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ScienceDirect
Journal of Sport and Health Science xx (2016) 1–6
www.jshs.org.cn

Original Article

Does the McNeill Alexander model accurately predict maximum walking speed in novice and experienced race walkers?

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Received 17 January 2016; revised 14 March 2016; accepted 11 April 2016
Available online

Abstract

Background: Mathematical models propose leg length as a limiting factor in determining the maximum walking velocity. This study evaluated the effectiveness of a leg length-based model in predicting maximum walking velocity in an applied race walking situation, by comparing experienced and novice race walkers during conditions where strictly no flight time (FT) was permitted and in simulated competition conditions (i.e., FT ≤ 40 ms).

Methods: Thirty-four participants (18 experienced and 16 novice race walkers) were recruited for this investigation. An Optojump Next system (8 m) was used to determine walking velocity, step frequency, step length, ground contact time, and FT during race walking over a range of velocities. Comparisons were made between novice and experienced participants in predicted maximum velocity and actual velocities achieved with no flight and velocities with FT ≤ 40 ms. The technical effectiveness of the participants was assessed using the ratio of maximum velocity to predicted velocity.

Results: In novices, no significant difference was found between predicted and maximum walking speeds without flight time but there was a small 5.8% gain in maximum speed when FT ≤ 40 ms. In experienced race walkers, there was a significant reduction in maximum walking speed compared with predicted maximum ($p < 0.01$) and a 11.7% gain in maximum walking speed with FT ≤ 40 ms.

Conclusion: The analysis showed that leg length was a good predictor of maximal walking velocity in novice walkers but not a good predictor of maximum walking speed in well-trained walkers who appear to have optimised their walking technique to make use of non-visible flight periods of less than 40 ms. The gain in velocity above predicted maximum may be a useful index of race walking proficiency.

Keywords: Biomechanics; Gait; Mathematical modelling; Race walking; Sports technique; Technique development

1. Introduction

Race walking is a highly technical sport that features in most major athletic championships worldwide. It was introduced into the Olympic Games in 1908 as a standalone event and the primary distances currently used in competition are 20 km and 50 km. Due to the high technical demands of the event, race walkers are constantly monitored during races to ensure they adhere to the rules. The rules as outlined by the International Association of Athletics Federations (IAAF) state that, "race walking is a progression of steps taken so that the walker makes contact with the ground, so that no visible (to the human eye) loss of contact occurs. The advancing leg must be straightened (i.e., not bent at the knee) from the moment of first contact with the ground until the vertical upright position".[1] Therefore the rule can be divided into 2 main components, contact with the ground and knee straightness. When a judge observes an athlete breaking either component of the rule, the athlete receives a red card which is reported to the chief judge. If an athlete receives 3 red cards from 3 separate judges, this results in disqualification from the race. Currently in international competitions, the judging relies on subjective human observation which naturally introduces the capacity for human error.[2,3]

Race walkers are trained to overcome the body's natural reaction to run, which is a more economical form of movement at higher velocities.[4,5] More recent studies have shown that transitioning from walking to running results in an increase in energy expenditure[6] and the point at which the walk–run

Peer review under responsibility of Shanghai University of Sport.
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http://dx.doi.org/10.1016/j.jshs.2016.04.010

transition occurs in untrained race walkers is thought to be influenced by the plantarflexor and dorsiflexor muscles. This transition of gait occurs to prevent the dorsiflexor muscles from being over-exerted.[7] There is evidence that at walking speeds close to the preferred walk–run transition, poor contractile conditions may necessitate a change in gait[8] while peak and mean plantar pressures were found to be significantly higher during race walking compared to normal walking.[9] Consequently, race walkers use a unique walking gait to optimise speed while still adhering to the rules.

Various models have been proposed to explain the biomechanical limitations on walking speed.[10,11] Most of these models indicate that leg length is the primary limiting factor in determining the maximum velocity a race walker may achieve within the rules, (i.e., before lifting occurs). McNeill Alexander[11] proposed a mathematical model for predicting the maximum velocity (v_{pred}) of an individual adhering to the rules, i.e., when no flight time (FT) is allowed. This model proposes that the leg acts as an inverted pendulum of length (L), and the maximal walking speed of an individual is determined by Eq. (1).

