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Impulse Variability Following Increased Running Speed

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Abstract

Introduction: Running usually happens at faster speeds than walking and faster the speed of running variability of some biomechanical parameters seems to be controversial. The purpose of this study was to investigate the impulse variability following increased velocity. **Materials and Methods**: twenty eight elite runners with body mass: 69.63±6.670 kg, age: 34.75±6.626 years and height: 175.96±6.74 cm participated in the present study. Kinetic data were measured at speeds of 2.5, 3.5, and 4.5 meters per second at a sampling frequency of 300 Hz when running on a treadmill on a force plate, and then the total impulse and mean impulse variables were extracted. To analyze the data at three different speeds, two-factor analysis of variance with repeated measures with a significant level of $P<0.05$ was used. **Results**: These results showed that with increasing speed in the stance phase, significant differences were obvious in average impulse by increasing speed (2.5 & 3.5- 2.5 & 4.5 and 3.5& 4.5 m/s). Also, significant difference was presented in total impulse between speeds of 3.5 and 4.5 m/s. **Conclusion**: It seems that a change in running speed causes a change in the momentum of the running support phase and increases with higher impulse speed.

Keywords: Biomechanics; Impulse; Kinetics; Running

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Introduction

Ankle fractures are defined as a fracture or multiple fractures in Physical activity, including running, is important for public health by preventing chronic diseases and their precursors. To maintain the health of runners, it is very important to have a thorough knowledge of running biomechanics (1). Running speed is considered essential for most sports, including running faster enough to defeat the opponent or even jumping higher (2, 3).

Running usually occurs at faster speeds than walking. Running is defined as walking in which there is a swing phase in both feet when each foot touches the ground, while no segment is in contact with the ground. Apart from wind and gravity resistance, no external forces enter the body during this oscillation phase (2, 3). Therefore, it is the stance phase that must change and correct the running speed (2, 3). The forces involved in the stance phase in running can be measured. These forces are usually measured using a force plate. A force plane uses Newton's third law of motion: for every action, there was an equal and opposite direction. One of the quantities that can be measured by the force plate is impulse (2, 3).

Impulse is equal to the integral of the ground reaction force in the walking time interval, which is equal to the size of the body movement (4). The impulse is calculated using multiplying the force by the duration in which it is applied. The impulse is almost constant for one stage of running, regardless of how it is run. Mathematically, the momentum (I) of a step is given when running or walking with $I = \int Fdt$where F is the force and t is the duration of the force effect (2, 3). The forces that the earth exerts on the body at each step of the run as equal and opposite reactions were the forces measured by a force plane and the impulse describes the force exerted over a period of time (2, 3).

A study of 61 subjects by Xuanzhen *et al.* found that there was a relationship between impulse changes and stiffness of the plantar arch when running. In addition, impulse distribution patterns based on different mechanisms was different (5).Also, a study by Paul Allard& *et al.* on amputated people with a

Table 1.Demographic characteristics of the subjects

	N	Maximum	Minimum	Mean (SD)
Weight(kg)	28	82.15	56.85	69.63 (7.670)
Age(Year)	28	51.00	22.00	34.75 (6.626)
Height(cm)	28	187.20	162.70	175.96 (6.74)

Table 2.Average and total impulse at three different speeds

Variable		Speed (m/s)
Average impulse (N.s)	5.89 (0.81	**2.5**
	6.54 (0.80	**3.5**
	6.87 (0.88	**4.5**
Total Impulse(N.s)	40911.70 (4626.96	**2.5**
	40915.22 (4603.89	**3.5**
	41127.35 (4591.099	**4.5**

Table 3.Comparison of differences between means and standard error and significance level in Bonferroni post hoc test of three different speeds

Variable	Mean (SD)	Speed (m/s)	Sig.
Average impulse (N.s)	-.650 (.071)	2.5 & 3.5	0.000*
	-.981 (.097)	2.5 & 4.5	0.000*
	-.331 (.047)	3.5 & 4.5	0.000*
Total impulse (N.s)	-3.511 (147.947)	2.5 & 3.5	1.000
	-215.644 (145.350)	2.5 & 4.5	0.453
	-212.133 (42.389)	3.5 & 4.5	0.000*

** Significant difference :P<0.05*

prosthetic leg showed that there is an impulse asymmetry between the amputated leg and the healthy leg when running. Kelly showed that the impulse shows the asymmetry between the types of artificial legs better (6).

