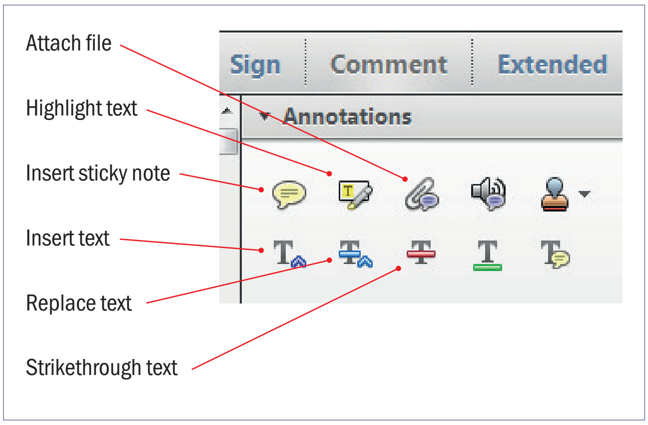
Making corrections to your proof

Please follow these instructions to mark changes or add notes to your proof. You can use Adobe Acrobat Reader (download the most recent version from **https://get.adobe.com**) or an open source PDF annotator.

For Adobe Reader, the tools you need to use are contained in **Annotations** in the **Comment** toolbar. You can also right-click on the text for several options. The most useful tools have been highlighted here. If you cannot make the desired change with the tools, please insert a sticky note describing the correction.

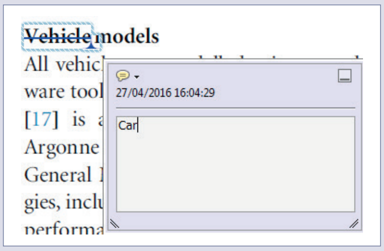
Please ensure all changes are visible via the 'Comments List' in the annotated PDF so that your corrections are not missed.



Do not attempt to directly edit the PDF file as changes will not be visible.

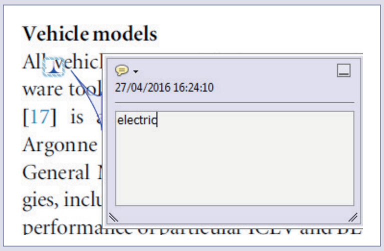
Replacing text

To replace text, highlight what you want to change then press the replace text icon, or right-click and press 'Add Note to Replace Text', then insert your text in the pop up box. Highlight the text and right click to style in bold, italic, superscript or subscript.



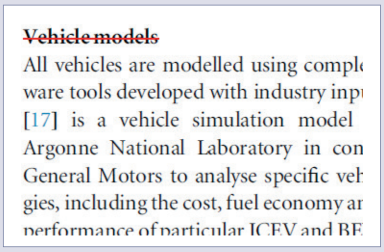
Inserting text

Place your cursor where you want to insert text, then press the insert text icon, or right-click and press 'Insert Text at Cursor', then insert your text in the pop up box. Highlight the text and right click to style in bold, italic, superscript or subscript.



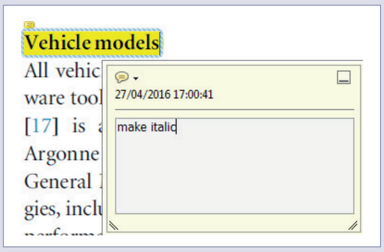
Deleting text

To delete text, highlight what you want to remove then press the strikethrough icon, or right-click and press 'Strikethrough Text'.



Highlighting text

To highlight text, with the cursor highlight the selected text then press the highlight text icon, or right-click and press 'Highlight text'. If you double click on this highlighted text you can add a comment.



QUERIES

Page 1
AQ1
Your article has been processed in line with the journal style. Your changes will be reviewed by the Production Editor, and any amendments that do not comply with journal style or grammatical correctness will not be applied and will not appear in the published article.
AQ2
Please provide the city name for affiliation [2].
AQ3
Please check that the **names of all authors as displayed in the proof are correct**, and that all **authors are linked to the correct affiliations**. Please also confirm that the correct corresponding author has been indicated. **Note that this is your last opportunity to review and amend this information before your article is published**.
AQ4
Articles for this journal should include the headings 'Objective', 'Approach', 'Main results', 'Significance' in the abstract; please indicate where these should be inserted.
Page 9
AQ5
Please check that the funding information below is correct for inclusion in the article metadata. Secretaríde Estado de InvestigacióDesarrollo e Innovacióhttp://dx.doi.org/10.13039/501100007136: DEP2013-48420-P; Ministerio de Ciencia, Innovació Universidades: FPU.
AQ6
If an explicit acknowledgment of funding is required, please ensure that it is indicated in your article. If you already have an Acknowledgments section, please check that the information there is complete and correct.
AQ7
We have been provided with ORCID iDs for the authors as below. Please confirm whether the numbers are correct. M Gil-Calvo 0000-0003-4792-1782, J I Priego Quesada 0000-0002-0375-1454, P Pérez-Soriano 0000-0002-9825-3801.
Page 10
AQ8
Only permanent or persistent web links should be used in reference lists. Examples of acceptable links include: Digital Object Identifier (DOI), PubMed identifier (PMID), PubMed Central reference number (PMCID), SAO/NASA Astrophysics Data System (ADS) Bibliographic Code, and arXiv e-print number. Please review your web links and provide updates as required.
AQ9
Please check the details for any journal references that do not have a link as they may contain some incorrect information. If any journal references do not have a link, please update with correct details and supply a Crossref DOI if available.
AQ10
Please provide the volume in Burns *et al* (2007).
AQ11
Please provide the institution in ISO 18434-1 (2008).
AQ12
Please update the publication details if appropriate in Priego Quesada *et al* (2015).
Page 11
AQ13
Please provide the volume and page/article number details in Marins *et al* (2014), Staffa *et al* (2016) and Trecroci *et al* (2018).
AQ14
Please provide the page/article number details in van Melick *et al* (2017).

