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PROCENA DUŽINE I FREKVENCIJE KORAKA PRI TRČANJU RAZLIČITIM BRZINAMA KOD MUŠKARACA I ŽENA [1]

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Apstrakt: Uspešnost u toku trčanja zavisi od mnogobrojnih faktora, a jedni od najbitnijih jesu dužina i frekvencija koraka. Prvi cilj ovog istraživanja je procena razlika dužine i frekvencije koraka između muškaraca i žena pri različitim brzinama trčanja. Drugi cilj jeste ispitivanje povezanosti morfoloških karakteristika muškaraca i žena sa dužinom i frekvencijom koraka. U ovom istraživanju su učestvovale dve grupe od 37 rekreativnih trkača (22 muškaraca i 15 žena). Ispitanici su trčali na tredmilu noseći na svakom članku noge dva prenosiva Prosense akcelerometra. Protokol je podrazumevao 10 minuta trčanja i to: 3 minuta zagrevanja na 8 km/h, po jedan minut trčanja na 8, 10, 12 i 14 km/h (korišćeno za dalje analize) i 3 minuta trčanja na 8 km/h. Glavne varijable koje su se koristile su dužina i frekvencija koraka. Rezultati su pokazali da su žene imale veću frekvenciju koraka od muškaraca pri gotovo svim brzinama trčanja ($p < 0,05$), ali u dužini koraka nije bilo razlike između muškaraca i žena. Takođe, kod muškaraca su dobijene visoke i statistički značajne negativne korelacije visine i frekvencije koraka (r >-0,59<-0,66), kao i niske do umerene pozitivne korelacije visine sa dužinom koraka (r >0,17<0,46). Kod žena su dobijene niske do umerene negativne korelacije visine i frekvencije koraka (r >-0,28<-0,43) i takođe niske do umerene pozitivne korelacije visine sa dužinom koraka (r >0,34<0,52). Rezultati istraživanja kao i moderna tehnologija korišćena u ovom radu bi značajno unapredila trenažni proces trkača rekreativaca.

Ključne reči: *akcelerometar, biomehanika, trčanje, kinematika, Smart4Fit*

UVOD

Rekreativno trčanje je tokom godina doživelo potpuni procvat i postalo prepoznato kao najmasovnija fizička aktivnost rekreativaca (Scheerder et al., 2015). Isti autor navodi kako se sam pojam rekreativnog trčanja menja kroz godine i kako ga je moderno društvo stidljivo izbegavalo. Uviđanjem mnogobrojnih zdravstvenih benefita koje ovaj vid fizičke aktivnost donosi (Wirnitzer et al., 2022) ono postaje sve prihvaćenije, a danas je sastavni deo života moderne zajednice. Pored uticaja na fizičko zdravlje bitno je istaći i ogromne benefite rekreativnog trčanja na psihičko stanje vežbača (Marković et al., 2020). Sastavni deo modernog društva su i moderne tehnologije koje olakšavaju život čoveku. U sferi rekreativnog trčanja, moderne tehnologije pružaju izvanredne mogućnosti svim korisnicima. Jedan od vidova primene moderne tehnologije je korišćenje prenosivih uređaja koji prate različite

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parametre fizičke aktivnosti. Tačnost varijabli koje su prikupljene je dokazana u ranijim istraživanjima (Germini et al. 2022; Xiang et al., 2022; Aleksić et al., 2023; Hadži Pavlović & Nikolić, 2024) što rekreativcu pruža jasan oslanac za praćenje svog postignuća i trenutne fizičke spreme. Međutim, još uvek je oskudan broj istraživanja koji su prikupljali vrednosti dužine i frekvencije koraka koristeći sve popularnije i lako dostupne prenosive uređaje.

Sama uspešnost u toku trčanja zavisi od mnogobrojnih faktora koji utiču na različite varijable. Jedni od najbitnijih faktora pri analizi ove aktivnosti su dužina i frekvencija koraka. Dužina koraka označava rastojanje koje se pređe u periodu između dva koraka dok frekvencija koraka označava ukupan broj koraka u jednoj minuti. Analizom prethodnih istraživanja uviđa se tendencija porasta ove dve vrednosti sa povećanjem brzine trčanja (Rajkumar, 2020). Međutim, ono što su isti autori izdvojili kao zanimljivost je razlika u tendenciji porasta vrednosti između muških i ženskih trkača. Druga istraživanja ukazuju na mnogobrojne kinematičke, fiziološke, biomehaničke, ali i razlike u samoj motivaciji između muškaraca i žena prilikom trčanja (Bruening et al., 2020; Senefeld et al., 2021; Maksimović i Barić, 2022). Svakako da većina razlika počiva na antropometrijskoj različitosti između muškaraca i žena koja dovodi do različitih strategija savladavanja većih brzina prilikom trčanja na traci.

