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Original Article

Kinematics of the forefoot in the horizontal plane during progressive pace barefoot racewalking on a treadmill after aerobic exercise load

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Abstract. [Purpose] The aim of this study was to measure the changes in forefoot maximum medial/lateral rotation in the horizontal plane during progressive pace barefoot racewalking on a treadmill after a physically demanding aerobic exercise load (a fatigue protocol). [Subjects] Eleven junior racewalking men participated in this study. [Methods] To identify changes in forefoot maximum medial/lateral rotation in the horizontal plane after physically demanding aerobic exercise load, an 8 ch wireless Motion Recorder (MVP-RF8-BC) was utilized. [Results] Forefoot maximum medial/lateral rotation in the horizontal plane was significantly associated with increased paces during progressive pace treadmill racewalking. Significant increases in forefoot maximum medial/lateral rotation were observed during progressive pace barefoot racewalking on the instrumented treadmill at 8 km/h and 10 km/h after a physically demanding aerobic exercise load. [Conclusion] The findings of this study indicated that forefoot maximum medial/lateral rotation increased during progressive pace barefoot racewalking in the fatigue state after a physically demanding aerobic exercise load, which implies that the kinematic features of the forefoot are changed in the fatigue state.

Key words: Racewalking, Medial/lateral rotation

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INTRODUCTION

Walking is an essential movement and is the most frequently performed action by human beings[1)]. Racewalking is an Olympic event, and the popularity of racewalking has increased steadily. Racewalking has not yet attracted large numbers of adolescents in China, but there appear to be indications that the event is growing in popularity. Racewalking events of 5 and 10 km are becoming increasingly popular for amateur athletes, and successes in these relatively short events have inspired some teenagers to attempt longer distance races. A number of walking enthusiasts have attributed the rising popularity of racewalking to decline in the popularity of jogging, and this trend has been influenced by widespread belief that racewalking is a sport providing opportunities for competitions, as well as valuable health and fitness benefits, without significant risk of injury[2)].

Sports fatigue, which is an inevitable feature in the career of any athlete, is both a physical and a mental state, representing

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the state in a difficult training session or competition when the body demonstrates a reduced ability to work efficiently. In longer activities such as distance running and racewalking, fatigue will arise through a combined effect of muscle repetition and depleted energy stores, especially local muscular fatigue that can be caused by insufficient energy to perform the legally specific technique and increased levels of muscular discomfort that may cause the body to shift into deviated biomechanics state.

Previous research has shown that success in race walking is related more to the efficiency of technique rather than physiological factors[3)]. The kinematics of the forefoot in racewalking are triplanar motions. Since the axis of the subtalar joint is not in any cardinal plane, the motions occurring in the subtalar joint present a triplanar motion pattern. The triplanar motions of the forefoot are as follows: transverse motion, frontal motion, and sagittal motion. The transverse motions occurring primarily in the subtalar joint are composed of medial rotation, which is movement of the forefoot or part of the foot medially in the horizontal plane, and lateral rotation, which is movement of the forefoot or part of the foot laterally in the horizontal plane. During running, both a medial and a lateral rotation were observed in the footprint when comparing the rear foot and forefoot in the horizontal plane[4)]. There are significantly differences between racewalking and normal walking or jogging during the stance phase (closed kinematic chain motions) of the gait cycle. This is because racewalking demands a straight leg from when the support leg touches ground until to the vertical upright position relative to the ground is reached. Keeping the leg straight with introversion of the foot causes a torque to be applied to the knee and this may be a potential factor for lower extremity injuries.

Racewalkers often use treadmills because of the benefits of having a flat unchanging surface on which pace judgment can be learned[5)]. The effects of fatigue associated with racewalking on a treadmill have not been evaluated and could be informative in regard to maintenance of the legal technique. The purpose of this study was to investigate the association of the forefoot's kinematic variables (medial and lateral rotation) in the horizontal plane with the racewalking linear speed during progressive pace treadmill racewalking in the fatigue state after a physically demanding aerobic exercise load.

