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Original scientific paper

ASSESSMENT OF STRIDE LENGTH AND FREQUENCY AT DIFFERENT RUNNING SPEEDS FOR MEN AND WOMEN[1]

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Abstract: Success in running depends on numerous factors, with two of the most important being stride length and stride frequency. The first goal of this study is to assess the differences in stride length and stride frequency between men and women at different running speeds. The second goal is to examine the correlation between the morphological characteristics of men and women with stride length and stride frequency. This study involved two groups of 37 recreational runners (22 men and 15 women). The participants ran on a treadmill, wearing two portable Prosense accelerometers on each ankle. The protocol included 10 minutes of running, consisting of 3 minutes of warming up at 8 km/h, one minute of running at 8, 10, 12, and 14 km/h (used for further analyses), and 3 minutes of running at 8 km/h. The main variables used were stride length and stride frequency. The results showed that women had a higher stride frequency than men at almost all running speeds ($p < 0.05$), but there was no difference in stride length between men and women. Additionally, men showed strong and statistically significant negative correlations between height and stride frequency ($r > -0.59 < -0.66$), as well as low to moderate positive correlations between height and stride length ($r > 0.17 < 0.46$). Among women, low to moderate negative correlations between height and stride frequency ($r > -0.28 < -0.43$) were found, along with low to moderate positive correlations between height and stride length ($r > 0.34 < 0.52$). The results of the study, as well as the modern technology used in this paper, would significantly improve the training process for recreational runners.

Keywords: *Accelerometer, biomechanics, running, kinematics, Smart4Fit*

INTRODUCTION

Over the years, recreational running has experienced a complete boom and has become recognized as the most widespread physical activity among recreational athletes (Scheerder et al., 2015). The same author notes that the very concept of recreational running has changed over the years and that modern society initially shied away from it. However, as the numerous health benefits of this form of physical activity have become apparent (Wirnitzer et al., 2022), it has become increasingly accepted and is now an integral part of modern community life. Besides its impact on physical health, it's important to highlight the significant benefits of recreational running on the psycho-

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logical well-being of exercisers (Marković et al., 2020). Modern technologies, which make life easier, are also an integral part of modern society. In the realm of recreational running, modern technologies offer exceptional opportunities to all users. One type of application of modern technology is the use of portable devices that track various physical activity parameters. The accuracy of the variables collected by these devices has been proven in previous studies (Germini et al., 2022; Xiang et al., 2022; Aleksić et al., 2023; Hadži Pavlović & Nikolić, 2024), providing recreational runners with a reliable means to monitor their progress and current physical fitness. However, there is still a limited number of studies that have collected stride length and frequency values using increasingly popular and readily available portable devices.

Success in running depends on numerous factors that influence different variables. Two of the most important factors in analyzing this activity are stride length and stride frequency. Stride length refers to the distance covered between two strides, while stride frequency refers to the total number of strides taken in one minute. An analysis of previous studies reveals a tendency for these two values to increase with running speed (Rajkumar, 2020). However, the same authors have pointed out an interesting difference in the tendency for these values to increase between male and female runners. Other studies highlight numerous kinematic, physiological, biomechanical, and even motivational differences between men and women during running (Bruening et al., 2020; Senefeld et al., 2021; Maksimović & Barić, 2022). Most of these differences undoubtedly stem from anthropometric differences between men and women, which lead to different strategies for handling higher running speeds on the treadmill.

Given these differences in speed management strategies, the question arises as to whether there should be separate approaches in training male and female recreational runners. It is generally observed that recreational runners do not have a systematic approach to training, but rather see it as a form of relaxation and stress relief from modern life. This opens up an excellent opportunity for all manufacturers of portable devices, who, in conjunction with smartphones, can contribute to a more efficient training process for recreational runners by providing them with real-time information about increases or decreases in stride length and frequency without additional cognitive burden on the user. Certainly, the differences in the values of these two variables between men and women are rooted in the different movement of the body's center of mass and the different movement of the lower extremities due to the significant average height difference between the sexes.