IOP Publishing Physiol. Meas. 00 (2019) 000000 (11pp) UNCORRECTED PROOF

Physiological Measurement

IPEM Institute of Physics and Engineering in Medicine

CrossMark

RECEIVED
5 October 2018

REVISED
12 April 2019

ACCEPTED FOR PUBLICATION
25 April 2019

PUBLISHED AQ2

PAPER

Effects of prefabricated and custom-made foot orthoses on skin temperature of the foot soles after running AQ1

M Gil-Calvo[1], J I Priego Quesada[1,2], I Jimenez-Perez[1,2], A Lucas-Cuevas[1] and P Pérez-Soriano[1] AQ3

[1] Department of Physical Education, GIBD, University of Valencia, Valencia, Spain

[2] Department of Physiology, GIFIME, University of Valencia, Spain

E-mail: m.gil.gibd@gmail.com

Keywords: insoles, infrared thermography, intense run, foot, sport

Abstract

AQ4 Foot orthoses are increasingly used by runners despite the controversy about whether its use can reduce the risk of overuse injuries. Some authors have found modifications in plantar pressures with the use of foot orthoses, which could produce changes in surface skin temperature of the foot soles. The aim of the study was to analyse the effects of custom-made and prefabricated foot orthoses on skin temperature of different regions of both foot soles after running. Twenty-four participants carried out a maximal aerobic speed test as a pre-test, and three running tests at the laboratory wearing different foot orthoses conditions (control, prefabricated and custom-made) previously randomized. Skin temperature of four regions of interest of the foot soles was assessed before, immediately after and ten minutes after running. The use of prefabricated and custom-made foot orthoses did not produce changes on skin temperature of the foot soles neither in absolute temperatures ($p > 0.05$), nor in temperature variations: between immediately after and before running ($p > 0.05$), and between ten minutes after and immediately after running ($p > 0.05$). Otherwise, there were found higher values with no insoles than with prefabricated foot orthoses, 10 min after running in relation to before running, in forefoot [Mean (standard deviation): 5.6 (2.4) versus 3.7 (2.7) °C; $p = 0.02$; Effect Size (ESd) = 0.72], midfoot [3.7 (1.5) versus 2.7 (1.5) °C; $p = 0.03$; ESd = 0.65] and rearfoot [4.18 (2.05) versus 2.9 (1.82) °C; $p = 0.02$; ESd = 0.64)]. In conclusion, the use of foot orthoses, in general, do not affect the surface skin temperature of the foot soles after an intense run.

1. Introduction

Running is one of the most practised physical activities because of the physical, social and mental benefits (Saragiotto *et al* 2014) and its low cost and ease of implementation (Ooms *et al* 2013, Hespanhol Junior *et al* 2015). However, there is a high frequency of lower limb overuse injuries associated to this activity (van Gent *et al* 2007, Ferber *et al* 2009, Fields *et al* 2010, Daoud *et al* 2012), between 19% and 79% depending on injury definition, study population and follow-up periods (Hoeberigs 1992). This kind of injury occurs when forces, below the detrimental acute threshold, are applied to a biological structure (bones, tendons or muscles) in a repetitive manner (van der Worp *et al* 2015). Overuse injuries aetiology is diverse and multifactorial (Saragiotto *et al* 2014) but it has been determined some risk factors that affect injury incidence. These factors are classified as intrinsic or non-modifiable (such as age, sex, previous injuries, the range of movement, muscular weakness and foot type) and/or extrinsic or modifiable (such as running technique, training errors, training surface and footwear) (Taunton *et al* 2002, Chang *et al* 2012). Therefore, in order to reduce injury risk, some prevention systems and ergonomic aids have been developed, such as improving running technique, improving flexibility or the use of foot orthoses (Johnston *et al* 2003, Fields *et al* 2010, Chang *et al* 2012, Murphy *et al* 2013).

Foot orthoses are defined as a tool that facilitates, stabilizes or improves the range of motion and functional capacity of the ankle and foot areas (Hirschmüller *et al* 2011). Foot orthoses can be classified according to various criteria: stiffness, adaptation, objective and manufacturing method, within which it can find prefabricated,

JNL:PMEA PIPS: AB1C8C TYPE: SPE TS: NEWGEN DATE:6/5/19 EDITOR: IOP SPELLING: UK

customised and custom-made foot orthoses (Burns *et al* 2007, Crabtree *et al* 2009). Although there has been a high increment in the use of insoles during running, there is still controversy about whether their use can reduce the risk of overuse injuries and may influence in biomechanic parameters in runners (Hume *et al* 2008, Fields *et al* 2010). In this sense, some authors found changes in plantar pressure in some regions by using prefabricated and custom-made foot orthoses (Burns *et al* 2006, Mickle *et al* 2011, Lucas-Cuevas *et al* 2014). In a previous study performed in our research group (Lucas-Cuevas *et al* 2014), it were found reductions in plantar loadings in different areas, such as hallux, toes, midfoot and heel, using prefabricated and custom made foot orthoses compared to not wearing foot orthoses.

Yavuz *et al* (2014) observed a positive correlation between triaxial contact loads and skin temperature during the gait. So, it is possible to hypothesize that the increment or reduction of plantar pressure and friction in different foot regions might influence skin temperature of foot soles. In this sense, infrared thermography (IRT) might be a useful tool to asses if the use of foot orthoses induces changes in skin temperature.

Therefore, the aim of this study was to analyse the effects of custom-made and prefabricated foot orthoses on skin temperature of different regions of both foot soles after running. We hypothesize that the use of foot orthoses will produce lower increments of the skin temperature of the foot soles after running, specially with custom-made foot orthoses in the forefoot and rearfoot regions.

2. Methods

2.1. Participants

Twenty four volunteer recreational runners, 18 males and six females, participated in this study with the following characteristics expressed as mean (standard deviation): age 35 (5) years, body mass 71.4 (12.5) kg, height 1.75 (0.07) m, training volume 37.5 (12.8) km/week, maximal aerobic speed (MAS) 4.36 (0.51) m s^{-1}. Inclusion criteria included: (1) be able to run 10 km between 40 and 50 min for men, and between 50 and 60 min for women; (2) no history of lower extremity injuries within the last year; (3) no previous use of foot orthoses; and (4) training volume of at least 15 km/week. Seven runners had the left feet, and seventeen the right feet, as preferred according to their response to the question 'If you would shoot a ball on a target, which leg would you use to shoot the ball?' (van Melick *et al* 2017). Participants signed an informed consent before participation. The study procedures complied with the Declaration of Helsinki and were approved by the university's ethics committee (approval number H1427706182089).

