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Experimental Study on Ground Reaction Force Parameters with Regard to Novice and Recreational Runners

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Abstract. The connection between running experience and running-related injuries is still unclear, and the underlying mechanisms are yet to be fully investigated. Therefore, this study aimed to investigate differences in ground reaction forces (GRFs) between novice runners and recreational runners. 15 novice and 15 recreational runners participated in this study. An independent samples T-test was applied using SPSS 25.0 and SPM1D via Matlab. The results showed that recreational runners exhibited a significantly larger peak vertical impact force and peak medial force than the novice group, while the peak propulsive force was smaller than the novice group. The SPM1D results also showed that recreational runners and novice runners exhibited significant differences in medial-lateral force, anterior-posterior force and vertical force. The differences between the groups may reveal differences in running kinetics, which could be related to superior running performance or ability. Valuable insights may be gained from this study to guide future research on injury risks and performance benefits from running.

Keywords. Biomechanics, ground reaction forces, injuries, SPM1D

1. Introduction

Regular running improves the efficiency of the cardiovascular system [1-4]. Despite its benefits, running is associated with a considerable risk of injury among runners. Studies

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suggest that as many as 79% of runners experience musculoskeletal injuries each year [5, 6], and the causes of these injuries are influenced by various factors. Given the alarming prevalence of running-related injuries (RRIs), healthcare professionals and researchers are actively pursuing a deeper understanding of the contributing factors behind such injuries [7, 8]. Their focus is on developing effective treatment strategies and prevention methods to address this issue.

When the runner's skeletal muscles and connecting soft tissues' elasticity and stiffness gradually become mismatched with the intensity of their running, it will lead to subtle damage to the musculoskeletal system. Repeated minor injuries and stress will result in more significant sports injuries, known as overuse injuries, which constitute the majority of running-related injuries [8-10]. The most common RRIs located in the knee joint, accounting for over half of all RRI cases. Apart from the knee joint, injuries in the ankle joint are also quite prevalent. During the running process, when muscular fatigue is not adequately addressed through timely recovery, or when such fatigue accumulates progressively, the potential risk of repetitive RRIs may be elevated. The factors causing RRIs are multifaceted, and the traditional risk factors can be broadly categorized into internal risk factors and external environmental risk factors [8, 11]. Among them, internal risk factors include the runner's gender, age, medical history, anthropometric factors, running habits, and athletic performance, which may lead to overuse injuries in running due to physiological or personal factors, and these factors could potentially be prerequisites for the occurrence of running injuries [12, 13].

Ground reaction forces (GRFs) have been a significant focus of investigation in running biomechanics. These forces have been linked to various RRIs, as they are associated with the body's motion patterns, tissue stresses, and loading rates [3, 13]. Davis et al. [14] observed that runners with tibial stress fractures experienced heightened loading on their lower extremities. Elevated GRFs represent a main risk factor for RRIs. The body's capacity to continuously absorb more forces over an extended period may elucidate the higher occurrence of overuse injuries in the lower limbs. Researchers have been investigating GRFs during running for the past few decades, exploring how these forces impact the body of runners and how various factors like footwear design, running experiences, and surface types, can influence GRFs [15-17]. While the vertical GRF in running has received extensive study, our understanding of the impact of running-related factors on the anterior-posterior and medial-lateral components is still limited. There is a need for more comprehensive research to better comprehend how these components interact with running mechanics and their role in influencing the risk of RRIs.

The risk of RRIs is influenced by an individual's running experience. Novice runners, across all runner groups, are especially susceptible to injuries [18]. However, the disparity in GRFs during running between novice runners and recreational runners has not been thoroughly investigated. Therefore, the main objective of our study was to analyze the effect of running experience on GRFs. By doing so, valuable insights can be gained to guide future research on injury risks and performance benefits in running. It was hypothesized that recreational runners would exhibit distinct running biomechanics in several GRF parameters compared to novice runners.

2. Methods

2.1. Participants

This study recruited 15 male novice runners (age: 23.80 ± 1.97 years, height: 1.76 ± 0.05 m, body mass: 71.93 ± 7.70 kg, running experience: 1.53 ± 0.74 years, running volume: 7.13 ± 2.67 km/week) and 15 recreational runners (age: 23.65 ± 1.67 years, height: 1.75 ± 0.06 m, body weight: 72.73 ± 6.44 kg, running experience: 6.07 ± 1.62 years, running volume: 38.33 ± 7.72 km/week) who regularly used heel strike running technique. Only individuals who had not sustained an injury for at least six months and had no underlying health issues were recruited. Prior to the study, written informed consent was obtained from each participant, in accordance with the approval provided by the Institutional Review Board of Ningbo University.

