EFFECTS OF RUNNING FATIGUE ON KNEE JOINT SYMMETRY AMONG AMATEUR RUNNERS

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The purpose of this study was to reveal the effects of running fatigue on the symmetry of lower limb dynamics and kinematics parameters. 18 male amateur runners participated in this study. The marker trajectories and ground reaction forces were collected via an 8-camera VICON and Kistler 3D force platform before and after the running-induced fatigue protocol. Symmetry angles (SA) of joint moments, range of motions (ROM), and joint stiffness in three planes were calculated pre- and post-fatigue. SA of knee Extension Angle, Internal rotation, Abduction moment, coronal ROM and joint stiffness significantly increased after fatigue($p<0.5$). SA of knee Flexion Angle and Extension rotation Angle decreased significantly after fatigue($p<0.5$). These findings provide preliminary evidence that fatigue changes lower limb symmetry in running gait and provide potential evidence for the exploration of lower limb function, athletic performance, running-related injuries, and the research and development of footwear and equipment.

KEYWORDS: Symmetry, Running-induced fatigue, Knee joint.

INTRODUCTION: Therefore, Long-distance running is one of the most common physical activities participated in during individual daily life. However, Fatigue from long distance running is also associated with a higher rate of injuries (Mei et al., 2019). One of the major causes of running injuries is the lower limbs' alteration of symmetry. However, previous studies have reported biomechanical changes in one leg during running and hypothesized that the opposite leg exhibits the same characteristics. this assumption may result in inaccurate data by ignoring differences between the lower extremities. It has also been demonstrated that biomechanical asymmetry exists in healthy individuals during running.

Furthermore, asymmetries in running can directly affect the quality of running. Beck et al. showed that running increased the level of foot contact time asymmetry by 10% and its metabolic cost increased by 7.8%. In addition, a 10% increase in the asymmetry of mean ground reaction forces resulted in a 3.5% increase in metabolic costs (Beck et al., 2018). In general, the gait of healthy people becomes asymmetrical with fatigue. Likewise, Gao reported that a Running-Induced Fatigue Protocol caused knee flexion Angle, hip flexion Angle, hip extension Angle, and the hip flexion moment to be more asymmetrical, while the knee extension velocity and hip flexion velocity became more symmetrical (Gao et al., 2020a). However, the biomechanical changes of human movement usually occur in three anatomical planes. The effect of fatigue on the symmetry of coronal and horizontal biomechanical parameters has been observed to be insufficient in previous studies.

METHODS: Eighteen healthy male amateur runners were recruited for this study, all subjects' dominant limb was the right leg, defined as the preferred leg when kicking a ball. the Over-ground running test before and after the running-induced Fatigue Protocol were successively implemented. A Vicon eight-camera motion capture system (Vicon Metrics Ltd., Oxford, United Kingdom) and a Kistler Force plate (Kistler, Winterthur, Switzerland) were used to collect the marker track and ground reaction force signals. The frequencies were 200Hz and 1000Hz, respectively. Twenty-one reflective markers and six reflective marker clusters were attached to the anatomy of the pelvis, left and right thighs, calves, and feet to define the hip, knee, and ankle joints for kinematic data collection. individual subject per-minute fatigue level, and pre-minute was digitally monitored using heart rate telemetry and the 15-point Borg scale, The

specific execution process is shown in Figure 1. Participants walked on the treadmill at their initial speed(6km/h). Then the speed was then increased by 1km/h every 2 minutes and the RPE index and heart rate were recorded and stop increasing speed until the RPE index was asked to reach 13(somewhat hard). The subjects were then asked to run at this speed until fatigued. Fatigue points were defined as running with a real-time heart rate greater than 90% of maximum heart rate or RPE index greater than 17 (very hard) that remained elevated for two minutes. Visual 3D (c-motion Inc., Germantown, MD, USA） human motion analysis software was used to obtain joint angles and joint moment.
The Symmetry Angle (SA) is commonly used to evaluate the relationship between the left and right discrete values (Zifchock et al., 2008).