2.2. Test conditions and insole customisation

IRT of the foot soles was measured under three different foot orthoses conditions: (1) control condition, using the original training footwear (CFO); (2) prefabricated foot orthoses (Technoped running, Herbitas), that were chosen only according to the runner's foot size, specially design for running and bought in a sport shop (PFO); and (3) custom-made foot orthoses (Podiatech OPCT® Run, Sidas), fabricated by a podiatrist from a 3D representation of the participant's feet, specially design for running (CMFO) (table 1). For the customisation of CMFO participants were asked to stand on a pair of silicon vacuum bags in order to reproduce plantar print of the participant's feet (Printlab2 platform, Podiatech, Voiron, France). A plaster mould was built based on the foot print and the 3D foot orthoses personalised to the athlete's feet were created through a thermo-welding process.

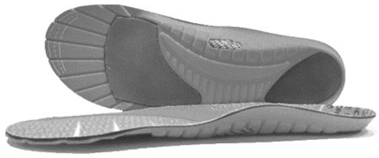
2.3. Protocol

Participants performed a pretest and three laboratory tests on different days, with different foot orthoses conditions randomly assigned (control, prefabricated foot orthoses and custom-made foot orthoses) and after a week of adaptation to each condition. To carry out this adaptation, participants were asked to wear the foot orthoses during the full day for the first two days and, for training, just during the warm-up and the cool down. From the third day, if they did not report discomfort, they wore the foot orthoses during the entire training. In the pretest, they performed a 5 min maximal effort run on a 400 m track to determine their individual maximal aerobic speed (Berthon *et al* 1997, García-Pérez *et al* 2013). The second, third and fourth tests were performed at the laboratory with custom-made insoles, prefabricated insoles and with no insoles (order randomized). In these sessions, participants carried out a running test on a treadmill (Excite Run 700, TechnogymSpA, Gambettola, Italy) with 1% of slope. The runners wore their own running training shoes in every test (Lewinson *et al* 2016). During these tests, participants warmed-up for 10 min at 60% of their MAS and run for 20 min at 80% of their MAS.

2.4. Thermographic measurements and analysis

Skin temperature was measured with an infrared camera (Flir E60bx, Wilsonville, Oregon, USA) with a resolution of 320 × 240 pixels, with noise equivalent temperature difference (NETD) < 0.05 °C, and measurement uncertainty of ±2 °C or 2%. Measurements were performed at laboratory tests in three different moments: (1)

Table 1. Properties of the foot orthoses studied.

Control condition	Prefabricated foot orthoses	Custom-made foot orthoses
		
Runner's training footwear	– *Top layer*: anti-slip fabric Drytech	– *Top layer*: Podiamic 160 micro-perforated polyethylene + ethyl-vinyl acetate (EVA), 2.5 mm thick
	– *Middle and lower layer*: antibacterial AirFoam	– *Forefoot insert*: Synthetic Viscotene®, 2.5 mm thick
	– *Forefoot and rearfoot reinforcement*: polyurethane foam, hardness 15–25°	– *Rearfoot insert*: Podiaflex® 0.9 mm thick
	– *Extra support under medial arch*: Technocarbon, 10 cm long and 3.5 cm high	– *Rearfoot reinforcement*: polyester resin Transflux®, 1.0 mm thick
		– *Sole reinforcement*: Polyester resin Transflux®, 1.0 mm thick

before running, after 10 min of adaptation of the room environment; (2) immediately after running; (3) 10 min after the running test. Prior to the first thermographic measurement, participants remained barefoot, sat down with the legs in a horizontal way in order to achieve a correct adaptation of the feet soles to the room temperature (Gil-Calvo *et al* 2017).

The images were taken from a distance of 1 m and the camera objective was kept parallel to the feet soles. Infrared camera was turned up 10 min before the measurements in order to ensure its electronic stabilization. Air temperature [22.9 (1.3) °C] and relative humidity [44.4 (11.7)%] were controlled using an air conditioning unit and monitored with a weather station (Digital thermos-hygrometer, TFA Dostmann, Wertheim-Reicholzheim, Germany). This data was introduced into the camera set up for every thermographic measurement, as well as reflected temperature, which was measured according to the standard method ISO 18434-1:2008 (ISO 18434-1 2008). Calibration of the camera was checked before the study using a black body (BX-500 IR Infrared Calibrator, CEM, Shenzhen, China). There were no electronic devices, lights or air flow lit in the room, and only the participant and the thermographer were present during the measurement. Moreover, TISEM checklist was used with the aim to corroborate that all-important thermographic aspects of the protocol were taken into account (Moreira *et al* 2017). In this sense, factors that could affect skin temperature were controlled, such as avoiding tobacco, alcohol, medicines, coffee or tea consumption 12 h before the test, avoiding heavy meals 2 h before the test, avoid creams or sprays on the skin surface of the foot soles, and avoid therapeutic treatments on the regions measured within the last 24 h. Participants were also asked to wear the same clothes and socks for each laboratory test and had to come to the laboratory at the same period of time on each test. In addition, the three sessions were carried out on the same day of the week and in the same time slot in order to avoid the effects of the circadian rhythm on surface skin temperature.

Four regions of interest (ROIs) were defined and analysed in both foot soles: (1) Complete foot sole (2) Forefoot (50% of the anterior part of the foot soles); (3) Midfoot (19% of the middle region of the foot soles); (4) Rearfoot (31% of the posterior region of the foot soles) (Priego Quesada *et al* 2015a, Gil-Calvo *et al* 2017) (figure 1). These percentages of the definition of the ROIs were as a proportion of the total feet length (Priego Quesada *et al* 2015a, Gil-Calvo *et al* 2017) and were defined in a copy of the image using the software ImageJ (v.1.52a, National Institutes of Health, Bethesda, Maryland, USA). To ensure the accuracy in the definition of the image, it was worked with two computer screens, in one with the image visualization with the ROIs defined with the ImageJ; in the other screen was reproduced the same areas with the thermography software when absolute mean temperature of each ROI was computed (ThermacamResearcher Pro 2.10 software, FLIR, Wilsonville, Oregon, USA). All this procedure was performed by the same *researcher* to ensure the consistency. All images were processed using an emissivity factor of 0.98 to obtain skin surface temperatures (Steketee 1973). Following temperature variations were calculated (Vargas *et al* 2009): ΔT (difference between the temperature immediately after and before the running test, expressed in °C), ΔT_{10} (difference between the temperature 10 min after and before the running test, expressed in °C), and ΔT_{after} (difference between temperature 10 min after and immediately after the running test, expressed in °C). Finally, absolute values of thermal symmetry (difference between both feet) were calculated.

