

# Influence of speed and heel-to-toe drop in running shoes for female recreational runners

## A cross-sectional study

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### Abstract

In recent years, the popularity of running has boomed and the number of women runners has risen sharply. However, little research has been conducted into the running cycle as concerns female runners. The aim of this study is to analyse, in women runners, the relationships between spatiotemporal parameters in the running cycle, the heel drop in running shoes and a progressive increase in training speed, when running on a treadmill.

Thirty-eight female runners were recruited from the Malaga University Athletics Club and Nerja Athletics Club. All were at least 18 years old, recreationally active (3–4 running sessions per week) and able to run 5 km in less than 25 min. Their running performance on a treadmill was recorded and spatiotemporal parameters assessed using the OptoGait system.

As the running speed increased (8–12–15 km/h) the spatiotemporal parameters of the running cycle altered: the flight time increased ( $P < .001$ ) and the contact time decreased ( $P = .05$ ). Heel drop (4–12 mm) was not significantly associated with any of the parameters (phase 1:  $P = .198$ ; phase 2:  $P = .191$ ; phase 3:  $P = .242$ ).

A progressive increase in training speed on a treadmill directly influences the spatiotemporal parameters of the running cycle in women runners.

**Abbreviations:** ANOVA = analysis of variance, CEUMA = Ethic Committee of the University of Málaga, CI = confidence intervals, CT = contact time, FT = flight time, MI = Minimalist Index, s = seconds, SD = standard deviation, STJ = subtalar joint, .

**Keywords:** female runners, heel-to-toe drop, running, spatiotemporal parameters, speed

## 1. Introduction

Running is one of the most popular physical activities among adults worldwide, and many cities organise recreational running

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Informed consent: Informed consent was obtained from all participants in the study.

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events.<sup>[1]</sup> Recreational running is becoming increasingly popular; in the UK, more than two million people run every week.<sup>[2]</sup> The demographics of runners have changed, too, and large numbers of female now commonly take part in races. In the USA in 2013, 43% of runners were female in marathons. Half-marathon growth has been even more impressive, increasing from 300,000 finishers in 1990 to almost 2 million in 2013. Greater than 60% of half-marathon participants are female.<sup>[3,4]</sup> Performance in long-distance races has been predicted from the analysis of aspects of anthropometry, training, physiology, and biomechanics.<sup>[5–7]</sup> Although recent studies have proposed equations based on anthropometric and training variables for predicting performance in recreational runners,<sup>[7,8]</sup> none have focused exclusively on female runners. In a recent systematic review, Van der Worp et al reported evidence that the risk profiles of male and female runners are different.<sup>[9]</sup> Because, as a mass phenomenon, women started running later than men, there is a gap in the literature on the running-related injury risk factors for running-related injuries in females.<sup>[10]</sup>

Running technique is affected by many factors. Conoboy<sup>[11]</sup> observed that age and sex modify stride length, flight time (FT) and the duty factor; all of these are of a lower magnitude in older vs younger and in female vs male runners. Female runners have a shorter stride length and therefore a shorter stride time; to put it another way, they have a longer contact time (CT) and a shorter FT. In another study, women's running speed was always lower than that of men of comparable age; hence, differences in running technique might be due to variations in running speed and not directly related to the sex of the runner.<sup>[12]</sup>

The above studies compared male and female runners, but with specific respect to female runners. No analysis has been made of

the relevant parameters or of changes that may influence the running cycle, such as training speed or the type of footwear used.

Footwear and its characteristics can influence a runner's performance. Characteristics such as the weight of the shoe, the elements of the midsole and heel-toe drop have been considered in studies of young athletes.<sup>[13–16]</sup> The running pace is another variable that has been analysed.<sup>[8]</sup>

The aim of this study is to analyse, in female runners, the relationships among spatiotemporal parameters in the running cycle, the heel-to-toe drop in running shoes and a progressive increase in training speed, when running on a treadmill.

## 2. Material and methods

### 2.1. Protocol and registration

This study was carried out in full accordance with the Declaration of Helsinki on ethical principles for medical research involving human subjects, and was approved by the Ethics Committee of the University of Malaga (CEUMA 25/2016-H) Spain.

### 2.2. Design

Cross-sectional study.

### 2.3. Participants

The original study group was composed of 45 female endurance runners, of whom 38 met the criteria for inclusion and were subjected to analysis. All were members of the Malaga University Athletics Club or of Nerja Athletics Club. The study data were obtained from February to June 2017. All subjects were at least 18 years old and were able to follow the study instructions.

