, Brian, 2013).

The biomechanics of race walking have been the subject of considerable research, as coaches and scientists seek to identify the specific kinematic and kinetic patterns that distinguish this sport from other forms of ambulation. Notably, race walkers must adhere to strict rules regarding the maintenance of contact with the ground and the straightening of the supporting leg, which places unique demands on the lower-limb musculature and joint kinematics.

Previous studies have examined the biomechanics of race walking in comparison to normal walking (Han & Wang, 2011), as well as the effects of load carriage on gait mechanics (Yang et al., 2015). However, a more thorough investigation of the specific biomechanical characteristics of elite race walkers is warranted to provide a deeper understanding of the factors that contribute to their high levels of performance and efficiency.

This study aims to provide a comprehensive biomechanical analysis of the lower-limb movements of elite race walkers, with the goal of better understanding the key factors that contribute to their performance and efficiency. Race walking is a unique form of competitive walking that involves maintaining contact with the ground at all times while striving for an efficient and economical gait. The biomechanics of race walking have been the subject of considerable research, as coaches and scientists seek to identify the specific kinematic and kinetic patterns that distinguish this sport from other forms of ambulation. Notably, race walkers must adhere to strict rules regarding the maintenance of contact with the ground and the straightening of the supporting leg, which places unique demands on the lower-limb musculature and joint kinematics. Previous studies have examined the biomechanics of race walking in comparison to normal walking, as well as the effects of load carriage on gait mechanics. However, a more thorough investigation of the specific biomechanical characteristics of elite race walkers is warranted to provide a deeper understanding of the factors that contribute to their high levels of performance and efficiency.

2. ANGULAR KINETICS

Although there are a number of research on joint angles in the literature, there isn't a comprehensive quantitative description that takes into account the various speeds involved.

When the heel strikes, the sagittal plane shows that the ankle is dorsiflexed in comparison to the standing position, the knee is fully extended, and the hip is flexed. The elbow is reported to have an angle of 79° ± 9°, and the contralateral shoulder is extended (Hanley et al., 2011a). The knee is hyperextended by approximately 10°, the shoulder is flexed, the elbow has nearly a flexion of 82° ± 7°, and the ankle is still dorsiflexed at mid-stance (Hanley et al., 2011a). At toe off, the elbow is flexed 67° ± 7°, the knee is flexed, the hip is extended, the ankle is plantar flexed, and the contralateral shoulder is flexed (Hanley et al., 2011a).

According to Murray et al. (1983) and Phillips & Jensen (1984), the column formed an S-shape curve in the frontal plane, where the hip is in the highest position over the support leg and the lowest position over the swinging leg (pelvic tilt). In contrast, the shoulder ipsilateral to the support leg is in the lowest position and the contralateral shoulder is in the highest position. At 3.6 m s^{-1} (13 km h^{-1}), the pelvic tilt is approximately 7° ± 4°, however it tends to rise with speed (Cairns et al., 1986). Although a quantitative analysis or confirmation is needed, these research suggest that trunk and pelvic adjustments should reduce the vertical excursion of the body centre of mass during the single support.

The results of the description of the pelvic rotation in the transverse plane were contentious. Hanley et al. (2011a) reported an angle of 18° ± 3°, whereas others reported larger pelvic rotation ranging from 35° ± 8° (Cairns et al., 1986) to 44° (Murray et al., 1983). It can be related to a different choice of reference for measuring joint angle: Murray et al. (1983) and Cairns et al. (1986) computed the entire angular rotation of the same marker, while Hanley et al. (2011a) estimated pelvic angle using hip joint coordinates. In contrast, Murray et al. (1983), White and Winter (1985), and Hanley and Bissas (2013) demonstrated the angular time course of the hip, knee, and ankle joints during a stride. This may be a crucial functional parameter for a more comprehensive view of the locomotion pattern and to give athletes and coaches additional technical feedback appropriate for training.

3. KNEE JOINT ANGLES

The precise relationship between knee joint angles and race walking performance has been a subject of interest for researchers in the field of sports biomechanics. Several studies have examined the role of lower extremity strength and joint angles in gait performance, including during race walking. One study found that kinematic alterations, such as a more flexed knee and ankle, are a postural strategy used to adapt to different walking surfaces and inclines. (Shi & Yu, 2016) Another study suggested that age-related changes in gait characteristics, including slower speed, shorter stride length, and wider stride width, can be detected at relatively younger ages and are strongly associated with lower extremity strength. (Ko et al., 2012)

In the context of race walking, the requirement to maintain a straightened knee during a portion of the stride has been a subject of debate. Some researchers have defined a "straight" knee as having an angle between 175 and 185 degrees. (Hanley et al., 2009) This extended knee position, which is abnormal in normal walking or running, may provide benefits to the race walker in terms of increasing walking speed through decreased support time and increased hip extension velocity. (Hanley et al., 2009)

However, the exact angle required for a "straight" knee in race walking has not been clearly defined, and the potential advantages or disadvantages of a hyperextended knee during midstance have not been conclusively established.