SUBJECTS AND METHODS

This study was conducted with 11 healthy young amateur racewalkers. The participants were students of the Huaian Sports School of Huaian City, China. To be included in the study, each participant was required to have been trained at the school for at least 3 years. The subjects' characteristics are detailed in Table 1.

Participants were excluded if they had a lower limb or foot injury, visual problems, or vestibular problems. The exclusion criteria were assessed by using a questionnaire and through physical tests. The subjects signed an informed document approved by the ethics committee of Jangsu Province Huaian Sports School, which also approved the study. Before the testing session, all of the participants were supervised while they performed a 10-minute conventional routine warm-up. The participants were asked to refrain from any exercise for 2 hours before testing.

Participants walked barefoot on an instrumented treadmill. We measured the forefoot maximum medial/lateral rotation with an 8 ch Wireless Motion Recorder (MVP-RF8-BC, MicroStone Inc., Saku, Japan) during progressive pace racewalking before and after a physically demanding aerobic exercise load, which consisted of racewalking 5 km on the instrumented treadmill at a pace equivalent to 100% of their recent best load intensity. The wireless motion recorder was adhered to the third and forth metatarsal above the right foot. The sampling rate used for detecting the forefoot maximum medial/lateral rotation in the horizontal plane with the wireless motion recorder (bluetooth) was 200 Hz. The data were collected for 6 seconds on five successive capture stages, and the subjects maintained the appropriate pace for each stage, 2 km/h, 4 km/h, 6 km/h, 8 km/h and 10 km/h for about 30 seconds each without a rest break. The motion characteristics of the participants in 3 consecutive gait cycles at each of the 5 speeds were recorded and analyzed with the MVP-RF8-BC analysis software system. A video camera (200 fps) was simultaneously used to record the cycle phases and technique.

Two-way analysis of variance and multiple comparisons (Bonferroni) were used to test for statistically significant differences in forefoot maximum medial/lateral rotation in the horizontal plane before and after physically demanding aerobic exercise load during progressive pace racewalking, and the factors examined were before and after the physically demanding aerobic exercise load and the 2 km/h, 4 km/h, 6 km/h, 8 km/h, and 10 km/h paces. If a significant interaction was found, one-way analysis of variance was performed for each factor. The independent *t*-test was performed to compare between before and after the physically demanding aerobic exercise load. The associations between the forefoot maximum medial/lateral rotation and paces were determined by Pearson's product moment correlation. Data were analyzed by using PASW Statistics 18 for Windows. The level of statistical significance was set as $p = 0.5$.

Table 1. Characteristics of the subjects (n=11)

Age (years)	16.3±1.9
Weight (kg)	58.4±10.1
Height (cm)	177.8±10.7

Data are presented as the mean ± SD

RESULTS

The results for forefoot maximum medial/lateral rotation in the horizontal plane during progressive pace treadmill racewalking are shown in Tables 2 and 3. Two-way analyses of variance showed that there were main effects in the statistics between before and after the physically demanding aerobic exercise load. The independent t-test showed after the physically demanding aerobic exercise load, there were no significant differences in forefoot maximum medial/lateral rotation at the 2 km/h, 4 km/h, and 6 km/h paces compared with before the physically demanding aerobic exercise load and that there were significant differences in forefoot maximum medial/lateral rotation at the 8 km/h and 10 km/h paces compared with before the physically demanding aerobic exercise load. There were significant associations between the forefoot maximum medial/lateral rotation and increased paces during progressive pace treadmill racewalking, especially after intervention after the physically demanding aerobic exercise load.