However; a review on changing impulse magnitude at different speeds seems to be necessary to investigate any probable differences of impulse during running in progressive speeds. In this study, changes in impulse at different speeds running on a treadmill were examined among elite runners and impulse changes were evaluated over a period of 9 seconds.

Methods and Materials

This research was a quasi-experimental study. The purpose of this study was to investigate the variability of impulse following the increase in running speed. The study was performed at the Biomechanics and Motion Control Laboratory (BMClab; http: //demotu.org) at ABC Federal University (UFABC). Data were collected by experienced physiotherapist researchers. UFABC (CAAE: 53063315.7.0000.5594) was approved and written and informed consent was obtained from each person before participating in the study.

Participants

Twenty eightelite runners participated in this study voluntarily. Inclusion criteria included a typical runner with a weekly mileage of more than 20 km, a minimum average running speed of 1 km per 5 minutes during 10 km races, familiarity with running on a treadmill. Exclusion criteria were any neuromuscular or musculoskeletal disorders that endanger movement, or the use of any assistive device.

Equipment

Subjects while running on a treadmill performed ground reaction force data through a treadmill equipped with two belts (FIT, Bertec, Columbus, OH, USA) (Figure 1). The treadmill had a measuring instrument mounted on a pit, which was level with the laboratory floor (Figure 1). Data sampling rate was adjusted to 300 Hz sampling frequency. The laboratory coordinate system used for the study was the same as proposed by the International Society of Biomechanics. As shown in Figure 1, it includes the following:

The X-axis was forward running and positive pointing forward.

The Y axis was upward in a vertical and positive direction.

Z axis inward-outward and positive to the right.

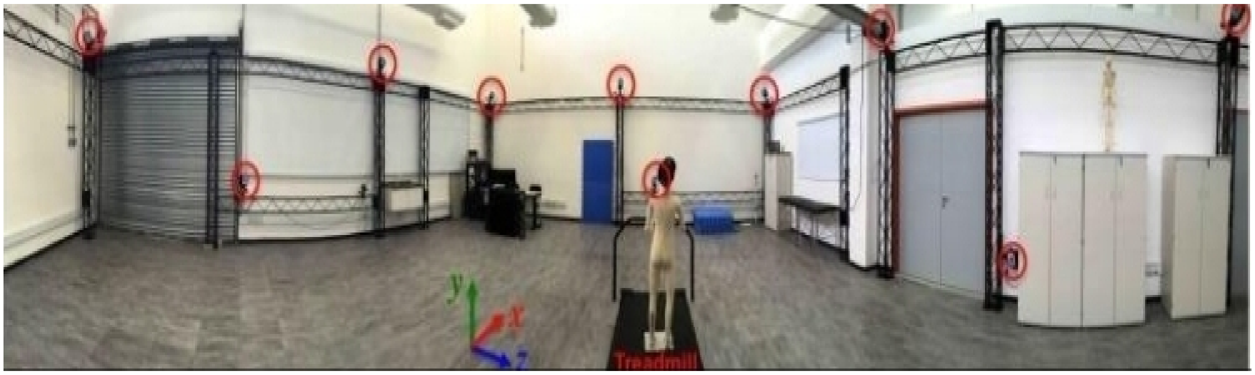

Figure 1. Overview of the Laboratory of Biomechanics and Motor Control. Expanded view of the Laboratory of Biomechanics and Motor Control (BMC lab), showing 10 of the 12 motion-capture system cameras (marked with red circles), the instrumented treadmill, and the laboratory coordinate system

Protocol

The data-collection protocol involved the following procedures: Upon arrival, participants were asked to provide written and informed consent and to conduct short interviews on eligibility criteria, demographic data, and running habits. The force plates were zeroed, the subjects were asked to step onto the treadmill, and the protocol was as follows:

The subjects walked at a speed of 1.2 meters per second for 1 minute to get acquainted with the treadmill. The subjects was then asked to stay on the left belt of the treadmill, the belt speed was gradually increased to 2.5 m/s, and after a period of 3 minutes of activity at this speed, the data were recorded for 9 seconds. This method was also performed for speeds of 3.5 and 4.5 meters per second and force and time variables were extracted from the force plate data to calculate the total impulse and mean impulse.

