EFFECTS OF MINIMALIST FOOTWEAR ON THE LOWER LIMB LINEAR ACCELERATION AND ANGULAR VELOCITY DURING RUNNING

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The purpose of this study was to explore if the tri-axial linear acceleration and angular velocity of knee and ankle joints differ between barefoot and minimal footwear running through investigating the extreme value difference. Eight participants were recruited for this experiment, acceleration parameters were measured utilizing IMU sensors. For the angular velocity, the minimum value in the frontal plane ($p = 0.028$) showed a decrease in the ankle joint. The minimal value in the sagittal plane and maximal value in the transverse plane ($p = 0.001$, $p = 0$) increased significantly. For the knee joint, the extreme values in the frontal plane increased ($p = 0$, $p = 0$), the maximal value increased and minimal value decreased with $p = 0$ and $p = 0$ in the sagittal plane. A significant decrease in the maximal value ($p = 0$) was exhibited in the transverse plane. The increased angular velocity may contribute to a result, with an insufficient arch support condition (minimalist shoes running) causing the foot's intrinsic and extrinsic muscles and lower limb joints injury. These injuries should be a consideration for the novice minimalist runners.

Keywords: minimalist running footwear, inertial measurement unit (IMU), acceleration, running.

INTRODUCTION: Studies of barefoot or minimalist shoe running started around 2010 (Lieberman et al., 2010). Since then, there have been many studies as to whether barefoot running is more conducive to improve biomechanical performance (such as the change in foot strike pattern) and reducing sports injuries. A study found that a forefoot strike pattern can reduce running injuries by reducing the impact of the ground, increasing the flexion of the knee joint and reducing knee joint adduction, during the gait landing phase (Altman & Davis, 2016). Furthermore, less arch support is good for maintaining the longitudinal arch structure of the foot and stimulating foot intrinsic muscles function (Lieberman, 2010). However, barefoot running will also be accompanied by higher risks of sole abrasions and bruises. Therefore, researchers have begun to pay more attention to the research of minimalist shoe running.

The calculation of joint acceleration by the wireless inertial measurement unit sensor (IMUs) is widely used in human biomechanics studies (Silder, Delp & Besier, 2013). Joint acceleration data can be used for the evaluation of sports biomechanical performance, the detection of sports fatigue, and the prevention of sports injuries (Ahamed et al., 2019). The validity of IMU sensor recordings of lower limb acceleration has been proven by the previous study (Sheerin, Besier & Reid,2018). 'Extreme values' data are important for measuring fatigue and preventing injuries (Pohl, Mullineaux & Milner, 2008). There have been many studies focusing on ground reaction force (GRF), kinematics and electromyogram (EMG), comparing the minimalist and conventional running shoes (Miller et al., 2014; Fuller et al., 2018). However, no study has investigated the lower limb joint accelerations effect when running with minimalist footwear.

Therefore, this study set out to explore if the 3-Axial linear acceleration and angular velocity of knee and ankle joints differ between barefoot and minimal shoe running through investigating the extreme value change utilizing IMU sensors. It was hypothesized that less arch support (minimalist footwear condition) could increase the maximal and minimal values of acceleration.

METHODS: A total of eight male university students (age: 24.0 ± 0.8 years; height: 175.7 ± 2.6 cm; weight: 67.2 ± 7.3; BMI: 21.8 ± 2.4kg/m^2; years of running: at least 2 years) were recruited for this experiment. Participants reported an average engagement in running of 5-15 km per week and had no experience of minimalist footwear running. All subjects used the right leg as the dominant leg, with no lower extremity-related injuries and treatment occurring in the past six months. The study procedures being in accordance with the Declaration of Helsinki and were approved by the Ethics Committee from the University. Prior to the experiment, each subject provided duly completed written consent forms. Anta SuperFlexi and Vibram V-RUN were the conventional and minimalist footwear used in this experiment. The conventional shoe (EU-size 41-43) has a heel-forefoot offset of 9mm and the minimalist footwear (EU-size 41-43) 0mm. The midsole of the conventional running shoe was made of ethylene-vinyl acetate (EVA).

Before the experiment, each subject was given five minutes to familiarize themselves with the experimental environment and five minutes for warm-up running on an instrumented treadmill (Quasar, h/p cosmos®, Germany) with a speed of 8 km/h wearing the conventional footwear. The joint acceleration sensor 'ImeasureU' Sensor V1 (IMU, Vicon, Oxford Metrics, UK, 40×28×15 mm, Weight: 12 grams, resolution: 16 bit) with accelerometer and gyroscope was worn on the ankle and knee joints of the subject's right leg without affecting the joints activity (as shown in Figure 1). All participants completed 6×1-minute running trials at the speed of 10±0.5 km/h in these two types of running footwear. The choice order of shoes was randomized and there was a three minutes break between the two sessions.