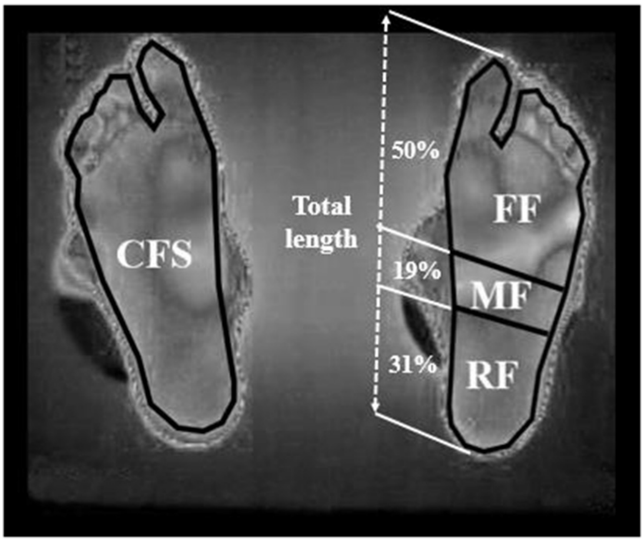


Figure 1. Regions of interest (ROIs) defined: CFS (complete foot sole); FF (forefoot); MF (midfoot) and RF (rearfoot). ROIs were defined as a percentage of the total feet length.

2.5. Statistical analysis

Data were analysed using SPSS Statistics 20.0 (IBM Armonk, New York, USA). Normality was confirmed by the Shapiro-Wilk test ($p > 0.05$) for absolute temperatures and temperature variations, but not for thermal symmetry ($p < 0.05$). Non-parametric Friedman test were performed to assess the differences between foot orthoses conditions in thermal symmetry. Repeated measures ANOVAs were performed to assess the differences between ROIs in absolute temperatures and temperature variations. In complete foot sole analysis two factors (moment and foot orthoses), and in the forefoot, midfoot and rearfoot analysis were used three factors (moment, ROI, foot orthoses). A Bonferroni correction were done in pair comparisons as a post-hoc test, with a significance level $\alpha = 0.05$. Data are expressed as mean (standard deviation (SD)). Moreover, Cohen's *d* effect size (ES*d*) were calculated to classify pair differences as small (ES*d* 0.2–0.5); moderate (ES*d* 0.5–0.8); or large (ES*d* > 0.8) (Cohen 1988).

3. Results

Table 2 presents the comparisons between dominant and non-dominant absolute temperatures and temperature variations of the different ROIs studied. In absolute temperatures were found differences with a small effect size between contralateral ROIs in complete foot soles [31.6 (1.5) °C versus 31.7 (1.5) °C; $p = 0.01$; ES$d = 0.07$] and midfoot [32.0 (1.2) °C versus 32.1 (1.2) °C; $p = 0.03$; ES$d = 0.08$] 10 min after running. These results were not reproduced in temperature variations, where no significant differences between both feet were found in any ROI analysed ($p > 0.05$). Because the effect size was small and was not observed in skin temperature variations, we consider the mean data of both feet in the results. Finally, no differences were observed between foot orthoses on absolute values of thermal symmetry ($p > 0.05$). Values and participants' distribution of thermal symmetry are presented in the table 3.

In absolute temperatures, no significant differences were found between foot orthoses in any of the ROIs analysed at any moment studied ($p > 0.05$) (table 4). The results showed the highest temperatures immediately after running [34.3 (1.1) °C], the lowest before running [27.6 (2.2) °C], and 10 min after running [31.7 (1.5) °C] were lower than immediately after, but higher than before running.

In ΔT and ΔT_{after}, no differences were found between conditions in any region of interest ($p > 0.05$). Nevertheless, in ΔT_{10}, there were found higher values with no insoles than with prefabricated foot orthoses, with a moderate effect size, in forefoot [5.6 (2.4) versus 3.7 (2.7) °C; $p = 0.02$; ES$d = 0.72$], in midfoot [3.7 (1.5) versus 2.7 (1.5) °C; $p = 0.03$; ES$d = 0.65$] and in rearfoot [4.18 (2.05) versus 2.9 (1.82) °C; $p = 0.02$; ES$d = 0.64$)]. However, these results were no reproduced in complete foot soles, where no differences were found between conditions in any temperature variation ($p > 0.05$) (figure 2).

4. Discussion

The objective of the present study was to analyse the effects of custom-made and prefabricated foot orthoses on skin temperature of different regions of both foot soles in running. Thermographic results of the different

Table 2. Comparison (mean (SD)) of the absolute temperatures and the temperature variations between the dominant and non-dominant ROIs of the foot soles.