Usled razlika u strategijama savladavanja brzine postavlja se i pitanje da li trebaju da postoje zasebni pristupi pri treningu muških i ženskih rekreativnih trkača. Opšta je pojava da rekreativci nemaju sistematičan pristup treningu već da on predstavlja određeni vid relaksacije i rasterećenja usled stresnog modernog života. To otvara odlično područje za sve proizvođače prenosivih uređaja koji u sadejstvu sa pametnim telefonima mogu da doprinesu efikasnijem trenažnom procesu rekreativaca tako što bi im davali trenutne informacije o povećanju ili smanjenju dužine i frekvencije koraka bez dodatnog kognitivnog opterećivanja korisnika. Svakako da razlike u vrednostima ove dve varijable između muškaraca i žena počivaju na drugačijem kretanju centra mase tela kao i različitom kretanju donjih ekstremiteta usled značajne razlike u prosečnoj visini između polova.

S tim u vezi, prvi cilj ovog istraživanja je da proceni razlike u dužini i frekvenciji koraka između muškaraca i žena pri različitim brzinama trčanja. Drugi cilj jeste ispitivanje povezanosti morfoloških karakteristika muškaraca i žena sa dužinom i frekvencijom koraka pri različitim brzinama trčanja. Za oba cilja koristiće se ProSense akcelerometarski senzori i Smar4Fit aplikacija. U skladu sa ciljevima, postavljene su i dve hipoteze. Prva hipoteza jeste da će muškarci pri povećavanju brzine trčanja povećavati dužinu koraka, a žene frekvenciju. Druga hipoteza je da će visina visoko pozitivno korelirati sa dužinom koraka, a negativno i visoko sa frekvencijom koraka i kod muškaraca i kod žena.

METOD

Ispitanici

Veličina uzorka određena je uz pomoć G*power programa. Za veličinu efekta od 0,25, alfa nivo 0,05 i statističku snagu od 0,95, ukupna preporučena veličina uzorka je 36 ispitanika. S tim u vezi, u ovom istraživanju je učestvovalo 37 rekreativnih trkača podeljenih u dve grupe po polovima (22 muškaraca i 15 žena). Svi učesnici su pre početka istraživanja obavešteni o protokolu i svrsi istraživanja. Dobrovoljno su pristali da učestvuju u istraživanju i potpisali su formular o saglasnosti. Istraživanje je sprovedeno u skladu sa Helsinškom deklaracijom. Antropometrijske mere učesnika su prikazane u Tabeli 1.

Procedure i protokol

U istraživanju su analizirane dve glavne varijable:

1. Prosečna dužina zasebnog koraka (dužina koraka);
2. Broj koraka u minuti za svaku brzinu trčanja (frekvencija koraka).

Osim toga, analizirane su i antropometrijske varijable visina i masa tela, kao i procenat masti.

Za prikupljanje podataka o telesnoj kompoziciji ispitanika korišćena je "Total InBody 720" bodi impedanca (masa tela i procenat masti) i antropometar po Martinu (visina tela). Na početku testiranja učesnicima je traženo da budu bosi i u sportskoj opremi kako bi aparatura prikupila tačne podatke o njihovoj telesnoj kompoziciji. Prvi korak je merenje visine tela tako što ispitanici stoje ispravljeni dok im se meri visina tela pomoću antropometra po Martinu. Redni broj ispitanika, telesna visina i godine starosti su uneti u program. U skladu sa protokolom koji predlaže proizvođač aparature ispitanici su mirno stajali na aparaturi i pratili instrukcije koje su im zadavane. Bilo je neophodno da instrukcije budu pravovremene i tačne kako bi se obezbedio kontakt tela sa osam elektroda, po dve za svaku ruku i nogu. Kada se obezbedi pravilan položaj ispitanici stoje mirno, gledaju pravo i čekaju dalje instrukcije (Gibson et al., 2008).