The inclusion criteria were: age at least 18 years, recreationally active (3–4 running sessions per week), able to run 5 km in <25 min. The exclusion criteria were:

1. degenerative bone and joint disease (diagnosed from medical history);
2. lower limb surgery;
3. recent knee-ankle injuries or serious foot injury that could have left morphological alterations;
4. obvious leg length discrepancy;
5. loss of balance as measured with Romberg's test;
6. painful cutaneous conditions such as callus or plantar warts.

After receiving detailed information on the objectives and procedures of the study, each subject signed an informed consent form to participate.

### 2.4. Procedures

Before starting the tests, the women performed 10 min of low-intensity running and 5 min of general exercise. Following the protocol reported by Fredericks et al, the subjects ran on a treadmill at three different running speeds, using two types of running shoes<sup>[17]</sup> (the selection of these parameters was randomised by software, for the six measurements to be obtained [three speeds for two types of shoe]). Each session lasted for 30 s (20 s for acclimatisation and 10 s for data recording). In the subsequent analyses, running speeds of 8, 12, and 15 km/h were defined as low, moderate, and high intensity. The running shoes used were chosen by reference to the minimalist index (MI) (20–40%). The MI is composed of 5 shoe features: weight, stack

height, heel to toe drop, motion control and stability technologies, and flexibility. The more minimalist, the higher the score. All shoes can be rated on the scale, whether they are minimalist or cushioned.<sup>[18,19]</sup>

The running shoes used were Brooks Pure Cadence 6 (characteristics: heel-to-toe drop 4 mm, weight 234 g and surface system BioMoGo DNA) and Brooks Ghost 10 (characteristics: heel-to-toe drop 12 mm, weight 258 g and surface system BioMoGo DNA).

Spatiotemporal parameters were measured with OptoGait. This is an optical detection system that incorporates two parallel bars, composed of a transmitter and a receptor slat (with 96 LEDs). The LEDs on the transmitting bar communicate continuously with those on the receptor. Optical sensors, operating at a frequency of 1000 Hz and with an accuracy of 1 cm, detect the spatiotemporal parameters related to running and other types of movement.<sup>[20]</sup> The software used was OptoGait version v. 1.11.1.0. For this study, the two parallel bars were placed on the side edges of the treadmill, level with the contact surface. Two of the researchers (PSC and ELR) controlled the system software and collected the study data, including runners' height and weight. Taking into account the findings reported previously by Brown et al, limb dominance was not taken into account. Therefore, the left-right results were averaged.<sup>[21]</sup>

The OptoGait system has been validated previously for the assessment of spatiotemporal gait parameters in young adults.<sup>[22]</sup> It is capable of detecting interruptions, and measures CT and FT with a precision of 1/1000 s. CT is measured in seconds as the time from when the foot contacts the ground until the moment the toes lift off the ground; FT is the number of seconds from toe-off to initial ground contact of consecutive footfalls (i.e., right-left). We also determined the percentage of ground CT at which the different sub-phases of stance occurred (according to the LEDs activated). This parameter was measured automatically for every step during the treadmill test by the Optogait system, as follows. Initial contact (Phase 1): time from initial ground contact (when one LED is activated) to foot flat (when the number of LEDs activated remains steady  $\pm 2$  LEDs). Midstance (Phase 2): time from foot flat to initial take-off. During this phase, the number of LEDs remains steady  $\pm 1$  LEDs. The phase ends when the heel comes off the ground and the number of LEDs decreases to 2. Propulsion (Phase 3): time from initial take-off (the number of LEDs decreases to 2) to toe-off (when the forefoot leaves the ground and the number of LEDs decreases to 0).

### 2.5. Sample size

The sample size required was determined by the EPIDAT program,<sup>[23]</sup> using a post hoc pilot sample to evaluate the statistical power, and taking as the primary outcome CT and FT measured by OptoGait.<sup>[22]</sup> The study was designed to detect changes exceeding 0.8 (high effect size) for a variation of the sample according to the above classification, with a type I error of 0.05 and a type II error of 0.2. This calculation produced a necessary sample size of 32 subjects, although in fact 38 were included in the final sample analysed.