	Complete foot sole			Forefoot			Midfoot			Rearfoot		
	Dom	Non-Dom		Dom	Non-Dom		Dom	Non-Dom		Dom	Non-Dom	
ROI/pie	Mean (SD)	Mean (SD)	*p* value	Mean (SD)	Mean (SD)	*p* value	Mean (SD)	Mean (SD)	*p* value	Mean (SD)	Mean (SD)	*p* value
Absolute temperatures												
Before running (°C)	27.6 (2.2)	27.7 (2.2)	0.29	27.1 (2.5)	27.2 (2.6)	0.15	29.0 (1.9)	28.9 (1.9)	0.47	27.7 (2.0)	27.7 (2.1)	0.95
Immediately after running (°C)	34.2 (1.1)	34.3 (1.0)	0.19	34.4 (1.1)	34.5 (1.0)	0.37	34.6 (1.1)	34.6 (1.0)	0.61	33.8 (1.2)	33.8 (1.2)	0.37
10 min after running (°C)	31.6 (1.5)	31.7 (1.5)	*0.01	31.8 (1.6)	31.9 (1.7)	0.13	32.0 (1.2)	32.1 (1.2)	*0.03	31.2 (1.6)	31.2 (1.8)	0.78
Temperature variations												
ΔT (°C)	6.7 (2.1)	6.7 (2.1)	0.96	7.3 (2.6)	7.3 (2.6)	0.59	5.6 (1.7)	5.7 (1.7)	0.38	6.1 (2.00)	6.2 (2.0)	0.61
ΔT_{10} (°C)	4.0 (2.1)	4.1 (2.1)	0.7	4.7 (2.6)	4.7 (2.7)	0.79	3.0 (1.8)	3.2 (1.7)	0.3	3.5 (2.0)	3.5 (2.3)	0.83
ΔT_{after} (°C)	−2.6 (1.3)	−2.6 (1.2)	0.75	−2.6 (1.5)	−2.6 (1.5)	0.63	−2.6 (1.1)	−2.5 (1.1)	0.14	−2.6 (1.4)	−2.6 (1.7)	0.78

Table 3. Mean, standard deviation (SD), median and interquartile range (IQR) of Absolute skin temperature symmetry of the total days measurements ($N = 72$) in the four ROIs (complete foot sole, forefoot, midfoot and rearfoot) at the three measurement moments (before, immediately after and 10 min after running).

	Absolute skin temperature symmetry (°C)											
	Before running				Immediately after running				10 min after running			
Parameter	Complete Foot Sole	Forefoot	Midfoot	Rearfoot	Complete Foot Sole	Forefoot	Midfoot	Rearfoot	Complete Foot Sole	Forefoot	Midfoot	Rearfoot
Mean (SD)	0.4 (0.4)	0.5 (0.4)	0.3 (0.3)	0.4 (0.6)	0.3 (0.3)	0.3 (0.3)	0.3 (0.2)	0.3 (0.3)	0.2 (0.2)	0.3 (0.3)	0.2 (0.2)	0.3 (0.3)
Median	0.3	0.4	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
IQR	0.4	0.5	0.4	0.4	0.2	0.3	0.3	0.3	0.2	0.3	0.3	0.3

Table 4. Effects of foot orthoses: control (CFO); prefabricated (PFO); custom-made (CMFO), on absolute temperatures in complete foot sole (CFS), forefoot (FF), midfoot (MF) and rearfoot (RF). No significant differences found ($p > 0.05$).

		CFO	PFO	CMFO	
Moment	Variable/condition (°C)	Mean (SD)	Mean (SD)	Mean (SD)	*p* value
Before running	CFS	27.3 (1.7)	28.1 (2.3)	27.5 (2.4)	$p > 0.05$
	FF	26.4 (1.9)	27.9 (2.8)	27.0 (2.6)	
	MF	28.6 (1.5)	29.2 (1.9)	29.0 (2.2)	
	RF	27.3 (1.7)	28.1 (2.2)	27.6 (2.2)	
Immediately after running	CFS	34.3 (1.1)	34.3 (0.9)	34.2 (1.1)	
	FF	34.5 (1.2)	34.4 (0.8)	34.4 (1.1)	
	MF	34.7 (1.2)	34.5 (0.8)	34.5 (1.2)	
	RF	33.9 (1.2)	33.9 (1.0)	33.7 (1.3)	
10 min after running	CFS	31.8 (1.4)	31.6 (1.3)	31.5 (1.7)	
	FF	32.0 (1.7)	31.7 (1.4)	31.8 (1.8)	
	MF	32.3 (1.1)	31.9 (1.0)	31.9 (1.4)	
	RF	31.5 (1.3)	31.0 (1.4)	31.1 (1.9)	

regions of the foot soles showed that the use of prefabricated and custom-made foot orthoses seems not to change the skin temperature of the foot soles after an intense run. Moreover, results showed higher ΔT_{10} values (skin temperature difference between 10 min after running and before running) in the forefoot, midfoot and rearfoot in control condition than with the use of prefabricated foot orthoses.

The human body is thermally symmetric in basal conditions (at rest), and differences greater than 0.5 °C between dominant and non-dominant sides could imply physiological dysfunctions in the locomotor system (Niu *et al* 2001, Hildebrandt *et al* 2010, Vardasca *et al* 2012, Fernández-Cuevas *et al* 2015). As it has been explained, the participants in this study were healthy runners, without injuries in lower extremities in the last year, which explains that there was thermal symmetry between contralateral regions at rest in most of them (Niu *et al* 2001, Hildebrandt *et al* 2010, Vardasca *et al* 2012, Fernández-Cuevas *et al* 2015). After exercise, no asymmetries of skin temperature between contralateral regions has been found in cyclic sports such as cycling and rowing (Chudecka *et al* 2015, Trecroci *et al* 2018). However, there is a lack of information about the effect of running on skin temperature of contralateral regions, and specifically in foot soles. Looking absolute thermal symmetry values (table 3), percentage of participants that had a asymmetry higher than 0.5 °C was lower than before running. Then, it can be hypothesized that exercise could reduce asymmetry because it can be masked by the thermophysiological mechanisms (e.g. sweating and skin blood flow).

In relation to the effects of foot orthoses, no differences were observed in absolute temperatures among the different conditions (control, prefabricated and custom-made foot orthoses). Likewise, no significant differences were found in ΔT and in ΔT_{after}, among the different conditions studied. These results refuse the initial hypothesis, in which it was proposed that the use of foot orthoses would produce smaller increases in the surface skin temperature of the foot soles, specially with the use of custom-made insoles in forefoot and rearfoot regions. Several studies found changes in plantar pressure redistribution with the use of foot orthoses during running (Burns *et al* 2006, Mickle *et al* 2011, Salles and Gyi 2013, Lucas-Cuevas *et al* 2014). Specifically, Lucas-Cuevas *et al* (2014) found reductions of plantar loadings in hallux, toes, midfoot and heel, using the same foot orthoses as in the present study (both prefabricated and custom-made). Nevertheless, there is a lack of studies that measured the effects of foot orthoses in surface skin temperature of foot soles. Yavuz *et al* (2014) found a relationship between triaxial plantar loads and skin temperature of the foot soles. However, it is important to mention that this relationship was moderate (Yavuz *et al* 2014). In the same line, although Priego Quesada *et al* (2015a) tried to establish the relationship between skin temperature and plantar pressure during running, plantar pressure was measured statically, and dynamic measurements are necessary. In addition, no relationships were observed before and after running between plantar pressure and IRT (Priego Quesada *et al* 2015a). Therefore, more investigation about the relationship between plantar pressure and IRT is needed. Assuming that the use of foot orthosis produced differences in plantar pressure between the conditions of the present study, the results would not support this relationship between both variables. However, it is pure speculation because plantar pressure was not measured in the present study.