Glavni deo protokola podrazumeva trčanje na tredmilu i rađen je po uzoru na prethodno istraživanje koja su koristila istu opremu u sličnim uslovima (Hadži Pavlović & Nikolić, 2024). On je sačinjen od desetominutne aktivnosti koja se sastoji od trominutnog zagrevanja (pri brzini od 8 km/h), nakon čega sledi trčanje u trajanju od 4 minuta. Trčanje kreće pri brzini od 8 km/h i svakog minuta se povećava za 2 km/h , prvo na 10 km/h, potom na 12 km/h i završava se sa 14 km/h. Nakon toga sledi rasterećenje u vidu trominutnog trčanja pri brzini od 8 km/h. ProSense senzori su prenosivi uređaji koji su prikupljali biomehaničke parametre. Po jedan senzor je prikačen na svakoj nozi kao što je prikazano na Slika 1.

Slika 1. *Prikaz "ProSense" senzora u toku trčanja na tredmilu*

Senzori su preko Bluetooth-a povezani sa Smart4fit Android aplikacijom za pametne telefone. Na ekranu telefona se prikazuju fiziološki parametri poput pulsa i kalorijske potrošnje. Kako bi aplikacija adekvatno radila neophodno je uneti tačnu telesnu masu i visinu ispitanika. Senzor je opremljen akcelerometrom, žiroskopom i magnetometrom, koji daju podatke o ubrzanju, ugaonoj brzini i brzini magnetnog polja (Zemlje) pri brzini uzorkovanja od 50 Hz. Oni takođe pružaju podatke o kinematičkim parametrima kao što su brzina, sila, energija i snaga, a što je važno za ovo istraživanje, pružaju i podatke o nestabilnostima (čak i malim) i varijacijama između pojedinih segmenata tela učesnika. Nakon završetka trčanja, sa aplikacije se izvoze sirovi podaci o biomehaničkim parametrima trčanja, u ovom slučaju dužina i frekvencija koraka.

Statistička analiza

Pre svih statističkih testova, deskriptivna statistika je izračunata kao srednja vrednost i standardna devijacija. Kolmogorov-Smirnov (KS) test i vizuelna inspekcija histograma i QQ plotova potvrdili su normalnost distribucije podataka. Takođe, T-test za nezavisne uzorke je primenjen kako bi se ispitale razlike između polova u broju godina i antropometrijskim varijablama.

Za potvrdu prve hipoteze, dvofaktorske analiza varijanse (ANOVA) su sprovedene za varijable dužina koraka i frekvencija koraka kako bi se ispitale razlike između brzine trčanja (8, 10, 12 i 14 km/h), pola (muškarci i žene) i njihove interakcije (brzina trčanja x pol). Bonferroni post hok test je sproveden kako bi se ispitale dodatne razlike unutar grupa. Veličina efekta je prikazana putem eta kvadrata ($\eta 2$), gde su vrednosti od 0,01, 0,06 i iznad 0,14 smatrane malim, srednjim i velikim (Cohen, 1988). Alfa nivo je postavljen na $p < 0,05$.

Za potvrdu druge hipoteze, Pirsonova korelacija je korišćena za ispitivanje poveznosti između antropometrijskih varijabli (visina, masa i procenat masti) i dužine odnosno frekvencije koraka pri četiri brzine trčanja. Korelacioni koeficijent je interpretiran prema Sugiyono (2013) i to: ispod 0,20 veoma niska korelacija; od 0.20 do 0.399 niska; od 0.40 do 0.599 umerena; od 0.60 do 0.799 visoka i od 0,80 do 1 veoma visoka.

Svi statistički testovi su sprovedeni korišćenjem Microsoft Office Excel 2007 (Microsoft Corporation, Redmond, WA, SAD) i SPSS 26 (IBM, Armonk, NY, SAD).