In this context, the first goal of this study is to assess the differences in stride length and frequency between men and women at different running speeds. The second goal is to examine the correlation between the morphological characteristics of men and women with stride length and frequency at different running speeds. For both goals, ProSense accelerometer sensors and the Smart4Fit application were used. In line with these objectives, two hypotheses have been formulated. The first hypothesis is that as running speed increases, men will increase stride length, while women will increase frequency. The second hypothesis is that height will correlate highly positively with stride length, and negatively and highly with stride frequency in both men and women.

METHOD

Participants

The sample size was determined using the G*Power software. For an effect size of 0.25, an alpha level of 0.05, and a statistical power of 0.95, the total recommended sample size is 36 participants. Accordingly, this study involved 37 recreational runners divided into two sex-based groups (22 men and 15 women). All participants were informed about the protocol and purpose of the study before it began. They voluntarily agreed to participate and signed a consent form. The study was conducted in accordance with the Helsinki Declaration. The anthropometric measurements of the participants are presented in Table 1.

Procedures and Protocol

The study analyzed two main variables:

1. The average length of individual strides (stride length);
2. The number of strides per minute at each running speed (stride frequency).

Additionally, anthropometric variables such as height, body mass, and body fat percentage were analyzed.

Data on the participants' body composition were collected using the "Total InBody 720" body impedance analyzer (for body mass and fat percentage) and a Martin anthropometer (for body height). At the beginning of the testing, participants were asked to be barefoot and wear sports attire to ensure the equipment collected accurate data on their body composition. The first step is to measure the body height by having the subjects stand upright while their height is measured using a Martin anthropometer. The participants' ID number, body height, and age were entered into the program. Following the protocol suggested by the equipment manufacturer, participants stood still on the device and followed the instructions provided. It was necessary for the instructions to be timely and accurate to ensure proper contact between the body and the eight electrodes, two for each hand and foot. Once the correct position was secured, participants stood still, looked straight ahead, and waited for further instructions (Gibson et al., 2008).

The main part of the protocol involved running on a treadmill, modeled after previous studies that used the same equipment under similar conditions (Hadži Pavlović & Nikolić., 2024). It consisted of a ten-minute activity that included a three-minute warm-up (at a speed of 8 km/h), followed by four minutes of running. The running began at a speed of 8 km/h and increased by 2 km/h each minute—first to 10 km/h, then to 12 km/h, and concluding at 14 km/h. This was followed by a three-minute cool-down run at 8 km/h. The ProSense sensors were portable devices used to collect biomechanical parameters. One sensor was attached to each leg, as shown in Figure 1.

Figure 1. *"ProSense" Sensors During Treadmill Running*

The sensors are connected via Bluetooth to the Smart4fit Android application for smartphones. The phone screen displays physiological parameters such as heart rate and caloric expenditure. For the application to function properly, it is necessary to input the participant's exact body mass and height. The sensor is equipped with an accelerometer, gyroscope, and magnetometer, which provide data on acceleration, angular velocity, and magnetic field strength (of the Earth) at a sampling rate of 50 Hz. These sensors also provide data on kinematic parameters such as speed, force, energy, and power. Importantly for this study, they also provide data on instabilities (even slight ones) and variations between different body segments of the participants. After the run is completed, raw data on the biomechanical parameters of running—specifically stride length and frequency—are exported from the application.

Statistical Analysis

Before conducting any statistical tests, descriptive statistics were calculated as mean and standard deviation. The Kolmogorov-Smirnov (KS) test, along with visual inspection of histograms and QQ plots, confirmed the normality of the data distribution. Additionally, the T-test was applied for independent samples to examine differences between sexes in terms of age and anthropometric variables.

To test the first hypothesis, the two-way analyses of variance (ANOVA) were conducted for the variables of stride length and stride frequency to examine differences between running speeds (8, 10, 12, and 14 km/h), sex (men and women), and their interaction (running speed x sex). The Bonferroni post hoc test was conducted to further investigate differences within groups. Effect size was reported using eta squared (η^2), with values of 0.01, 0.06, and above 0.14 considered small, medium, and large, respectively (Cohen, 1988). The alpha level was set at $p < 0.05$.