$$v\text{pred} = \sqrt{g \cdot L} \tag{1}$$

where, g = gravitational acceleration (9.81 m/s) and L is the length of the leg which in practice may refer to the length of the leg from the iliac crest to the ground, including the height of the shoe. Therefore, an individual with an effective leg length of 0.90 m will achieve a predicted maximum velocity of 2.97 m/s during race walking.[11,12] Inspection of official performances in international competition indicates that race walkers achieve much higher walking speeds without disqualification. For example, the average speed recorded at a typical IAAF race was 4.03 ± 0.239 m/s for men and 3.54 ± 0.272 m/s for women;[13] this would require effective leg lengths of 1.66 m and 1.28 m, respectively (since $L = v_{pred}^2/g$). There are 2 likely explanations for this: firstly, race walkers employ techniques to alter the biomechanics of walking and facilitate greater velocities[14] and/or secondly, they lose contact with the ground for short periods which are undetectable by the methods currently employed by the IAAF judges. McNeill Alexander[15] proposed that the compensatory hip movements used by experienced race walkers may provide an explanation for this increased velocity; by lowering the centre of mass using compensatory hip movements, the centre of mass travels in a flatter arc (i.e., an arc of greater radius). The radius of this arc is greater than leg length and thus enables higher speeds to be attained. By calculating the race walker's predicted maximum speed and then establishing their maximum speed achieved within the rules of race walking, it may be possible to get an indication of their technical proficiency.

It has been proposed that the human eye can only process images at a maximum rate of approximately 16 Hz (i.e. that which lasts longer than 60 ms)[2] and any event of shorter duration than this will not be processed accurately by the observer. Knicker and Loch[3] established that the mean FT during phases of lifting in race walking was 46 ms and mean FTs for those for those not identified was 39 ms. This was further reinforced by De Angelis and Menchinelli[16] who found that when analysed by a coach of long-standing international experience, the athlete was seen to be lifting when FT approached and/or exceeded 40 ms. More recently, Hanley et al.[17] examined elite race walkers walking at their typical competition speeds and observed FTs of 30 ± 11 ms (mean ± SD),which suggests that some walkers used FTs > 40 ms. Practically, this means that race walkers could use FTs of approximately 40 ms to increase their race walking velocity when competing which is higher than their predicted maximum velocity.

Based on the above, there appears to be merit in evaluating whether the McNeill Alexander[11] model provides a valid prediction of maximum race walking speed in both trained and experienced race walkers as this could provide insights into the technical proficiency of race walkers. Recent research has demonstrated that elite race walkers achieve velocities in competition and training far greater than those predicted by McNeill Alexander's model and that up to 10% of the velocity achieved by elite race walkers accrues from the flight phase.[18] It is likely that FTs of ≤40 ms will be undetected in competitions.[3] Therefore, an evaluation of maximum walking speed should consider situations where the ground contact rule is strictly enforced and when a FT of ≤40 ms is used. Consequently, the aim of this study was to experimentally evaluate the validity of the McNeill Alexander[15] model in predicting the maximum walking velocity in a practical setting. This can be done by comparing experienced and inexperienced race walkers under conditions of no FT and in simulated competition conditions where a FT of ≤40 ms was permitted. The data could potentially be used to assess the effectiveness of an athlete's technique by comparing predicted speed with maximum speed achieved in simulated competition conditions (i.e., FT ≤ 40 ms). The ratio of predicted to maximum speed achieved could provide a useful index of technical proficiency.

2. Materials and methods

2.1. Participants

Following University Ethical Committee approval, 34 participants were recruited for this investigation. This included 16 individuals (14 males and 2 females) with no prior race walking experience (novice group; age: 21.0 ± 2.61 years; height: 1.76 ± 0.06 m; mass: 73.8 ± 9.6 kg) and 18 competitive "experienced" race walkers (7 males and 11 females) who were members of a national development squad (experienced group; age: 16.80 ± 2.46 years, height: 1.68 ± 0.06 m, mass: 56.6 ± 7.4 kg). All participants provided written informed consent to participate in this study and where participants were under 18 years, parental consent was also obtained. All participants were injury free at the time of testing.

2.2. Experimental protocol

The vertical height from the ground to the participant's iliac crest while standing in the shoes they wore for all trials was measured using a flexible steel tape measure. This measure provided the effective leg length for the prediction of maximum walking speed using the McNeill Alexander model.[11] This method was preferred to measurement of the height to greater

Please cite this article in press as: Andrew J. Harrison, Patrick G. Molloy, Laura-Anne M. Furlong, Does the McNeill Alexander model accurately predict maximum walking speed in novice and experienced race walkers?, Journal of Sport and Health Science (2016), doi: 10.1016/j.jshs.2016.04.010