$$\mathrm{SA}(\%) = \frac{(45° - \arctan\left(\frac{\mathrm{Xleft}}{\mathrm{Xright}}\right))}{90°} \times 100\% \quad (1)$$

Where the Xleft and Xright represents the left and right limb values respectively. SA with a value of 0% represents perfect symmetry, and 100% represents two values equal in magnitude and opposite in direction (complete asymmetry). If (45°-arctan (Xleft/Xright)) > 90°, the following equation should be substituted:

$$\mathrm{SA}(\%) = \frac{\left(45° - \arctan\left(\frac{\mathrm{Xleft}}{\mathrm{Xright}}\right)\right) - 180°}{90°} \times 100\% \quad (2)$$

The Shapiro-Wilks test was used to verify the normality of the data using SPSS (Version 19; SPSS, Inc., Chicago, IL, USA). Paired sample T-tests were used to examine joint angles, ROM, peak joint moment, joint stiffness, and SA for these parameters in the bilateral lower extremities before and after fatigue.

RESULTS: As shown in Table 1, the SA of the peak knee extension angle before fatigue was significantly smaller than that after fatigue (P=0.008), while the SA of the peak knee flexion angle was significantly larger than that after fatigue (P=0.026). Similarly, the SA of the peak Internal rotation angle of the bilateral knee joints was significantly larger after fatigue than before fatigue (P= 0.000). In comparison, the SA of peak external rotation angle in horizontal plane was significantly smaller than before fatigue (P=0.002). The SA of the peak abductive moment in the coronal plane of bilateral knee joints was significantly higher after fatigue than before fatigue (P=0.048). At the same time, there was no significant change in other parameters of movement. After fatigue, SA of ROM (P=0.004) and joint stiffness (P=0.005) on the coronal plane were significantly higher than those before fatigue.

Table 1: Changes of knee joint angle, joint moment, range of motion and joint stiffness symmetry before and after fatigue.

Knee	Symmetry Angle(%)		
	Pre- Mean±SD	Post- Mean±SD	Sig.
Joint angle			
Ext (+)	0.08(0.07)	0.25(0.26)	0.008**
Flex (-)	0.09(0.07)	0.04(0.03)	0.026*
Add (+)	0.38(0.46)	0.36(0.33)	0.851
Abd (-)	0.50(0.41)	0.47(0.38)	0.773
Intr (+)	0.17(0.18)	0.64(0.45)	0.000**
Extr (-)	0.84(0.53)	0.28(0.33)	0.002**
Joint Moment			
Extn (+)	0.18(0.13)	0.25(0.26)	0.327
Flex (-)	0.16(0.12)	0.18(0.16)	0.630

Add (+)	0.23(0.14)	0.27(0.11)	0.276
Abd (-)	0.26(0.13)	0.36(0.13)	0.048*
Intr (+)	0.24(0.13)	0.29(0.17)	0.311
Extr (-)	0.23(0.16)	0.26(0.21)	0.569
Joint ROM			
Ext (+)/Flexn (-)	0.05(0.06)	0.05(0.03)	0.825
Add (+)/Abd (-)	0.13(0.08)	0.25(0.15)	0.004**
Intr (+)/Extr (-)	0.07(0.04)	0.11(0.10)	0.194
Joint stiffness			
Ext (+)/Flex (-)	0.16(0.13)	0.21(0.17)	0.388
Add (+)/Abd (-)	0.19(0.13)	0.32(0.16)	0.005**
Intr (+)/Extr (-)	0.23(0.16)	0.28(0.16)	0.288