To test the second hypothesis, Pearson's correlation was used to examine the relationship between anthropometric variables (height, mass, and body fat percentage) and both stride length and frequency at the four running speeds. The correlation coefficient was interpreted according to Sugiyono (2013) as follows: below 0.20 = very low correlation; 0.20 to 0.399 = low; 0.40 to 0.599 = moderate; 0.60 to 0.799 = high; and 0.80 to 1 = very high.

All statistical tests were conducted using Microsoft Office Excel 2007 (Microsoft Corporation, Redmond, WA, USA) and SPSS 26 (IBM, Armonk, NY, USA).

RESULTS

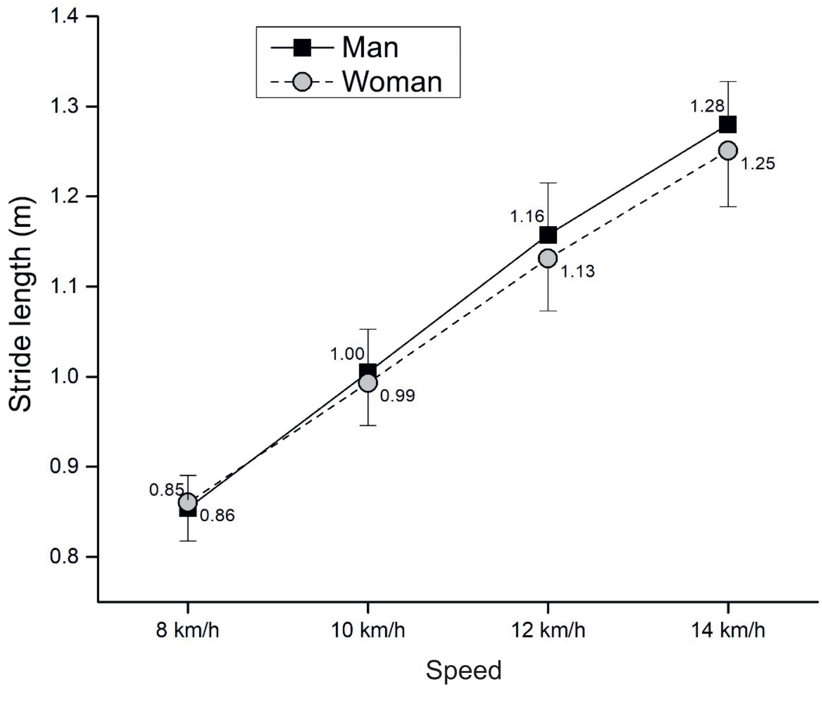
Table 1 shows the age and descriptive indicators of anthropometric characteristics of men and women. Additionally, differences between the displayed variables were examined using the T-test for independent samples.

Table 1. *Age, descriptive indicators of anthropometric characteristics of men and women, and di fferences between sexes in these variables*

Variable	Sex	N	Mean	Standard deviation	T-Value	Statistical significance (p)
Age	Men	22	23.18	2.28	-0.156	0.877
	Women	15	23.33	3.62		
Height (cm)	Men	22	182.50	5.03	7.614**	<0.001
	Women	15	169.86	4.86		
Weight (kg)	Men	22	82.77	11.16	6.150**	<0.001
	Women	15	62.80	6.94		
% Fat	Men	22	24.83	3.04	3.580**	0.001
	Women	15	21.73	1.70		