REZULTATI

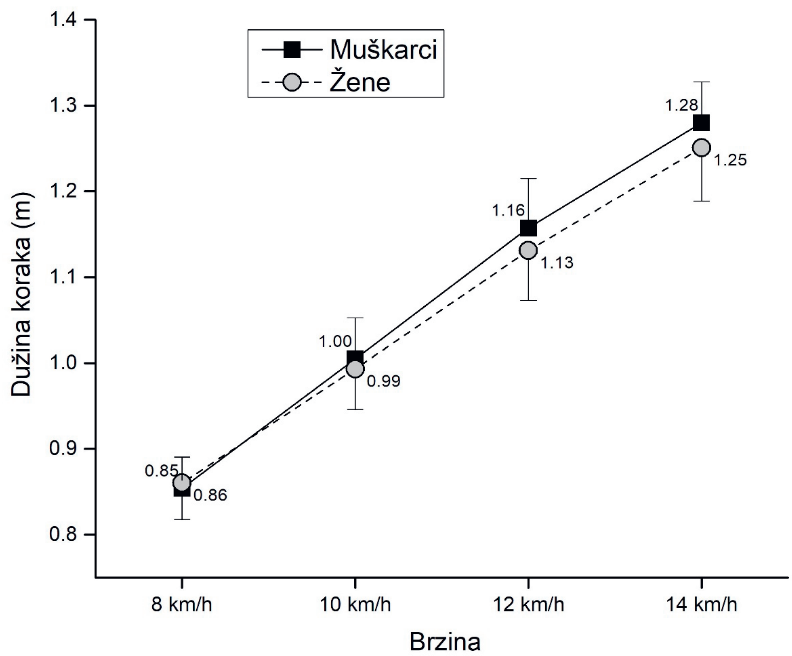
U Tabeli 1, prikazani su broj godina i deskriptivni pokazatelji antropometrisjkih karakteristika muškaraca i žena. Takođe, T-testom za nezavisne uzorke ispitane su razlike između prikazanih varijabli.

Tabela 1. *Broj godina, deskriptivni pokazatelji antropometrijskih karakteristika muškaraca i žena i razlike između polova u ovim varijablama*

Varijabla	Pol	N	Srednja vrednost	Standardna devijacija	T-vrednost	Statistička značajnost (p)
Godine	Muškarci	22	23.18	2.28	-0.156	0.877
	Žene	15	23.33	3.62		
Visina (cm)	Muškarci	22	182.50	5.03	7.614**	**<0.001**
	Žene	15	169.86	4.86		
Masa (kg)	Muškarci	22	82.77	11.16	6.150**	**<0.001**
	Žene	15	62.80	6.94		
% Masti	Muškarci	22	24.83	3.04	3.580**	**0.001**
	Žene	15	21.73	1.70		

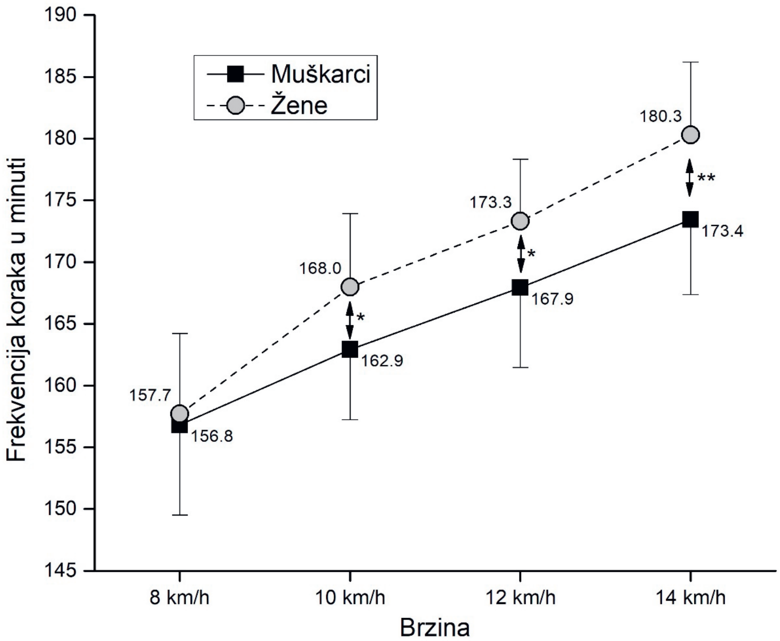
Dvofaktorska ANOVA primenjena na varijablu dužina koraka pokazala je značajan glavni efekat za brzinu trčanja [F(3,35) = 1116,1; ŋ2 = 0,97; p < 0,001], ali ne i za efekat pola [F(3,35) = 5,68; ŋ2 = 0,14; p = 0,023] i interakciju brzina trčanja x pol [F(3,35) = 2,32; ŋ2 = 0,06; p = 0,091]. Post hok analiza (Grafikon 1) je pokazala da se dužina koraka značajno povećavala i kod muškaraca i žena sa porastom brzine trčanja (p < 0,001). Između muškaraca i žena nije bilo razlika u dužini koraka (p > 0,05).