### 2.6. Statistical analysis

The data were analysed using SPSS 25.0 computer software (SPSS Science, Chicago, IL). Levene's test and the Shapiro–Wilk

**Table 1**  
Spatiotemporal parameters according to heel drop.

n=38	Drop (mm)	Mean	SD	P Value
Flight time (s)	4	0.49	0.50	.617
	12	0.25	0.32	
Contact time (s)	4	0.45	0.38	.495
	12	0.31	0.14	
Initial contact (phase 1) (%)	4	9.51	3.15	.198
	12	10.62	4.47	
Midstance (phase 2) (%)	4	54.31	5.43	.191
	12	55.71	4.94	
Propulsive (phase 3) (%)	4	35.71	6.81	.242
	12	33.56	6.46	

s=seconds, SD=standard deviation.

test were performed to assess the variance and normality, respectively, of the distribution.

The independent variables in this study were the running speed (8, 12, and 15 km/h) and the heel-to-toe drop of the running shoes used (4 and 12 mm). The dependent variables (CT, FT, and the stance sub-phases) were compared using a repeated measures analysis of variance (ANOVA) together with the Games-Howell post-hoc test, to determine the differences arising from variations in running speed and type of shoe. The descriptive statistics obtained are represented as the mean and the SD. The level of statistical significance was set at  $P < .05$ . The interactions between running speed (8, 12, and 15 km/h), heel-to-toe drop and the dependent variables were analysed by the Bonferroni test.

**3. Results**

The following mean characteristics were recorded for the 38 participants: age  $22.7 \pm 2.5$  years; height:  $163 \pm 6.5$  cm; body mass:  $57.9 \pm 8.03$  kg.

The biomechanical data obtained showed that FT and CT were positively associated with heel-to-toe drop (4 and 12 mm), although the difference was not statistically significant ( $P = .617$  and  $P = .495$ , respectively) (Table 1).

There was no statistically significant association between heel-to-toe drop and the stance sub-phases (phases 1, 2, and 3,  $P = .198$ ,  $P = .191$ ,  $P = .242$ , respectively).

Running speed was positively associated with FT ( $P < .001$ ) and inversely associated with CT ( $P = .05$ ). The same pattern was observed for each of the phases, and was statistically significant. Thus,  $P = .04$ ,  $P < .001$ , and  $P < .001$  for phases 1, 2, and 3, respectively (Table 2).

As shown in Table 3 and Fig. 1, the greatest differences were observed for the speed change from 8 to 15 km/h. The difference was statistically significant in the flight phase (Diff.=0.19,  $P < .001$  and Diff.=0.24  $P < .001$ ).

Moreover, the difference in the means was significant in the contact phase and in the propulsive phase, for changes of speed from 8 to 15 km/h (25.93%,  $P > .001$  and 11.65%,  $P > .001$ , respectively) and from 12 to 15 km/h (25.38%,  $P > .001$  and 11.14%,  $P > .001$ , respectively) (Table 3).

Table 4 shows the interaction observed between speed and heel-to-toe drop. The degree of contact decreases with greater speed, and the relation is statistically significant ( $P = .05$ ) in the midstance (phase 2) with a heel-to-toe drop of 12 mm.

**Table 2**  
Spatiotemporal parameters according to speed.

n=38	Speed, km/h	Mean	SD	P Value
Flight time(s)	8	0.06	0.02	<.001
	12	0.25	0.32	
	15	0.30	0.31	
Contact time(s)	8	0.31	0.02	.051
	12	0.31	0.14	
	15	0.42	0.33	
Initial contact (phase 1) (%)	8	10.62	3.39	.041
	12	10.62	4.47	
	15	8.10	5.29	
Midstance (phase 2) (%)	8	56.32	3.93	<.001
	12	55.71	4.94	
	15	30.38	23.66	
Propulsive (phase 3) (%)	8	33.05	3.93	<.001
	12	33.56	6.46	
	15	44.70	12.62	

s=seconds, SD=standard deviation.