2.2. Procedures

All participants were outfitted with uniform running shoes (ART NO.11725599-7, ANTA). A motion capture system comprising eight cameras (Vicon Metrics Ltd., Oxford, UK) and a force plate (AMTI, Watertown, MA, USA) were used to collect running data at a frequency of 200 Hz and 1000 Hz, respectively [19]. Vicon Nexus 1.8.5 (Vicon Motion Systems Limited, Oxford, UK) matched with the Vicon system supports simultaneous acquisition of kinematics and kinetics. Each runner had 39 retroreflective markers affixed to their body to facilitate movement tracking. The marker placement is shown in Fig. 1. The model used in this study contained with 10 rigid bodies, 23 degrees of freedom and 92 Hill-type musculotendon actuators. To establish running data, participants ran at their self-selected speed, representing their "natural running pace." This speed was maintained for all running trials (novice runners: 3.28 ± 0.30 m/s; recreational runners: 3.39 ± 0.32 m/s). The participants' speed on the runway was monitored and controlled using timing gates. Before tests, runners underwent a 10-minute warm-up and were familiarized with the procedures and instrumentation. The process of comprehending the experiment typically involves familiarizing oneself with the experimental equipment and adjusting the running speed to ensure that the runner consistently passes over the force plate at a steady speed, positioning the right foot entirely on the plate. During the testing, each participant finished five running trials.

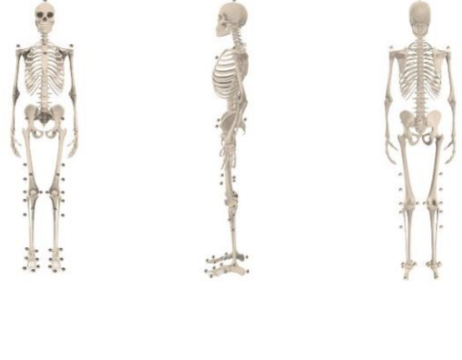

Figure 1. Illustration of markers placement.

2.3. Data analysis

The data of GRFs were filtered by 20 Hz fourth-order zero-phase low pass Butterworth filter. A 20 N threshold was utilized on the vertical GRF to detect the moments of initial foot contact and toe-off. Subsequently, the GRFs were adjusted to the body weight (BW) of each runner through normalization. The specific variables of interest included: peak impact force and peak active force, vertical average loading rate (VALR) and maximum instantaneous loading rate (VILR), peak medial force and peak lateral force, peak propulsive force and peak braking force (Fig. 2 for visualization of the mentioned GRFs).

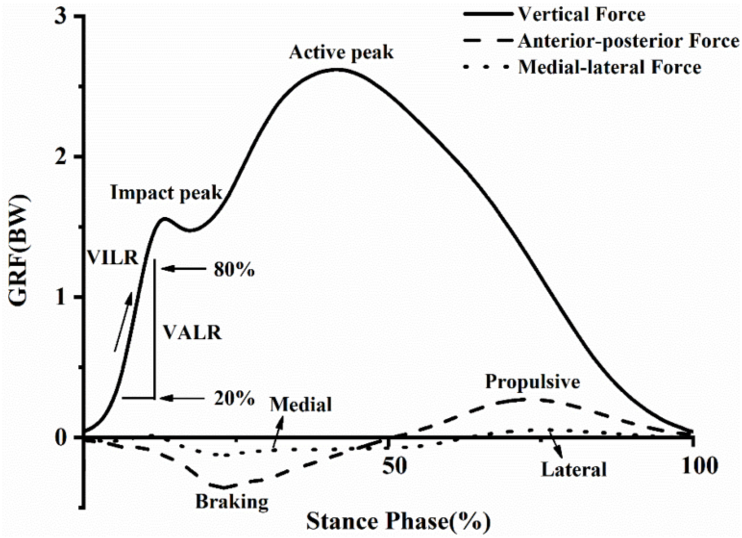

Figure 2. Illustration of ground reaction force trajectories and specific parameters.