Grafikon 1. *Razlike u dužini koraka u minuti za muškarce i žene pri trčanju različitim brzinama*



Dvofaktorska ANOVA primenjena na varijablu frekvencija koraka pokazala je značajne glavne efekte za brzinu trčanja [F(3,35) = 297,2; ŋ2 = 0,89; p < 0,001], pol [F(3,35) = 1,18; ŋ2 = 0,03; p = 0.284] i interakciju brzina trčanja x pol [F(3,35) = 7,06; ŋ2 = 0,17; p = 0,001]. Post hok analiza (Grafikon 2) je pokazala da se dužina koraka značajno povećavala i kod muškaraca i žena sa porastom brzine trčanja (p < 0,001). Osim toga, žene su imale veću frekvenciju koraka pri brzini trčanja od 10 km/h (p = 0,014), 12 km/h (p = 0,010) i 14 km/h (p = 0,002).

Grafikon 2. *Razlike u frekvenciji koraka u minuti za muškarce i žene pri trčanju različitim brzinama*



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

U Tabeli 2 i 3 prikazane su korelacije između antropometrijskih varijabli (visina, masa i procenat masti) i dužine odnosno frekvencije koraka pri četiri brzine trčanja odvojeno za muškarce (Tabela 2) i žene (Tabela 3).

Tabela 2. *Korelacije između antropometrijskih varijabli i dužine i frekvencije koraka pri četiri brzine trčanja kod muškaraca*

Varijabla	**Visina (cm)**		**Masa (kg)**		**% masti**	
Statistička analiza	Korelacioni koeficijent (r)	Statistička značajnost (p)	Korelacioni koeficijent (r)	Statistička značajnost (p)	Korelacioni koeficijent (r)	Statistička značajnost (p)
Frekvencija koraka (8 km/h)	-0.625**	**0.002**	-0.218	0.329	0.044	0.845
Frekvencija koraka (10 km/h)	-0.590**	**0.004**	-0.164	0.465	0.075	0.740
Frekvencija koraka (12 km/h)	-0.659**	**0.001**	-0.255	0.252	0.021	0.926
Frekvencija koraka (14 km/h)	-0.602**	**0.003**	-0.208	0.352	0.047	0.837
Dužina koraka (8 km/h)	0.458**	**0.032**	0.048	0.831	-0.143	0.526
Dužina koraka (10 km/h)	0.175	0.437	0.116	0.607	0.051	0.822
Dužina koraka (12 km/h)	0.376	0.084	0.171	0.448	0.000	1.000
Dužina koraka (14 km/h)	0.446**	**0.037**	0.200	0.373	0.002	0.991

Tabela 3. *Korelacije između antropometrijskih varijabli i dužine i frekvencije koraka pri četiri brzine trčanja kod žena*

Varijabla	**Visina (cm)**		**Masa (kg)**		**% masti**	
Statistička analiza	Korelacioni koeficijent (r)	Statistička značajnost (p)	Korelacioni koeficijent (r)	Statistička značajnost (p)	Korelacioni koeficijent (r)	Statistička značajnost (p)
Frekvencija koraka (8 km/h)	-0.335	0.223	-0.367	0.178	-0.279	0.314
Frekvencija koraka (10 km/h)	-0.279	0.314	-0.386	0.155	-0.337	0.219
Frekvencija koraka (12 km/h)	-0.434	0.106	-0.377	0.166	-0.210	0.453
Frekvencija koraka (14 km/h)	-0.305	0.268	-0.155	0.580	0.000	0.999
Dužina koraka (8 km/h)	0.460	0.084	0.108	0.703	-0.186	0.508
Dužina koraka (10 km/h)	0.343	0.211	0.182	0.516	0.007	0.979
Dužina koraka (12 km/h)	0.525*	**0.044**	0.231	0.408	-0.067	0.813
Dužina koraka (14 km/h)	0.471	0.076	0.280	0.313	0.033	0.906