Nevertheless, if it is not assumed that the use of foot orthoses could be affected by plantar pressures, the lack of differences within the different conditions could be also explained because of the week of adaptation to each condition prior to the laboratory test, which may have greatly reduced the effects of foot orthoses at kinetic and kinematic levels. In addition, surface skin temperature has a multifactorial dependence (Priego Quesada *et al* 2017), so it is possible that the use of foot orthoses was no large enough to not be neutralized by other factors

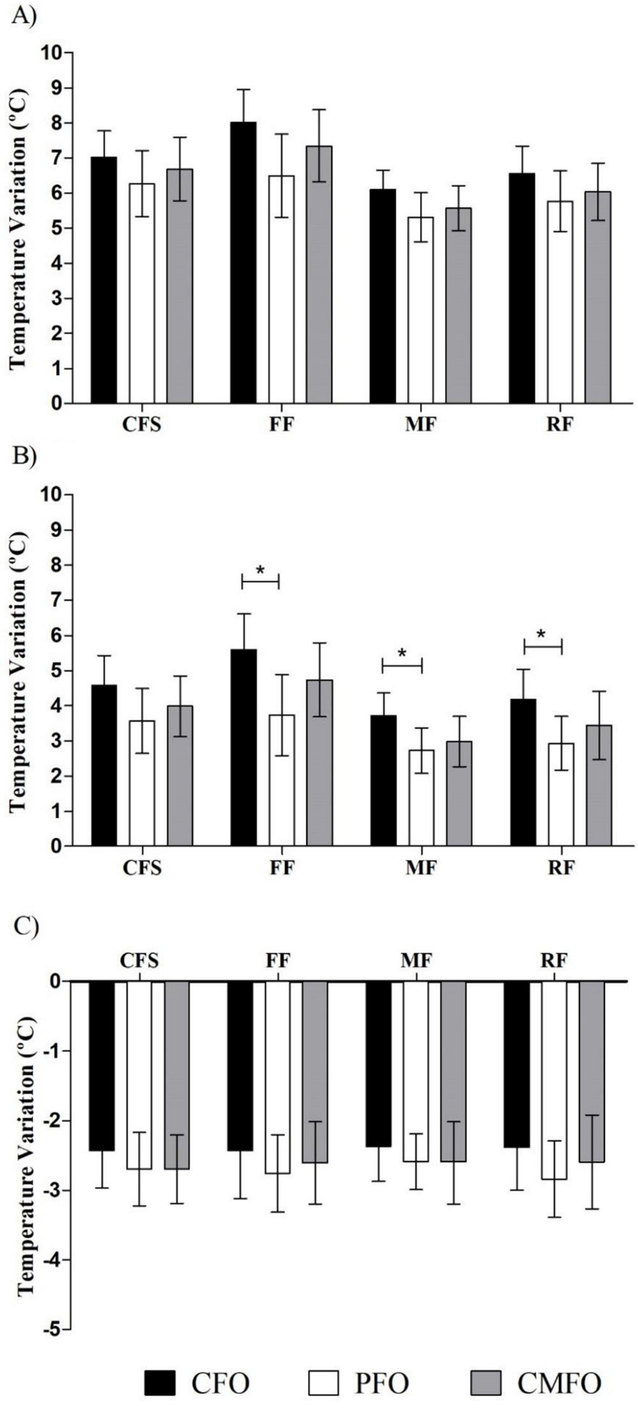


Figure 2. Effects of foot orthoses: control (CFO); prefabricated (PFO); custom-made (CMFO), on temperature variations in complete foot sole (CFS), forefoot (FF), midfoot (MF) and rearfoot (RF). *Significant differences among conditions $p < 0.05$.

such as the mechanical effect of running, the mechanisms of heat dissipation (specially sweat evaporation) or the increase of blood flow, among others.

There was a small rise in temperature, ΔT_{10}, when using prefabricated foot orthoses compared with no insoles, but not in comparison with wearing custom-made foot orthoses or between custom-made and no insoles conditions in forefoot, midfoot and rearfoot. These results were not reproduced in complete foot soles. This difference could be due to a higher initial temperature before running or a lower temperature 10 min after running. However, the lack of differences in absolute skin temperatures among conditions at the different moments makes it difficult to interpret the reason for this difference. If the difference is due to a higher initial temperature, although not significant, it could be the result of chance because, at that measurement moment, the conditions and the protocol were the same for all the tests. This possible chance could be supported by the non-reproduction of the results in the other temperature variations studied, and because of the great variability and low reproducibility of feet skin temperature (Zaproudina et al 2008, Gil-Calvo et al 2017). If the difference was due to a lower temperature of 10 min after running, other interpretations could be performed. Firstly, these small rise with prefabricated foot orthoses could be explained by the composition of the prefabricated foot orthoses materials, which could produce better breathability of the foot soles in comparison to training footwear and custom-made foot orthoses materials. In addition, the first layer of the foot orthoses was no controlled and, the prefabricated one, could generate less friction, and even being less thick, allowing greater freedom of the foot inside the shoe. In this way, it could favour the increase of blood flow in the feet and, also, the heat dissipation mechanisms. However, it is also possible to interpret that sweat was accumulated in the prefabricated foot orthosis due to lower breathability of the materials, and when footwear was taken off, skin temperature decreased more quickly due to the greater evaporation of the moisture generated (Priego Quesada *et al* 2015b, Shimazaki and Murata 2015, West *et al* 2019). These explanations should be addressed by future studies.