To calculate the impulse using the trapezoidal method for the X, Y and Z axes, it was calculated as follows:

$$\text{Impulse} = \Delta t\left((\frac{F_{1+F_n}}{2}) + \sum_{i=2}^{n-1} \text{Fi}\right)$$

In the above formula, F_1 was the first force, F_n was the final force, Δt was equal to the sampling time, and n was equal to the number of recorded force data points (4, 7, 8).

Statistical analysis of processed data

Descriptive statistics was used for determined mean and standard deviation of data. To check the normality distribution of data Shapiro-Wilk test was used and for comparison between different situations repeated measurements with a significant level of $P<0.05$ was used. In case of significance, Bonferroni post hoc test was used. Data analysis was performed using SPSS software version 22.

Results

Based on the findings of normality, data distribution was normal. No significant differences were observed between various situations of running speed ($P\leq0.05$).

Based on the findings of Table 2, the results of the means and standard deviation of the two variables of average impulse and total impulse are presented fora group of 28 subjects at three different speeds.

In addition, based on the findings in Table 3, the results of the Bonferroni post hoc test showed significant differences were obvious in average impulse by increasing speed (2.5 & 3.5- 2.5 & 4.5 and 3.5 & 4.5 m/s). Also, a significant difference was presented in total impulse between speeds of 3.5 and 4.5 m/s. No significant differences were reported between the speeds of 2.5 & 3.5 as well as 2.5 & 4.5 m/s considering total impulse.

Discussion

The aim of this study was to investigate the variability of impulse following increasing running speed. The findings of the present study showed that a change in running speed could cause a change in the impulse of the running support phase and increases with increasing speed from 3.5 m / s to 4.5 m / s impulse. The area below the force-momentum curve of the initial impact (impulse): F × t is equal to the duration of the force applied to separate the foot from the ground (7). Impulse was also equal to the integral of the ground reaction force in the time interval of applying force which was equal to the size of the body motion(8). This indicates that the impulse distribution pattern was different based on different walking tasks (such as walking, running and walking end(8, 9) when the walking speed increases, different phases of the single-legged stance including: A. foot contact with the ground; (strike b; middle support) (mid support and c); foot off the ground (take off) decreases, but the amount of force applied to the force plate increases throughout the movement phase; The duration of the oscillation phase also increases from the moment the foot separates from the ground until the foot comes in contact with the ground again. According to a study by Peter *et al*. the sprinters have less time to apply the vertical force of the ground reaction (impulse), so they need more force than usual, and in the acceleration phase, they needed a larger relative vertical impulse, which was consistent with the results of the present study(10). On the other hand, the total impulse for running in 9 seconds has increased from 3.5 m / s to 4.5 m / s. This increase was related to the total number of strokes at the moment the stance applied to the force plate embedded in the treadmill, which can be the result of increasing the step length, increasing the force applied to the force plate, reducing the stance time, and also increasing the speed of walking. However, any increase in speed, especially in lower ones i.e. 2.5 to 3.5, did not present significant difference in impulse. In a study conducted by Nelson *et al.* the total impulse values was decreased in running, but they did not observe a statistically significant difference between the groups, which was not consistent with the results of the present study (11). A study by Nilsson *et al*. showed that in running, the total values of vertical impact (impulse) was decreased and no significant difference was observed between the groups, which was inconsistent with the present study (12).

The findings of the present study also showed that a change in running speed could cause a change in the momentum of the average running support phase the findings of the present study showed that changes in running speed may lead to changes in momentum of the running during stance phase. In the other word, increasing speed from 2, 5 to 3,5, 3,5 to 4,5 as well as 2.5 to 4,5 increases the impulse significantly. Impulse describes the force exerted over a period of time. Impulse changes in running can be due to changes in the total average impulse in the running cycle over the entire 9-second run time on the treadmill. Although this change may not have occurred on a single stroke, the mean impulse was increased with increasing speed. In running, a uniform increase in impulse has been observed, which can be related to the increase in leg distance (11). In a study by Caroline *et al.* (13) was reported that changes in impulse and vertical ground reaction force average were significantly increased while increasing speed, was significantly increased with a change in velocity from 3 to 5 m / s, which was consistent with the results of this study. In a study conducted by Hunter *et al.* to determine the relationship between relative impulse and running speed during the acceleration phase of two speeds, the relationship between impulse and running speed had a nonlinear relationship. The result was that there was a strong relationship between impulse and running speed. Theoretically, the production of a larger impulse in the vertical direction during contact with the ground leads to a greater vertical velocity of the center of mass at take-off, which in turn leads to a longer flight time(14). Step length and walking frequency increase with increasing running speed(15). The length of the step depends on the length of the leg, the range of motion of the hip joint, and the strength of the leg extensions. The frequency of gait depends on the speed of muscle contraction and running skills. For speeds of more than 7 m / s, the increase in step length decreases but the stepping frequency significantly increases. As a result, the impact force increases with increasing running speed. Therefore, applying more impulses in the vertical direction can be important in achieving maximum running speed during contact with the ground (16). A study conducted by Jafarnejad *et al.* showed that when running, the impulse values in both anterior-posterior and vertical directions during the taping position was larger than the values of these variables without banding (17).