DISKUSIJA

Ovo istraživanje imalo je za cilj da proceni razlike u dužini i frekvenciji koraka između muškaraca i žena pri različitim brzinama trčanja. Drugi cilj bio je ispitivanje povezanosti morfoloških karakteristika muškaraca i žena sa dužinom i frekvencijom koraka pri različitim brzinama trčanja. S tim u vezi, postavljene su dve hipoteze. Prva hipoteza da će muškarci pri povećavanju brzine trčanja povećavati dužinu koraka, a žene frekvenciju delimično je potvrđena. Naime, žene su imale veću frekvenciju koraka od muškaraca pri gotovo svim brzinama trčanja, ali u dužini koraka nije bilo razlike između muškaraca i žena. Druga hipoteza da će visina visoko pozitivno korelirati sa dužinom koraka, a negativno i visoko sa frekvencijom koraka i kod muškaraca i kod žena takođe je delimično potvrđena. Kod muškaraca dobijene su visoke i statistički značajne negativne korelacije visine i frekvencije koraka, kao i niske do umerene pozitivne korelacije visine sa dužinom koraka. Sa druge strane, kod žena su dobijene niske do umerene negativne korelacije visine i frekvencije koraka i takođe niske do umerene pozitivne korelacije visine sa dužinom koraka.

Očekivano, i frekvencija koraka i dužina se povećavaju kako se povećava brzina trčanja kao i u ranijim istraživanjima (Hunter et al., 2003; Barnes et al., 2013; Rajkumar, 2020), dok masa i procenat masti veoma nisko koreliraju sa dužinom i frekvencijom koraka kod muškaraca, a nisko i negativno kod žena što se delimično podudara sa tvrdnjama iz prethodnih radova (Šentija et al., 2011; Taylor-Haas et al., 2022).

Na osnovu ovoga postavlja se pitanje na osnovu kojeg parametra muškarci prate rast brzine trčanja. Pretpostavka je da muškarci drastično povećavaju silu kojom deluju na podlogu (sila reakcije podloge) kako bi ispratili uvećanje zadate brzine na tredmil. Kako je već dokazano u mnogobrojnim istraživanjima (Schubert et al. ,2014; Yong et al., 2018; Farina et al., 2021) veći broj koraka u jednom minutu drastično smanjuje silu reakcije podloge koja se javlja pri trčanju što značajno umanjuje rizik od nastakna akutnih povreda donjih ekstremiteta. Ističe se da na razliku ovih vrednosti između polova ne utiču samo navedeni parametri već i drugi poput razlike u mehanici zglobova i celokupnog lokomotornog sistema koja je dokazana u ranijim radovima (Bruening et al., 2020; Rojano et al., 2021).

Na osnovu povezanosti ovih antrompometrijskih mera i ispitanih varijabli možemo zaključiti da visina mnogo više utiče na broj koraka kod muškaraca nego što je to slučaj kod žena. To dodatno ide u prilog pretpostavci da muškarci prate uvećanje brzine trčanja tako što uvećavaju silu kojom deluju na podlogu pri svakom zasebnom koraku. Takođe primećujemo da je kod žena sa uvećanjem mase tela primećen blagi pad u broju koraka što se podudara sa rezultatima prethodnog itraživanja (Luedke et al., 2021).

Ograničenje ovog istraživanja može biti korišćenje nove opreme (senzori i aplikacija), koja zahteva dodatno testiranje i verifikaciju kako bi se usavršila i proširila njena sveobuhvatna primena. Pored toga, time što smo uvideli da se dodatno povećavaju i brzina i frekvencija koraka, može se tvrditi da je sistem dovoljno osetljiv da uoči ove očekivane promene. Osim toga, jedno od ograničenja ove studije je i nedostatak ispitivanja još nekih varijabli koje bi doprinele boljem razumevanju mehanika trčanja kod muškaraca i žena.

ZAKLJUČAK

Dobijeni rezultati govore o značajnom uticaju visine tela na frekvenciju koraka kod muškaraca dok su te vrednosti kod žena nešto manje. Takođe primećuje se umeren do nizak uticaj visine tela na dužinu koraka kod oba pola što predstavlja zanimljivost u odnosu na druge radove koji govore o njihovoj visokoj povezanosti. Frekvencija koraka i dužina koraka jesu rasle kod obe grupe ispitanika, ali je skok frekvencije koraka kod žena drastično veći nego kod muškaraca. Veća frekvencija koraka smanjuje rizik od nastanka povrede jer nema potrebe za drastičnim uvećanjem sile reakcije podloge. Ovo predstavlja odličan prostor za dalja istraživanja koja mogu ispitivati i povezanost sile reakcije podloge sa frekvencijom i dužinom koraka. Moderna tehnologija korišćena u ovom radu bi značajno unapredila trenažni proces svih njenih korisnika dodatnom analizom spomenutih varijabli.