In relation with thermal behaviour, as we can see in the results, foot soles temperature was similar at the beginning of each condition, which might show that 10 min sit down with legs extended of thermal adaptation to laboratory conditions, is enough to achieve a good adaptation of the foot soles (Marins *et al* 2014, Priego Quesada *et al* 2015a, Sillero-Quintana *et al* 2015, Staffa *et al* 2016). It can also be seen that immediately after running, foot soles temperature is higher in every condition. This increments of temperature (greater than 10 °C in some cases), could be explained by different reasons. First of all, aerobic physical activity could produce peripheral vasodilation with the aim to dissipate core temperature, which leads to an increase of skin temperature (Kenney and Johnson 1992, Merla *et al* 2010, Charkoudian 2010). This fact is also linked to the mechanical effect of the race on the foot soles, and also, the environment generated inside the footwear, which are factors that, in general, increase the temperature of the feet (Shimazaki and Murata 2015, West *et al* 2019). Finally, 10 min after running, feet soles temperature is lower than immediately after running but higher than at the beginning. So, 10 min seems not to be enough to recover basal temperature of the foot soles after running 30 min, and this fact should be taken into account in further research.

The main limitations of the study were the speculative explanation of the results, since the moisture vapour transmitted by the different materials of the foot orthoses and footwear and plantar pressure of the foot soles were not measured. In addition, this technique does not allow to measure thermal behaviour of the foot soles in real time, which could give extra information about the skin temperature during running. Further research should measure the effects of foot orthoses in populations with pathologies on the foot soles. Some considerations were taken into account in order to improve the consistency of the ROIs analysis (e.g. all analysis were performed by the same researcher or the use of an image software to define the length proportion of each ROI). However, it is important to consider that it is unknown the intra-operator or inter-operator reproducibility in the ROIs defined, which should be considered to analyse by future work. Moreover, a large number of ROIs should be measured in order to have more specific information from areas with special thermal behaviour, such as Hallux or toes. Finally, it would be interesting to measure plantar pressures during running in the same sample and correlate the results in order to avoid speculation in the interpretation of the results.

5. Conclusions

In conclusion, the use of foot orthoses, in general, do not affect the surface skin temperature of the foot soles after an intense run. Although not using foot orthoses produces a higher increment of foot soles temperature 10 min after running, in relation with before running, than wearing prefabricated foot soles, it is necessary future research to know if this result is reproducible and not a result of a chance.

AQ5
Acknowledgments

This research has been supported by the Spanish Government: 'Ministerio de Economía y Competitividad, Subdirección General de Proyectos de Investigación, Convocatoria de Poryectos I + D "Excelencia", Subprograma de Generación de Conocimiento (2013)'. Project reference: DEP2013-48420-P.

AQ6 Ms Irene Jimenez Perez's work has been funded with a doctoral fellowship (FPU) received from the Spanish Ministry of Science, Innovation and Universities.

Conflicts of interest

The authors declare that there are no conflicts of interest concerning the content of this paper.

AQ7
ORCID iDs

M Gil-Calvo https://orcid.org/0000-0003-4792-1782
J I Priego Quesada https://orcid.org/0000-0002-0375-1454
P Pérez-Soriano https://orcid.org/0000-0002-9825-3801

AQ8
References

AQ9 Berthon P, Dabonneville M, Fellmann N, Bedu M and Chamoux A 1997 Maximal aerobic velocity measured by the 5 min running field test on two different fitness level groups *Arch. Physiol. Biochem.* **105** 633–9

Burns J, Crosbie J, Ouvrier R and Hunt A 2006 Effective orthotic therapy for the painful cavus foot *J. Am. Pediatr. Med. Assoc.* **96** 205–11

Burns J, Landorf K B, Ryan M M, Crosbie J and Ouvrier R A 2007 Interventions for the prevention and treatment of pes cavus *Cochrane*
AQ10 *Database Syst. Rev.* CD006154

Chang W-L, Shih Y-F and Chen W-Y 2012 Running injuries and associated factors in participants of ING Taipei Marathon *Phys. Ther. Sport* **13** 170–4

Charkoudian N 2010 Mechanisms and modifiers of reflex induced cutaneous vasodilation and vasoconstriction in humans *J. Appl. Physiol.* **109** 1221–8

Chudecka M, Lubkowska A, Leźnicka K and Krupecki K 2015 The use of thermal imaging in the evaluation of the symmetry of muscle activity in various types of exercises (symmetrical and asymmetrical) *J. Hum. Kinet.* **49** 141–7

Cohen J 1988 *Statistical Power Analysis for the Behavioral Sciences* 2nd edn (Hillsdale, NJ: Erlbaum)

Crabtree P, Dhokia V G, Newman S T and Ansell M P 2009 Manufacturing methodology for personalised symptom-specific sports insoles *Robot. Comput.-Integr. Manuf.* **25** 972–9

Daoud A I, Geissler G J, Wang F, Saretsky J, Daoud Y A and Lieberman D E 2012 Foot strike and injury rates in endurance runners: a retrospective study *Med. Sci. Sports Exerc.* **44** 1325–34

Ferber R, Hreljac A and Kendall K D 2009 Suspected mechanisms in the cause of overuse running injuries: a clinical review *Sports Health* **1** 242–6

Fernández-Cuevas I *et al* 2015 Classification of factors influencing the use of infrared thermography in humans: a review *Infrared Phys. Technol.* **71** 28–55

Fields K B, Sykes J C, Walker K M and Jackson J C 2010 Prevention of running injuries *Curr. Sports Med. Rep.* **9** 176–82

García-Pérez J A, Pérez-Soriano P, Llana S, Martínez-Nova A and Sánchez-Zuriaga D 2013 Effect of overground versus treadmill running on plantar pressure: influence of fatigue *Gait Posture* **38** 929–33

Gil-Calvo M, Jimenez-Perez I, Pérez-Soriano P and Priego Quesada J I 2017 Foot temperature assessment *Application of Infrared Thermography in Sports Science* (*Biological and Medical Physics, Biomedical Engineering*) (Berlin: Springer) pp 235–63

Hespanhol Junior L C, Pillay J D, van Mechelen W and Verhagen E 2015 Meta-analyses of the effects of habitual running on indices of health in physically inactive adults *Sports Med.* **45** 1455–68