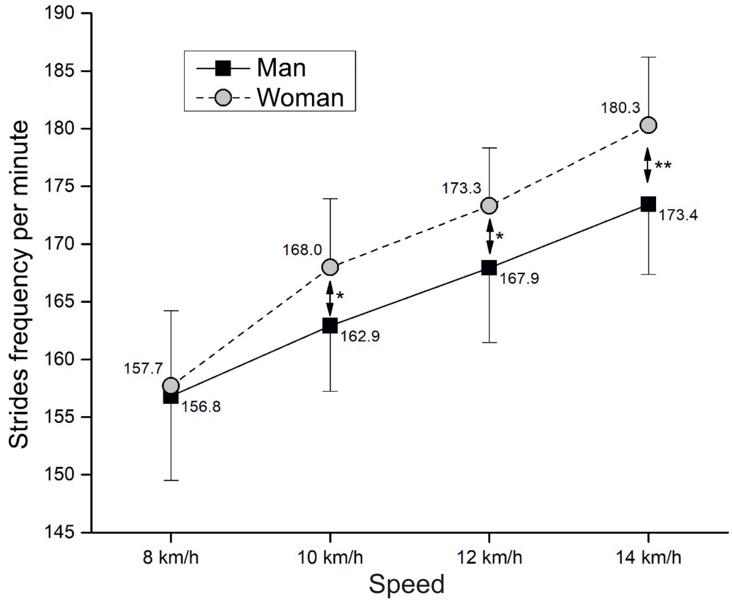
Two-factor ANOVA applied to the stride length variable revealed a significant main effect for running speed [$F(3,35) = 1116.1$; $\eta^2 = 0.97$; $p < 0.001$], but not for sex effect [$F(3,35) = 5.68$; $\eta^2 = 0.14$; $p = 0.023$] and the interaction of running speed x sex [$F(3,35) = 2.32$; $\eta^2 = 0.06$; $p = 0.091$]. The post hoc analysis (Graph 1) showed that stride length significantly increased with running speed for both men and women ($p < 0.001$). There were no differences in stride length between men and women ($p > 0.05$).

Graph 1. *Differences in stride length per minute for men and women running at different speeds*



Two-factor ANOVA applied to the stride frequency variable revealed significant main effects for running speed [F(3,35) = 297.2; $\eta^2 = 0.89$; p < 0.001], sex [F(3,35) = 1.18; $\eta^2 = 0.03$; p = 0.284], and the interaction of running speed x sex [F(3,35) = 7.06; $\eta^2 = 0.17$; p = 0.001]. Post hoc analysis (Graph 2) showed that stride length significantly increased with running speed for both men and women (p < 0.001). Additionally, women had a higher stride frequency at running speeds of 10 km/h (p = 0.014), 12 km/h (p = 0.010), and 14 km/h (p = 0.002).

Graph 2. *Differences in stride frequency per minute for men and women running at different speeds*



* p < 0,05; ** p < 0,01

Tables 2 and 3 show the correlations between anthropometric variables (height, weight, and percentage of body fat) and stride length and frequency at four running speeds, separately for men (Table 2) and women (Table 3).

Table 2. *Correlations between anthropometric variables and stride length and frequency at four running speeds for men*

Variable	Height (cm)		Weight (kg)		% fat	
Statistical Analysis	Co-relation coefficient (*r*)	Statistical importance (*p*)	Co-relation coefficient (*r*)	Statistical importance (*p*)	Co-relation coefficient (*r*)	Statistical importance (*p*)
Stride frequency (8 km/h)	-0.625**	**0.002**	-0.218	0.329	0.044	0.845
Stride frequency (10 km/h)	-0.590**	**0.004**	-0.164	0.465	0.075	0.740
Stride frequency (12 km/h)	-0.659**	**0.001**	-0.255	0.252	0.021	0.926
Stride frequency (14 km/h)	-0.602**	**0.003**	-0.208	0.352	0.047	0.837
Stride length (8 km/h)	0.458**	**0.032**	0.048	0.831	-0.143	0.526
Stride length (10 km/h)	0.175	0.437	0.116	0.607	0.051	0.822
Stride length (12 km/h)	0.376	0.084	0.171	0.448	0.000	1.000
Stride length (14 km/h)	0.446**	**0.037**	0.200	0.373	0.002	0.991

Table 3. *Correlations between anthropometric variables and stride length and frequency at four running speeds for women*