This study had some limitations. The subjects were only men and the female subjects were not studied. Also, the pattern of walking was not investigated in this study, which requires further research in the future.

Conclusion

The findings of the present study showed that the mean impulse value was increased with increasing speed. It also showed that the total impulse value was increased with increasing speed from 3.5 m / s to 4.5 m / s, which could possibly indicate that the amount of force produced by the active muscles in running and the electrical activity of these muscles increased.

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All authors made substantial contributions to the conception, design, analysis, and interpretation of data.

References

1. Dugan SA, Bhat KP. Biomechanics and analysis of running gait. Physical Medicine and Rehabilitation Clinics. 2005;16(3):603-21.
2. Milner CE, Davis IS, Hamill J. Free moment as a predictor of tibial stress fracture in distance runners. Journal of biomechanics. 2006;39(15):2819-25.
3. Milner CE, Hamill J, Davis I. Are knee mechanics during early stance related to tibial stress fracture in runners? Clinical Biomechanics. 2007;22(6):697-703.
4. Robertson DGE, Caldwell GE, Hamill J, Kamen G, Whittlesey S. Research methods in biomechanics: Human kinetics; 2013.
5. Cen X, Xu D, Baker JS, Gu Y. Association of arch stiffness with plantar impulse distribution during walking, running, and gait termination. International Journal of Environmental Research and Public Health. 2020;17(6):2090.
6. Prince F, Allard P, Therrien R, McFadyen B. Running gait impulse asymmetries in below-knee amputees. Prosthetics and Orthotics International. 1992;16(1):19-24.
7. Hamilton NP. Kinesiology: Scientific basis of human motion: Brown & Benchmark; 2011.
8. Almosnino S, Kajaks T, Costigan PA. The free moment in walking and its change with foot rotation angle. BMC Sports Science, Medicine and Rehabilitation. 2009;1(1):1-9.
9. Yousefian Molla R, Fatahi A. Analysis of Lower Limb Joint Kinetics With Increasing Running Speed. Physical Treatment Journal. 12(2) 65-76; 2022.
10. da Silva Azevedo AP, Cardoso Filho CA, Lima WP, Colturato MdAB, Serrão JC. Efeito Agudo Da Corrida Com Os Pés Descalço Sobre As Componentes Anteroposterior E Mediolateral Da Força De Reação Do Solo. Corpoconsciência. 2021:175-85.
11. Nilsson J, Thorstensson A, Halbertsma J. Changes in leg movements and muscle activity with speed of locomotion and mode of progression in humans. Acta Physiologica Scandinavica. 1985;123(4):457-75.
12. Nilsson J, Thorstensson A. Ground reaction forces at different speeds of human walking and running. Acta Physiologica Scandinavica. 1989;136(2):217-27.
13. Munro CF, Miller DI, Fuglevand AJ. Ground reaction forces in running: a reexamination. Journal of biomechanics. 1987;20(2):147-55.
14. Hunter JP, Marshall RN, McNair PJ. Interaction of step length and step rate during sprint running. Medicine and science in sports and exercise. 2004;36(2):261-71.
15. Molla RY, Sadeghi H, Farahmand F, Azarbayjani MA. Effect of excessive Arm Swing on Speed and Cadence of walking. Men's Health Journal. 2020;4(1):e5-e.
16. Weyand PG, Sternlight DB, Bellizzi MJ, Wright S. Faster top running speeds are achieved with greater ground forces not more rapid leg movements. Journal of applied physiology. 2000;89(5):1991-9.
17. Jafarnezhadgero AA, Sorkheh E. Immediate effects of femoral external rotational and abductoral taping on ground reaction force characteristics during running. Research in Sport Medicine and Technology. 2017;15(14):47-57.