**4. Discussion**

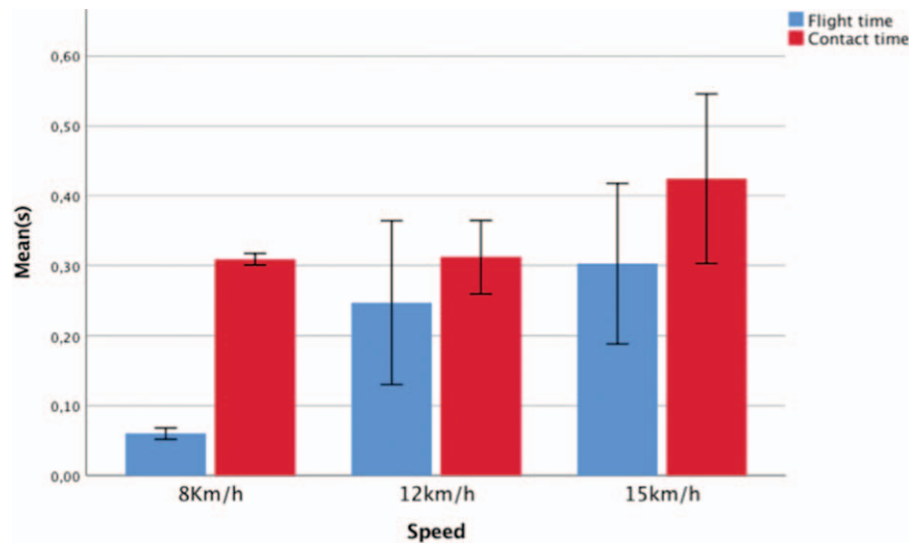
The aim of this study was to analyse, in female runners, the relationships among spatiotemporal parameters in the running cycle, heel-to-toe drop in running shoes and a progressive increase in training speed, when running on a treadmill.

The results obtained show that a progressive increase in training speed (8–15 km/h) directly influences the phases of the running cycle (Initial Contact: Phase 1, Propulsive: Phase 3). Greater running speed is associated with reduced support time in Phase 1, and hence greater FT. The duration of Phases 2 and 3, as well as FT, increased with training speed. Esculier et al<sup>[18]</sup> observed a relation between heel-to-toe drop and stride length, and concluded that changes in running mechanics are associated with shoes with a greater level of minimalism. However, this study used shoes with several MI (20–40% and 40–60%). The moderate correlations obtained suggest that lower shoe mass is indicative of a greater step rate ( $r = 0.531$ ,  $P < .001$ ). In our own

**Table 3**  
Difference of mean speeds in relation to the spatiotemporal parameters.

n=38	Speed, km/h	Speed, km/h	Diff. means	P Value	95%CI	
Flight time (s)	8	12	-0.19*	<.001	-0.33	-0.05
		15	-0.24*	<.001	-0.38	-0.10
	12	15	-0.05	.768	-0.25	0.14
Contact time (s)	8	12	-0.003	.99	-0.07	0.06
		15	-0.11	.146	-0.26	0.03
	12	15	-0.11	.207	-0.27	0.04
Initial contact (phase1) (%)	8	12	0.01	1	-2.42	2.43
		15	2.52	.074	-0.2	5.24
	12	15	2.52	.115	-0.47	5.51
Midstance (phase 2) (%)	8	12	0.55	.875	-2.17	3.28
		15	25.93*	<.001	15.35	36.53
	12	15	25.38*	<.001	14.72	36.04
Propulsive (phase 3) (%)	8	12	-0.50	.926	-3.788	2.77
		15	-11.65*	<.001	-17.46	-5.85
	12	12	-11.14*	<.001	-17.31	-4.97

CI=confidence interval, Diff=differences, s=seconds, SD=standard deviation.  
\* $P < .05$ .



**Figure 1.** Differences in contact time and flight time with a speed change from 8 to 15 km/h.

study, two different types of shoe were used, with the same MI (20–40%) and shoe mass (234 and 258 g) but different heel-to-toe drops (4 and 12 mm).

Our findings corroborate those of Babic et al<sup>[24]</sup> and Debaere et al,<sup>[25]</sup> that as the speed of movement increases, so does the

range of movement in the lower limbs. In consequence, the duration of the support phase is reduced and that of the flight phase is extended.<sup>[26]</sup> However, the above-cited studies focused on a specific type of running—sprinting—and the participants were mostly male, although similar in age to the participants in our study. It is confirmed, therefore, that stride length (phases 2 and 3) increases with speed. This parameter is very important in our analysis of the running cycle, because as the length of the foot strike becomes more distant from the centre of gravity and hence the reaction force of the ground towards the hips and knees increases, the supported load intensifies, provoking a deterioration in the running technique<sup>[27]</sup> and heightening the risk of injury.<sup>[9]</sup> These authors, too, observed an increase in stride length in phases 2 and 3, for similar-aged runners, although their study was conducted in a different context and spatiotemporal parameters in the running cycle were not specifically analysed.