Variable	Height (cm)		Weight (kg)		% fat	
Statistical Analysis	Co-relation coefficient (*r*)	Statistical importance (*p*)	Co-relation coefficient (*r*)	**Statistical Analysis**	Co-relation coefficient (*r*)	Statistical importance (*p*)
Stride frequency (8 km/h)	-0.335	0.223	-0.367	0.178	-0.279	0.314
Stride frequency (10 km/h)	-0.279	0.314	-0.386	0.155	-0.337	0.219
Stride frequency (12 km/h)	-0.434	0.106	-0.377	0.166	-0.210	0.453
Stride frequency (14 km/h)	-0.305	0.268	-0.155	0.580	0.000	0.999
Stride length (8 km/h)	0.460	0.084	0.108	0.703	-0.186	0.508
Stride length (10 km/h)	0.343	0.211	0.182	0.516	0.007	0.979
Stride lengthm (12 km/h)	0.525*	**0.044**	0.231	0.408	-0.067	0.813
Stride length (14 km/h)	0.471	0.076	0.280	0.313	0.033	0.906

DISCUSSION

This study aimed to assess differences in stride length and frequency between men and women at various running speeds. The second goal was to examine the relationship between morphological characteristics of men and women and stride length and frequency at different running speeds. In this context, two hypotheses were posed. The first hypothesis, that men would increase stride length with running speed while women would increase stride frequency, was partially confirmed. Namely, women had a higher stride frequency than men at almost all running speeds, but there was no difference in stride length between men and women.The second hypothesis, that height would highly positively correlate with stride length and negatively and highly with stride frequency for both men and women, was also partially confirmed. For men, there were strong and statistically significant negative correlations between height and stride frequency, as well as low to moderate positive correlations between height and stride length. For women, there were low to moderate negative correlations between height and stride frequency and also low to moderate positive correlations between height and stride length.

As expected, both stride frequency and stride length increase with running speed, as seen in previous studies (Hunter et al., 2003; Barnes et al., 2013; Rajkumar, 2020). Body mass and percentage of body fat show very low correlations with stride length and frequency in men, and low and negative correlations in women, which partially aligns with findings from previous research (Šentija et al., 2011; Taylor-Haas et al., 2022).

This raises the question of which parameter men use to keep up with increased running speed. It is assumed that men significantly increase the force they exert on the ground (ground reaction force) to match the increased speed on the treadmill. As demonstrated in numerous studies (Schubert et al., 2014; Yong et al., 2018; Farina et al., 2021), a higher number of strides per minute drastically reduces the ground reaction force experienced during running, significantly reducing the risk of acute lower extremity injuries. It is important to note that differences between sexes are influenced not only by these parameters but also by other factors, such as variations in joint mechanics and the overall locomotor system, as evidenced in previous studies (Bruening et al., 2020; Ortega et al., 2021).

Based on the relationships between these anthropometric measures and the studied variables, it can be concluded that height has a greater impact on the number of strides in men compared to women. This further supports the hypothesis that men adjust to increased running speed by increasing the force they exert on the ground with each stride. Additionally, we observe that in women, an increase in body mass is associated with a slight decrease in the number of strides, which aligns with previous research findings (Luedke et al., 2021).

A limitation of this study may be the use of new equipment (sensors and applications), which requires additional testing and validation to refine and broaden its comprehensive application. Despite this, the observed increases in both stride speed and frequency suggest that the system is sensitive enough to detect these expected changes. Additionally, a limitation of this study is the lack of investigation into other variables that could contribute to a better understanding of running mechanics in men and women.

CONCLUSION

The results indicate a significant impact of height on running strides frequency, while this effect is somewhat lower in women. Additionally, there is a moderate to low impact of height on stride length for both sexes, which is interesting compared to other studies that report a high correlation. Stride frequency and stride length increased in both groups of participants, but the increase in stride frequency was much more pronounced in women than in men. A higher stride frequency reduces the risk of injury as it eliminates the need for a drastic increase in ground reaction force. This highlights an excellent opportunity for further research that could examine the relationship between ground reaction force, stride frequency, and stride length. Modern technology used in this study could significantly enhance the training process for all its users through additional analysis of these variables.

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