A KINEMATIC COMPARISON OF RUNNING ON TREADMILL AND OVERGROUND SURFACES

Kam-Ming MOK, Justin Wai-Yuk LEE, Mandy Man-Ling CHUNG, Youlian HONG

**Human Movement Laboratory,
Department of Sports Science and Physical Education,
Faculty of Education,
The Chinese University of Hong Kong, Hong Kong SAR, China**

Treadmills are often used for research in sport running shoes and physical training. The purpose of this study was to compare the kinematics in treadmill and overground running, and to investigate if the shoe testing on treadmill can reflect the performance of the running shoes on overground surfaces. Thirteen male subjects were recruited to run on treadmill, tartan, grass and concrete surfaces. Effective vertical stiffness, temporal and kinematic parameters were measured. The results showed that the running patterns within overground surfaces were not significantly different, while the significant differences were found between treadmill and overground running.

KEY WORDS: treadmill, shoe testing, overground, kinematics

INTRODUCTION: Treadmills are often used for research in sport running shoes and physical training. Human performing similar running pattern on treadmill compared to overground is necessary. Otherwise, the change of the running pattern may affect the research findings and training effects. Therefore, the increase in the usage of treadmill on scientific investigations and physical trainings raises the discussion on the difference in running pattern between treadmill and overground running. Previous studies (Riley et al., 2008; Schache et al., 2001; Novacheck, 1998; Wank et al., 1998; Nigg et al., 1995) reported the body kinematics on treadmill running and overground running. Those studies showed similar results on hip and knee kinematics, however, contradictory results on truck lean angle. Although the change of truck lean angle was preliminarily explained by the external drag force from the belt on treadmill (Wank et al., 1998), the mechanism is still unclear. The ankle kinematics is important information on sport running shoe testing. Previous studies reported ankle kinematics on sagittal plane; however, the rearfoot motion is not well-investigated. On the other hand, previous studies only included hard surfaces such as tartan and concrete as overground. The difference between treadmill running and soft overground running, such as grass surface, is not well known. The aim of the present study is to compare the kinematics in treadmill and overground running. Overground surfaces are tested, including tartan, grass and concrete, to investigate if the shoe testing on treadmill can reflect the performance of the running shoes on overground surfaces. This study provides information to judge the validity on human running simulation on treadmill in all aspects.

METHODS: Thirteen male subjects aged 22.4 ± 3.9 years (body height, 1.70 ± 0.06 m; body mass, 63.6 ± 9.2kg) were recruited from The Chinese University of Hong Kong. All subjects were heel-toe runners. Each subject wore a standard running shoe model (TN600, ASICS, Japan). Six minutes warm up and familiarization session (12 km/hr) on treadmill was provided to subjects before testing. They were tested on a treadmill (6300HR, SportsArt, US), tartan, grass and concrete. Tartan, grass and concrete were overground surfaces in different surface stiffness. Figure 1 shows the experimental set up on field. For the sagittal kinematic analysis, markers were attached to acromion process, greater trochanter, lateral fermoral condyle, lateral malleolus, heel and first metatarsal head. For rearfoot, the Achilles tendon and centre of calf were marked. Two posterior markers on shoe formed a vertical line in unloading condition. The running speed on treadmill was 3.8m/s. The acceptable running speed on overground surfaces was 3.6~4.0 m/s for each trial. An infra red timing system (Brower, US) was used to monitor the running speed on overground surfaces of each trial. In the testing, the average running speed of subjects on overground running was 3.85 m/s. Two high-speed cameras (DVL9600, Panasonic, Japan) with 50 Hz captured the motion from sagittal and rear view. Regarding each subject, five running trials from each of four different surfaces were processed. Temporal and kinematic parameters were calculated and outputted by motion analysis system (APAS, Ariel Dynamics, US). The kinematic data were smoothes using a fourth-order low-pass Butterworth filter with cut-off frequency of 8 Hz. The events of initial foot contact and toe off were defined from the trajectory of heel marker and first metatarsal head marker respectively, with the aid of visual identification on video recordings. The temporal parameter includes stride time, stance time. For sagittal view, the kinematic parameters included the range, the maximum value in one stride, the minimum value in one stride, the value at initial foot contact (IFC) and the value at toe off (TO) of trunk angle, hip angle, knee angle and ankle angle. For rear view, touch down angle, total range of motion, relative maximum pronation and peak pronation velocity were measured. Effective vertical stiffness was calculated from subject body mass and stance time by the method suggested by Cavagna (1988).The parameters were tested with a one-way repeated measure ANOVA ($P<0.05$), post-hoc test Tukey. The data were analyzed by SPSS statistical software (SPSS 15.0, SPSS Inc., US).