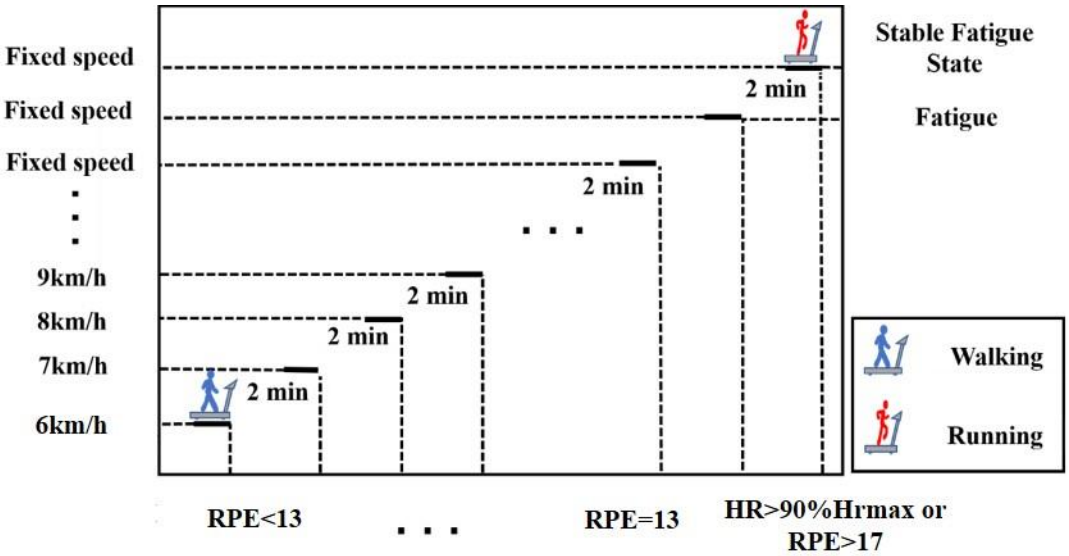

Figure 1. Execution method of running-induced fatigue experiment

DISCUSSION: Congenital slight asymmetry exists in the anthropometry and function of the human body. Previous literature has shown differences in the movement behaviours of dominant and non-dominant lower limbs during eccentric loading tasks. Although running and landing are different motor tasks, they are both high-impact activities that require increased muscle activity to reduce impact (Brown et al., 2014). Zifchock etal (Zifchock et al., 2008) have shown that the symmetry of running varies greatly among different subjects, with the asymmetry ranging from 3% to 54%. This study used male amateurs as subjects, which can represent part of the running population. When comparing the symmetry changes of the lower limbs before and after fatigue, Brown et al. (Brown et al., 2014) observed that the symmetry of the lower limbs did not change because of fatigue, and the neuromuscular fatigue rates of both limbs were the same, which contradicts the results of this study. In general, gait variability increases after fatigue intervention. Neuromuscular control is an essential factor in asymmetric settings and may be affected by fatigue. In this study, the symmetry of the knee joint parameters deteriorated most obviously after fatigue, and the symmetry of kinematics and dynamics parameters decreases in all three aspects. This deterioration of asymmetry may be associated with the risk of overuse injury of the knee joint, which may be caused by a high susceptibility to fatigue in the knee motor muscles of the non-dominant limb. Moreover, the more muscular symmetry of sagittal flexion Angle of the knee in this study may be a positive adjustment of the neuromuscular system to avoid overuse injury after fatigue. Another exciting result of this study is that SA of knee flexion angle and extension rotation angle decreased significantly after fatigue. This phenomenon may be a coordination mechanism generated by the body to maintain the symmetry and stability of the overall lower limbs after fatigue (Heil et al., 2020).

This study explored the biomechanical symmetry changes of the bilateral knee joints of amateur runners before and after running-induced fatigue experiments. However, there are still two limitations. First of all, the running-induced fatigue experiment in this study was carried out on a treadmill. In contrast, the biomechanical test before and after fatigue was carried out on the ground, ignoring the possible experimental errors caused by different planes. Secondly, the symmetry evaluation adopts extreme values, and a discrete data set, while ignoring data continuity. Future studies should consider using other methods, such as SINigg, to evaluate the symmetry of time series data.

CONCLUSION: This study reveals the effect of running fatigue on the symmetry of knee joint angles, ROM, moment, and stiffness of amateur runners' lower limbs. The results found that the symmetries of kinetics parameters change the most after fatigue. However, A few kinematic parameters became more symmetrical after fatigue, mainly in the coronal and horizontal planes of the knee joints. The knowledge of the effects of fatigue on lower extremity biomechanics may have implications for the training of long-distance running footwork, such as musculature development, to prevent load accumulation in unilateral joints and improve the efficiency of long-distance running.

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