The results obtained in the present study did not reflect any direct relationship among heel-to-toe drop and the spatiotemporal parameters considered. Slightly higher values were observed for the 12 mm drop than for the 4 mm drop, but neither was significantly associated with the parameters of the running cycle ( $P=.198$ ,  $P=.191$ , and  $P=.242$  for phases 1, 2, and 3, respectively). Our findings differ from those reported by Squadrone et al and by Barbado et al<sup>[28,29]</sup> who concluded that running in a minimalist way, with a drop of 4 mm or less, decreases impact peaks and CT, and therefore reduces the mechanical stress produced during successive foot contacts with the ground. This outcome was not observed in our study. In this respect, too, Fredericks et al<sup>[17]</sup> observed biomechanical changes in the foot when the heel-to-toe drop was modified.

Our study also showed that the percentage of contact, with a heel-to-toe drop of 12 mm, varies significantly with speed. This change may be more strongly related to the greater speed than to the change in drop height, as previously suggested by Malisoux et al.<sup>[30]</sup>

In most of the studies cited, the runners' gender was not specified. Only Navalta et al<sup>[12]</sup> distinguished between male and female athletes in their analysis of differences in running speed among half-marathon runners. In view of these considerations, we believe that further research considering running speed and biomechanical parameters is necessary.

**Table 4**  
Interaction observed between speed and heel-to-toe drop.

	Drop, mm	Speed, km/h	Mean	SD	P-Value
Flight time (s)	4	8	0.08	0.04	.607
		12	0.49	0.50	
		15	0.32	0.24	
	12	8	0.06	0.02	
		12	0.25	0.32	
		15	0.30	0.31	
Contact time (s)	4	8	0.28	0.06	.05
		12	0.45	0.38	
		15	0.32	0.31	
	12	8	0.31	0.02	
		12	0.31	0.14	
		15	0.42	0.33	
Initial contact (phase 1) (%)	4	8	10.07	3.84	.063
		12	9.51	3.15	
		15	7.51	4.41	
	12	8	10.62	3.39	
		12	10.62	4.47	
		15	8.10	5.29	
Midstance (phase 2) (%)	4	8	53.63	5.85	.05
		12	54.31	5.43	
		15	28.25	22.58	
	12	8	56.32	3.93	
		12	55.71	4.94	
		15	30.38	23.66	
Propulsive (phase 3) (%)	4	8	36.43	7.32	.103
		12	35.71	6.81	
		15	45.59	10.52	
	12	8	33.05	3.93	
		12	33.56	6.46	
		15	44.70	12.62	

s = seconds, SD = standard deviation.

An important strength of the present study is its focus on female runners, since very little prior research has been undertaken regarding female runners in particular, with an appropriate age range and considering spatiotemporal parameters.

Our study also has certain limitations. First, the sample size was relatively small, and so the data cannot properly be extrapolated to a larger population (risk of selection bias). Moreover, the decision to study only female runners, aged at least 18 years and who ran regularly (at least three times per week) complicated the selection of participants and heightened the risk of population bias.

Another limitation is that running characteristics on a treadmill are not necessarily the same as when running outdoors. Furthermore, the height of heel-to-toe drop used may have influenced the results, since most of the runners in our study had never used shoes with a heel-to-toe drop of 4 mm, and due to the lack of time for full adaptation, they may have felt uncomfortable.

As an interesting area for future research, we intend to conduct a prospective study with a more representative sample of female runners, and to include outcomes such as detailed anthropometric measurements and validated tests including the FPI or the navicular drop test, which can provide additional information on the structural changes to the foot, using the same study variables. Furthermore, a future study might consider the interaction among sex, age, and the type of sport practised, since at present it is unclear whether aging decreases the range of movement in the lower limbs.

## 5. Conclusions

Our study results show that a progressive increase in training speed modifies the spatiotemporal parameters of the running cycle in female runners (phases 2 and 3 increase, while phase 1 decreases significantly), when running on a treadmill. On the other hand, heel-to-toe drop (4 and 12 mm) does not directly affect these parameters.

## Author contributions

**Conceptualization:** Gabriel Gijon-Nogueron, Ana Belen Ortega-Avila.

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**Formal analysis:** Gabriel Gijon-Nogueron, Eva Lopezosa-Reca, David Cabello-Manrique, Ana Belen Ortega-Avila.

**Investigation:** Gabriel Gijon-Nogueron.

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**Writing – original draft:** Gabriel Gijon-Nogueron, Ana Belen Ortega-Avila.

**Writing – review & editing:** Gabriel Gijon-Nogueron, Francisco Jose Soler-Crespo, Eva Lopezosa-Reca, Raquel Sanchez-Rodriguez, David Cabello-Manrique, Ana Belen Ortega-Avila.

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