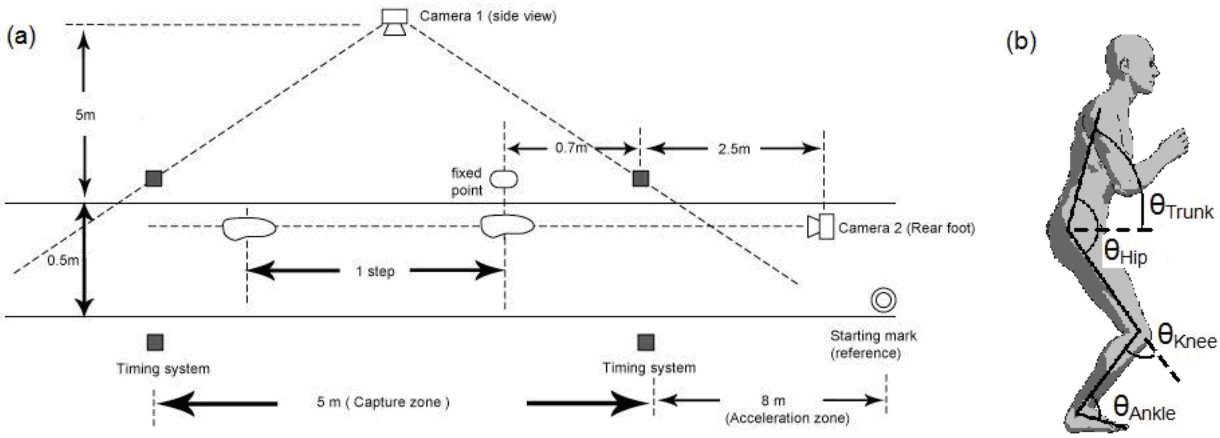

Figure 1: (a) Experimental set up on field, drawing not to scale
(b) Definition of kinematic parameters

RESULTS: Statistical analysis showed that most of the kinematic parameters in sagittal plane were found to be significantly different ($P<0.05$) between treadmill running and overground running. No significant difference was found between tartan, grass and concrete surface. Statistical analysis showed that there was no significant difference on the rearfoot motion parameters. Table 1 shows the temporal and kinematic parameters with significant difference.

DISCUSSION: Significant differences were found on the stride length and temporal parameters between treadmill and overground running. Stride length, stride time and stance time were smaller in treadmill running when compared to overground running. The results were consistent to previous studies (Schache et al., 2001; Wank et al., 1998) although our study was limited by 50Hz video motion analysis. In treadmill running, the backward moving belt provided an external backward drag force on the foot. Then, that external backward drag force assisted the runner to complete the stance phase. As a results, the stance time decreases and the stride time was shortened.

Table 1 Mean and S.D. of temporal and kinematic parameters (stance phase in % of stride; duration in seconds; angle in degrees; length in metres; vertical stiffness in kN/m; N=13)