2.4. Statistical analysis

Average data of the five trials for each participant were included in the analysis. Before conducting the statistical analysis, the normality of the data was evaluated via the Shapiro–Wilk test. To examine the difference in specific ground reaction forces (GRFs) of interest, an independent t-test was used by SPSS 25.0 (IBM, Armonk, NY, USA). Additionally, the GRF waveforms were analyzed using one-dimensional statistical parametric mapping (SPM1D) with independent t-tests in Matlab 2019b (The MathWorks, MA, United States) [20, 21]. The assumption criteria met for the conduction of the SPM1d analysis [20]. The significance level was set at $\alpha = 0.05$.

3. Results

The recreational group showed significant larger peak impact force ($p=0.020$) and peak medial force ($p=0.001$) than the novice group, while the peak propulsive force was smaller than the novice group ($p<0.001$) (Table 1). During stance phase, the SPM1D results showed that recreational runners and novice runners exhibited significant differences in medial-lateral force (25.91~33.78%, $p=0.007$), anterior-posterior force

(9.94~15.06%, p=0.007; 28.96~88.05%, p<0.001) and vertical force (22.56~34.40%, p<0.001; 54.16~79.75%, p<0.001) (Fig. 3).

Table 1. Mean (SD) of GRFs variables for runners

GRF variables	Novice runners	Recreational runner	P value	95% CI
Peak Impact Force (BW)	2.06 (0.26)	2.25 (0.47)	0.020*	2.08, 2.22
Peak Active Force (BW)	2.62 (0.15)	2.65 (0.26)	0.565	2.59, 2.69
VALR (BW/s)	92.64 (14.00)	94.21 (32.05)	0.764	88.25, 98.51
VILR (BW/s)	142.19 (21.28)	152.90(55.31)	0.230	138.86, 156.22
Peak Medial Force (BW)	0.11 (0.06)	0.15 (0.03)	0.001*	0.12, 0.14
Peak Lateral Force (BW)	0.09 (0.07)	0.13 (0.10)	0.055	0.09, 0.13
Peak Braking Force (BW)	0.36 (0.04)	0.38 (0.08)	0.407	0.36, 0.38
Peak Propulsive Force (BW)	0.37 (0.08)	0.30 (0.05)	0.000*	0.32, 0.35

Note: Statistical significance was set to p < 0.05. The "*" represented significant differences.

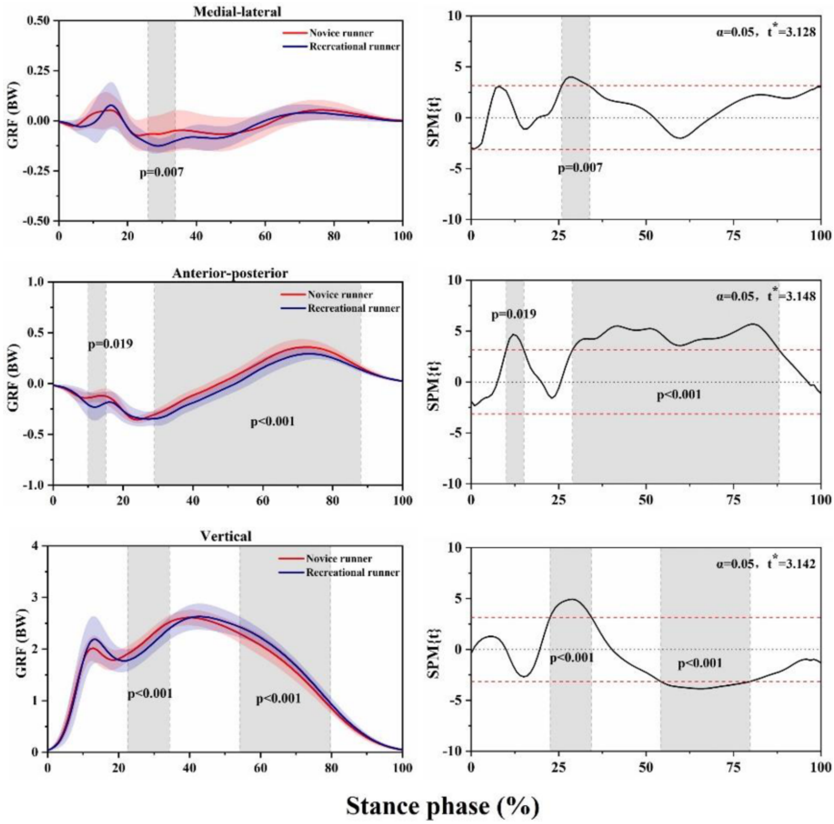

Figure 3. Ground reaction forces with SPM1d analyses. Grey shades represent significant differences between runners (p<0.05).