DISCUSSION

The aims of this study were to evaluate the changes in forefoot maximum medial/lateral rotation and to investigate whether the forefoot maximum medial/lateral rotation in the horizontal plane is associated with increased paces during progressive pace treadmill racewalking in the fatigue state after a physically demanding aerobic exercise load. There were no statistically significant differences in forefoot maximum medial/lateral rotation when the speed was set to 2 km/h, 4 km/h or 6 km/h. This implies that the speeds intensity was too slow to change the forefoot's kinematic parameters even though the subjects were in a fatigue state. The significant associations between forefoot maximum medial/lateral rotation and progressive paces might indicate that the motor skill of the participants were biomechanically constrained by increased paces during progressive pace treadmill racewalking in the fatigue state. Furthermore, in order to correspond with the progressive paces set on the treadmill, the maximum medial/lateral rotation of the forefoot increased to compensate for tiredness, and this could lead to prolonged pronation/supination of the subtalar joint and could be a potential factor for lower extremity injuries. The foot is not an isolated section but is part of the body's kinetic chain, which as a linked system of interdependent segments, often engages in interactions to efficiently achieve a desired movement. The body's kinetic chain is vulnerable to sport fatigue, while long-duration sports always eventually lead to fatigue, especially local muscular fatigue, which can be caused by insufficient energy to conduct a precise workout and increase levels of discomfort. Insufficient recovery or abnormal neuromuscular control of the foot and ankle during progressive pace treadmill racewalking in the fatigue state, particularly in the subtalar joint, is a primary contributor to inefficient alignment to burdened foot and ankle. As the forefoot turns inward/outward (medial/lateral rotation) excessively in the horizontal plane, the angles of the knees, hips, and back rotation are affected, throwing them out of alignment. Furthermore, it can be concluded that in the excessive medial/lateral rotation forefoot, the extension of the first metatarsophalangeal joint may be ineffective. When athletes and coaches address problems with the knees, hips, and backs, solutions may be found in the foot. Currently, the physical therapists should

Table 2. Comparison between pre- and post- intervention values of M/LR (°)

Paces	Before-intervention	After-intervention
2 km/h	3.7±0.5	4.2±0.8
4 km/h	5.3±0.6	5.3±0.5
6 km/h	6.1±1.0	7.0±0.9
8 km/h	6.3±0.9	9.6±1.3**
10 km/h	6.9±0.7	10.5±1.7**

Data are presented as the mean ± SD
Significant differences after the physically demanding aerobic exercise load: *p<0.05; **p<0.01.
M/LR: medial/lateral rotation

Table 3. Correlation coefficient values of progressive paces and M/LR during racewalking on a treadmill

	Correlation coefficient (r)
Before the exercise load	0.7 **
After the exercise lod	0.9 **

*p<0.05; **p<0.01. M/LR: medial/lateral rotation assist racewalkers for public health or competitiveness to reduce injuries for the development of lower extremity overuse and increase performance by providing knowledge surrounding efficient gait biomechanics model in the fatigue state after exercise training load. Further studies should be performed to explain the features of biomechanics disorders of the lower extremities and to design therapy programs.

REFERENCES

1) Lim HS, Yoon S: The influence of short-term aquatic training on obstacle crossing in gait by the elderly. J Phys Ther Sci, 2014, 26: 1219–1222. [Medline] [CrossRef]
2) Francis PR, Richman NM, Patterson P: Injuries in the sport of racewalking. J Athl Train, 1998, 33: 122–129. [Medline]
3) Hoga K, Ae M, Enomoto Y, et al.: Mechanical energy flow in the recovery leg of elite race walkers. Sports Biomech, 2003, 2: 1–13. [Medline] [CrossRef]
4) Freychat P, Belli A, Carret JP, et al.: Relationship between rearfoot and forefoot orientation and ground reaction forces during running. Med Sci Sports Exerc, 1996, 28: 225–232. [Medline] [CrossRef]
5) Hanley B: Gait alterations during constant pace treadmill racewalking. J Strength Cond Res, 2015, 29: 2142–2147. [Medline] [CrossRef]