Parameters	Treadmill	Tartan	Grass	Concrete
Stride Length	2.38(0.47)	2.74(0.16)^a	2.76(0.15)^a	2.78(0.11)^b
Stride Time	0.67(0.027)	0.71(0.025)^b	0.70(0.026)^b	0.71(0.030)^b
Stance Time	0.196(0.142)	0.225(0.020)^b	0.221(0.021)^b	0.228(0.167)^b
Stance Phase	29.55(2.73)	31.72(3.26)^a	31.99(2.64)^a	32.63(2.74)^b
θ_{Trunk} Range	10.9(3.50)	19.3(5.55)^b	18.8(5.33)^b	20.1(5.00)^b
θ_{Trunk} Max	88.8(4.02)	84.9(4.95)^b	85.4(5.08)^b	86.6(4.84)^b
θ_{Trunk} Min	77.9(3.18)	65.5(7.11)^b	66.5(7.59)^b	66.4(5.67)^b
θ_{Trunk} IFC	87.3(3.66)	74.3(7.70)^b	75.0(8.15)^b	74.4(6.41)^b
θ_{Trunk} TO	78.8(3.23)	66.3(6.83)^b	67.4(7.30)^b	67.2(5.29)^b
θ_{Hip} Range	48.9(4.88)	56.4(5.49)^b	58.1(6.52)^b	55.2(6.44)^b
θ_{Hip} Max	185.9(5.16)	181.5(6.53)^b	183.0(6.81)^a	180.8(6.27)^b
θ_{Hip} Min	137.0(5.67)	125.0(8.23)^b	124.8(8.68)^b	125.5(5.58)^b
θ_{Hip} IFC	145.7(5.07)	128.4(9.39)^b	128.7(9.72)^b	128.2(7.16)^b
θ_{Knee} Range	80.5(9.81)	89.2(11.9)^a	89.9(9.89)^b	88.0(10.6)^a
θ_{Knee} Max	106.2(8.50)	113.2(10.2)^a	113.2(9.58)^a	109.4(9.04)
θ_{Knee} IFC	28.9(3.81)	41.0(7.38)^b	41.3(7.57)^b	38.6(7.03)^b
θ_{Knee} TO	41.7(5.55)	28.1(5.38)^b	27.3(4.37)^b	27.0(5.89)^b
θ_{Ankle} Range	42.1(7.50)	51.7(9.06)^b	51.9(11.6)^b	48.4(7.12)^b
θ_{Ankle} TO	100.9(4.32)	113.2(10.6)^b	111.6(7.56)^b	112.6(7.84)^b
Effective Vertical Stiffness	65.18(12.30)	50.49(11.16)^b	50.45(10.37)^b	47.15(8.05)^b

[a] P<0.05 when compared with Treadmill
[b] P<0.01 when compared with Treadmill

The ankle angle at toe off was found to be less in treadmill running when compared to overground running. It can be explained that the external backward drag force from the treadmill belt assisted the foot to complete the take off motion with less plantarflexion. This change in running pattern leads to different plantar pressure distribution. A study on the difference in plantar pressure distribution between treadmill and overground running is needed.

Significance differences were found on the parameters of trunk angle between treadmill running and overground running. Less forward lean of trunk was found on treadmill running. In treadmill running, center of gravity of the body (CG) is not required to be moved forward. Novacheck (1998) suggested that greater forward trunk lean would move the CG forward of the support foot in stance. A greater horizontal GRF could be exerted against the running surface (Novacheck, 1998). However, the CG of runner is not required to move forward in treadmill running, and thus less horizontal GRF is required. Therefore, trunk was less forward leaned in treadmill running compared to overground running. It implied that runners who frequently trained on treadmill may have their running pattern changed to less truck forward lean because they used to not moving the CG forwards.

Stiffness during running has been related to the risk for bony injuries such as knee osteoarthritis and stress fractures. (Butler et al., 2003; Granata et al., 2002, Grimston et al., 1991).Increased stiffness is typically associated with reduced lower extremity excursions and increased peak force (Butler et al., 2003). The effective vertical stiffness values on overground running in this study were similar to those reported by other study (Arampatzis et al., 1999). Effective vertical stiffness in treadmill running was found to be significantly higher than that in overground running. It appears that there is a potential injury risk in treadmill running and should be studied in the future.

CONCLUSION: The running pattern changed significantly between treadmill running and overground running. It appears that treadmill running is not able to simulate overground running. Further investigation on trunk motion and plantar pressure in treadmill and overground running is needed. Moreover, the effective vertical stiffness was found to be higher in treadmill running. Research on the impact of the higher effective vertical stiffness in treadmill running is valuable.

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