Figure 1: Illustration of 'ImeasureU' sensors placement

The accelerometer and gyroscope data in this experiment were recorded by the ImeasureU Research software using an iPad 2018 (Apple, California). In this experiment, the maximum and minimum values of linear acceleration and angular velocity on the ankle and knee joints were chosen to compare the extreme values differences of two footwear, in the sagittal, frontal and transverse planes (Pohl, Mullineaux & Milner, 2008). The data collection method was " BLE Stream" and the collection parameter was 9-Axis with a frequency of 100 Hz. The collected data was transferred to a CSV file in a computer via Bluetooth transmission. The raw data was filtered using a 2nd order low pass Butterworth filter with the cut-off frequency of 15Hz. Six consecutive stable gait cycles were chosen for each trial using a previously published method (Aminian et al., 2002). The independent sample t-test was used to analyze the statistical significance of the collected linear acceleration (m/s^2) and angular velocity (deg/s) of ankle and knee joints in statistical software SPSS 22.0 (Chicago, IL, USA).

RESULTS: For the linear acceleration data (as shown in Table 1), the extreme values of linear acceleration showed an increasing trend but no significant difference statistically.

Table 1: 3-Axial acceleration of the ankle and knee joints

		Sagittal plane			Frontal plane			Transverse plane		
		con	min	P value	con	min	P value	con	min	P value
ankle	maximal value	80.85± 8.81	83.10± 7.78	0.5	41.41± 3.42	40.28± 1.62	0.34	23.72± 2.30	22.88± 4.45	0.63
	minimal value	-48.72 ±9.78	-50.90 ±8.54	0.61	-4.60± 0.75	-5.18± 0.76	0.18	-13.39 ±2.87	-11.62 ±2.70	0.2
knee	maximal value	29.15± 1.49	31.21± 3.66	0.08	32.44± 3.46	29.90± 2.65	0.09	21.25± 2.46	20.55± 1.29	0.4
	minimal value	-26.59 ±2.99	-24.34 ±3.71	0.11	-22.95 ±1.67	-21.82 ±1.34	0.17	-25.25 ±1.51	-25.08 ±1.26	0.79

Note. con: conventional running shoes; min: minimalist running shoes.

For the angular velocity data (as shown in Table 2), the minimum value in the frontal plane ($p = 0.028$) showed a decrease in the ankle joint. The minimal value in the sagittal plane and maximal value in the transverse plane ($p = 0.001$, $p = 0$) increased significantly in the minimalist footwear running condition. For the knee joint, the extreme values in the frontal plane increased ($p = 0$, $p = 0$), the maximal value increased and minimal value decreased with $p = 0$ and $p = 0$ in the sagittal plane. A significant decrease in the maximal value ($p = 0$) was exhibited in the transverse plane.

Table 2: 3-Axial angular velocity of the ankle and knee joints

		Sagittal plane			Frontal plane			Transverse plane		
		nor	min	P value	nor	min	P value	nor	min	P value
ankle	maximal value	120.16± 7.76	127.70± 12.17	0.08	241.16± 35.05	240.66± 19.89	0.97	329.11± 13.80	380.17± 22.94	**0***
	minimal value	-148.15 ±13.41	-128.50 ±12.61	**0.001***	-186.93 ±22.02	-205.94 ±8.81	**0.028***	-571.60 ±12.17	-577.63 ±11.50	0.32
knee	maximal value	193.61± 13.01	208.28± 9.70	**0***	195.69± 30.58	280.85± 26.90	**0***	294.34± 15.48	264.78± 13.24	**0***
	minimal value	-301.83 ±14.02	-409.11 ±15.76	**0***	-168.10 ±107.07	-154.68 ±19.24	**0***	-454.41 ±7.50	-424.37 ±10.77	0.7

Note. con: conventional running shoes; min: minimalist running shoes.

DISCUSSION: The present study was designed to detect the acceleration of lower limb differentials between conventional and minimalist footwear during running. It was discovered that the main significant difference, in the running gait, appeared in the angular velocity of both ankle and knee joints. The extreme values of linear acceleration showed an increasing trend but no significant differences.

The study found (Miller et al., 2014) that running in minimal shoes increased the activity of intrinsic and extrinsic foot muscles (such as the gastrocnemius). In fact, this was in accordance with our predictions, in that the lower limb angular velocity increased during running with minimalist footwear. Although previous studies have shown that this type of shoe can change the runner's spatiotemporal parameters whilst running, such as reducing stride length (Barcellona et al., 2017). However, this study found that both types of running footwear did not affect the linear acceleration of the ankle and knee joints. Therefore, minimalist shoes may change the landing pattern of the foot or the range of motion of the joints.

Modern running shoes are designed with thick midsoles intended to decrease injuries occurring in the foot, through increasing shock attenuation and reducing angular velocity. We found that the tri-axial angular velocity increased for minimalist footwear during running, which may contribute to increased injury risk to the lower limb muscles. In the early phase of transition from the conventional to the minimalist running shoe, users should be particularly aware of this potential problem, thus preventing the relevant injuries.

CONCLUSION: This study was conducted against a backdrop of a steady increase in barefoot or minimalist shoe running. We found increased angular velocity in the lower limb joints caused by minimalist footwear running, as compared to the conventional shoe condition. This scenario potentially results in a condition of less arch support prompting potential pressure on the foot's extrinsic muscles and lower limb joint activity. So, injuries awareness should be a serious consideration, especially for novice minimalist runners.

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