4. Discussion

The main objective of the present study was to investigate how running experiences influence GRFs. The key findings revealed significant variations in peak impact force, peak medial force, and peak propulsive force during the running between novice and recreational runners, the SPM1D results showed that recreational runners and novice runners exhibited significant differences in medial-lateral force (25.91~33.78%, $p=0.007$), anterior-posterior force (9.94~15.06%, $p=0.007$; 28.96~88.05%, $p<0.001$) and vertical force, which partially supported our hypothesis.

GRF plays a crucial role in running biomechanics, as it is closely associated with the body's motion state, tissue stress, and limb loading. Analyzing GRF can reveal potential factors contributing to running-related injuries. Additionally, GRF serves as a valuable indicator for assessing running performance [22]. In this study, all the runners included were heel strikers, leading to the presence of two peaks in the vertical GRF: the peak impact force and the peak active force. The findings demonstrate significant differences in GRF among runners of varying proficiency levels, with novice runners exhibiting a smaller peak vertical impact force compared to recreational runners. However, the relationship between GRF and injuries has been controversial.

Some researchers have established a link between higher vertical GRF during running and a heightened risk of injury [23-25], while others have associated greater vertical GRF with a reduced incidence of injuries [26]. Conversely, some studies have failed to find any correlation between GRF magnitude and running-related injuries [27, 28]. Recreational runners showed smaller vertical GRF than novice runners during the initial stance phase, while during the mid- to late-stance phase, recreational runners showed greater GRF. Higher vertical GRF may indicate that the runner absorbs less shock, which increases the likelihood of injury to the lower limbs [15].

In this study, we also observed that novice runners exhibited a smaller peak medial force compared to recreational runners. The GRF in the medial-lateral directions was associated with the running trajectory, suggesting that novice runners exhibited a reduced magnitude of motion in the medial direction. The statistical analysis also revealed significant changes in the lateral force. Such alterations in lateral force have the potential to induce foot pronation, and excessive pronation has been associated with knee pain [29]. Moreover, novice runners showed a higher peak propulsive force than recreational runners. The GRF in the anterior-posterior directions was divided into two stages: braking and propulsion, with backward force representing braking and forward force indicating propulsion [30]. The increased propulsion force seen in novice runners may be a compensatory mechanism to offset speed loss during the braking phase, thus maintaining their movement speed and ensuring the efficiency of their running technique [31]. Future research should consider investigating whether the enhanced propulsion could serve as a strategy to mitigate speed loss in long-distance running.

The results from current study indicate that running experience may not only impact the risk of RRIs but also influence the biomechanical efficiency of running. This investigation can serve as a useful reference for assessing and training novice runners. Furthermore, the protective benefits of experience against injury might not solely stem from enhanced running mechanics but could be attributed to improved movement patterns and functional adaptability to environmental and biological stressors, such as training factors [31]. Therefore, the significance of experience may not merely depend on years of participation but also on the mastery of skills and the ability to correct errors.

The current study has several limitations that need to be considered. Firstly, the running biomechanics differences observed in this study may be influenced by varying running speeds. Data was collected at each runner's preferred speed to maintain a natural gait pattern, but this may have impacted the results. Secondly, the study focused solely on male runners, and since sex differences exist in running biomechanics, caution should be exercised when extrapolating these findings to female runners. Thirdly, this study did not discuss the effects of long-distance running conditions and different shoes on GRFs. Running distance and footwear are both important factors that affect GRFs [31]. In future research, we will combine the three factors of running experience, long-distance running and shoes to explore. Additionally, the study did not collect kinematic parameters, and it's possible that novice and recreational runners exhibit different kinematic patterns. Exploring these kinematic aspects in future research would enhance our understanding of the topic. It is important to take these limitations into account in their future investigations to gain a more comprehensive understanding of the topic.

5. Conclusions

Running GRF differences between novice and recreational runners were investigated. The findings in our study indicated that running experience had an impact on GRFs. Recreational runners exhibited a significantly larger peak vertical impact force and peak medial force than the novice group, while the peak propulsive force was smaller than the novice group. The SPM1D results also showed that recreational runners and novice runners exhibited significant differences in medial-lateral, anterior-posterior and vertical forces. The discoveries from this study have the potential to offer valuable guidance for the development of training programs and injury prevention protocols tailored to runners with diverse levels of running experience.

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