4. FLIGHT TIME

Race walking, a unique form of competitive walking, requires athletes to maintain constant contact with the ground while avoiding any periods of flight, where both feet are off the ground simultaneously. In contrast, running involves a series of leaps through the air, with a significant increase in shock absorption and injury risk as the runner lands. (Fields et al., 2005) The transition between walking and running is marked by distinct differences in the body's center-of-mass energy fluctuations and the duty factor, the proportion of time spent in contact with the ground. (Segers et al., 2006)

Numerous investigations have identified the flight time, and its duration (0.01–0.05 s) varied with speed. Hanley et al. (2011a, 2011b) discovered that the flight time for a male 20-kilometer race (speed = 4 m s−1, 14.5 km h−1) was 0.03 s, whereas the flight time for a female 20-kilometer race and male 50-kilometer race (3.5–3.6 m s−1, 12.7 km h−1–13.1 km h−1 respectively) was 0.02 s. It should be mentioned that judges' psychophysiological visual limitations prevented them from detecting such brief flight lengths.

5. GROUND REACTION FORCES

Ground reaction forces play a crucial role in the biomechanics of race walking, a specialized form of competitive walking that emphasizes technical proficiency and efficiency. During race walking, athletes must maintain consistent contact with the ground while adhering to a set of technical rules, including the requirement to have one foot in contact with the ground at all times. Understanding the ground reaction forces experienced by race walkers is essential for optimizing their performance and minimizing the risk of injury. Recent research has focused on developing unobtrusive, on-athlete instrumentation to measure and characterize these ground reaction forces, providing valuable insights into the mechanics of race walking.

One study investigated the measurement and characterization of ground reaction forces during athletic activities, including race walking, using on-athlete instrumentation (Billing et al., 2004). The researchers developed instrumentation to simultaneously acquire in-shoe load and acceleration data, and proposed a signal processing method to determine ground reaction force data from the on-athlete instrumentation.

According to the International Society of Biomechanics (ISB) guidelines, three subjects in Fenton's study who were classified as less-trained (Fenton, 1984) and Cairns et al. (1986) and Rodano and Santambrogio (1987) displayed a "M" shaped vertical force with a local minimum between the two peaks, which is typical of walking. In four additional participants, Payne (1978) and Fenton reported a more consistent GRF vertical component that resembled the running GRF pattern (Figure 2), with a noticeable first peak and a lower relative maximum. Although force traces must be distributed over the speed since they are speed-dependent, the average peak magnitude was approximately 1.5 body weight (BW).

6. CONCLUSION

Race walking biomechanics involves complex joint kinematics, ground reaction forces, and adaptations for technical compliance and efficiency. In the sagittal plane, the ankle is dorsiflexed at heel strike, the knee fully extended, and the hip flexed, while the ipsilateral elbow is flexed at $79^0 \pm 79^0$, and the contralateral shoulder is extended. At mid-stance, the knee hyperextends by 10^0, which increases with speed to minimize the vertical excursion of the body's center of mass. Pelvic rotation in the transverse plane varies, with studies reporting angles between $18^0 \pm 3^0$ and 44^0, discrepancies arising from different measurement methods. Race walking also requires knee straightness during strides, defined variably as 175–185°; this hyperextended position may enhance speed by reducing support time and increasing hip extension velocity, though the exact advantage is unclear. Flight time, a critical distinction from running, is minimized, with elite athletes showing brief durations (0.02–0.03 s) undetectable by judges. Ground reaction forces during race walking show an "M" pattern, with two peaks and a mid-minimum typical of walking, though at higher speeds it can resemble a running-like force trace. Peak vertical forces average 1.5 body weight (BW) and depend on speed. Advancements in on-athlete instrumentation have enhanced the understanding of these forces, providing insights for performance optimization and injury prevention. These biomechanical insights, covering joint angles, gait adaptations, and ground forces, contribute to refining techniques, improving training strategies, and enhancing race walking performance.

CONFLICT OF INTERESTS

None.

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