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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

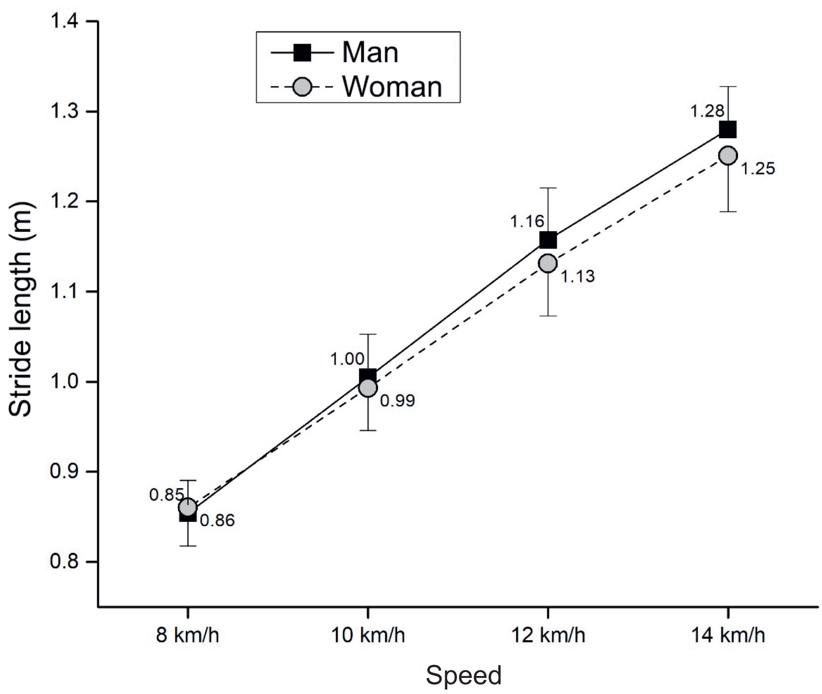
Table 1 shows the age and descriptive indicators of anthropometric characteristics of men and women. Additionally, differences between the displayed variables were examined using the T-test for independent samples.

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		

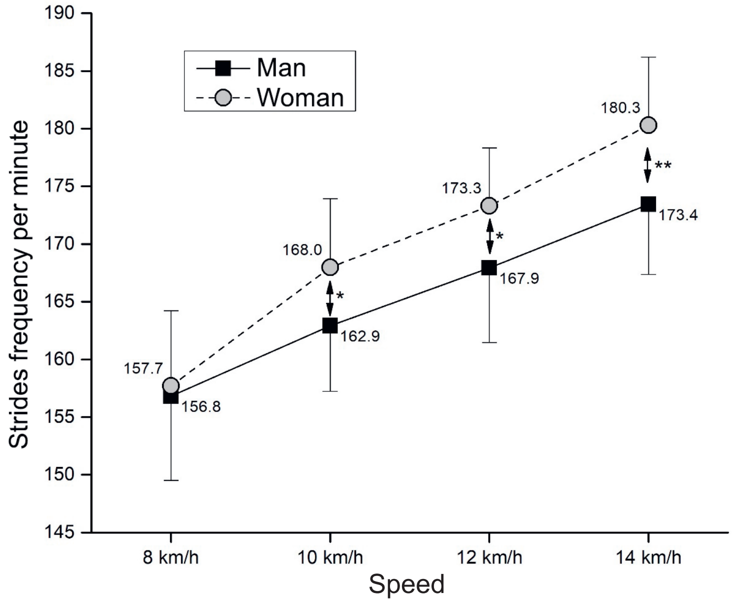
Two-factor ANOVA applied to the stride length variable revealed a significant main effect for running speed [F(3,35) = 1116.1; $\eta^2 = 0.97$; $p < 0.001$], but not for sex effect [F(3,35) = 5.68; $\eta^2 = 0.14$; $p = 0.023$] and the interaction of running speed x sex [F(3,35) = 2.32; $\eta^2 = 0.06$; $p = 0.091$]. 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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