Hildebrandt C, Raschner C and Ammer K 2010 An overview of recent application of medical infrared thermography in sports medicine in Austria *Sensors* **10** 4700–15

Hirschmüller A, Baur H, Müller S, Helwig P, Dickhuth H-H and Mayer F 2011 Clinical effectiveness of customised sport shoe orthoses for overuse injuries in runners: a randomised controlled study *Br. J. Sports Med.* **45** 959–65

Hoeberigs J H 1992 Factors related to the incidence of running injuries *Sports Med.* **13** 408–22

Hume P, Hopkins W, Rome K, Maulder P, Coyle G and Nigg B 2008 Effectiveness of foot orthoses for treatment and prevention of lower limb injuries *Sports Med.* **38** 759–79

ISO 18434-1 2008 *Condition Monitoring and Diagnostics of Machines—Thermography—Part 1: General Procedures* AQ11

Johnston C A M, Taunton J E, Lloyd-Smith D R and McKenzie D C 2003 Preventing running injuries. Practical approach for family doctors *Can. Fam. Physician* **49** 1101–9

Kenney W L and Johnson J M 1992 Control of skin blood flow during exercise *Med. Sci. Sports Exerc.* **24** 303–12

Lewinson R T, Worobets J T and Stefanyshyn D J 2016 Control conditions for footwear insole and orthotic research *Gait Posture* **48** 99–105

Lucas-Cuevas A G, Pérez-Soriano P, Llana-Belloch S, Macián-Romero C and Sánchez-Zuriaga D 2014 Effect of custom-made and prefabricated insoles on plantar loading parameters during running with and without fatigue *J. Sports Sci.* **32** 1712–21

Marins J C B *et al* 2014 Time required to stabilize thermographic images at rest *Infrared Phys. Technol.* www.sciencedirect.com/science/article/pii/S135044951400036X (Accessed: 6 March 2014)

Merla A, Mattei P A, Di Donato L and Romani G L 2010 Thermal imaging of cutaneous temperature modifications in runners during graded exercise *Ann. Biomed. Eng.* **38** 158–63

Mickle K J, Munro B J, Lord S R, Menz H B and Steele J R 2011 Gait, balance and plantar pressures in older people with toe deformities *Gait Posture* **34** 347–51

Moreira D G *et al* 2017 Thermographic imaging in sports and exercise medicine: a Delphi study and consensus statement on the measurement of human skin temperature *J. Therm. Biol.* **69** 155–62

Murphy K, Curry E J and Matzkin E G 2013 Barefoot running: does it prevent injuries? *Sports Med.* **43** 1131–8

Niu H H *et al* 2001 Thermal symmetry of skin temperature: normative data of normal subjects in Taiwan *Zhonghua Yi Xue Za Zhi* **64** 459–68

Ooms L, Veenhof C and de Bakker D H 2013 Effectiveness of start to run, a 6-week training program for novice runners, on increasing health-enhancing physical activity: a controlled study *BMC Public Health* **13** 697

Priego Quesada J I, Kunzler M R and Carpes F P 2017 Methodological aspects of infrared thermography in human assessment *Application of Infrared Thermography in Sports Science* (*Biological and Medical Physics, Biomedical Engineering*) (Berlin: Springer) pp 49–79 https://link.springer.com/chapter/10.1007/978-3-319-47410-6_3 (Accessed: 17 July 2018)

Priego Quesada J I, Kunzler M R, da Rocha E S, Machado Á S and Carpes F P 2015a Plantar pressure and foot temperature responses to acute barefoot and shod running http://roderic.uv.es/handle/10550/52739 (Accessed: 5 October 2018) AQ12

Priego Quesada J I *et al* 2015b Effect of perspiration on skin temperature measurements by infrared thermography and contact thermometry during aerobic cycling *Infrared Phys. Technol.* **72** 68–76

Salles A S and Gyi D E 2013 An evaluation of personalised insoles developed using additive manufacturing *J. Sports Sci.* **31** 442–50

Saragiotto B T, Yamato T P and Lopes A D 2014 What do recreational runners think about risk factors for running injuries? A descriptive study of their beliefs and opinions *J. Orthop. Sports Phys. Ther.* **44** 733–8

Shimazaki Y and Murata M 2015 Effect of gait on formation of thermal environment inside footwear *Appl. Ergon.* **49** 55–62

Sillero-Quintana M *et al* 2015 Infrared thermography as a support tool for screening and early diagnosis in emergencies *J. Med. Imaging Health Inform.* **5** 1223–8

Staffa E *et al* 2016 Infrared thermography as option for evaluating the treatment effect of percutaneous transluminal angioplasty by patients with peripheral arterial disease *Vascular*

Steketee J 1973 Spectral emissivity of skin and pericardium *Phys. Med. Biol.* **18** 686–94

Taunton J E, Ryan M B, Clement D B, McKenzie D C, Lloyd-Smith D R and Zumbo B D 2002 A retrospective case-control analysis of 2002 running injuries *Br. J. Sports Med.* **36** 95–101

Trecroci A *et al* 2018 Bilateral asymmetry of skin temperature is not related to bilateral asymmetry of crank torque during an incremental cycling exercise to exhaustion *PeerJ* https://search.proquest.com/docview/2009473909/abstract/F0DBCE965C014C42PQ/1
AQ13 (Accessed: 27 February 2019)

van der Worp M P, ten Haaf D S M, van Cingel R, de Wijer A, der Sanden M W G N and Staal J B 2015 Injuries in runners; a systematic review on risk factors and sex differences *PLoS One* **10** e0114937

van Gent R N, Siem D, van Middelkoop M, van Os A G, Bierma-Zeinstra S M A and Koes B W 2007 Incidence and determinants of lower extremity running injuries in long distance runners: a systematic review *Br. J. Sports Med.* **41** 469–80

van Melick N, Meddeler B M, Hoogeboom T J, Nijhuis-van der Sanden M W G and van Cingel R E H 2017 How to determine leg dominance: the agreement between self-reported and observed performance in healthy adults *PLoS One* **12** www.ncbi.nlm.nih.gov/pmc/articles/
AQ14 PMC5747428/ (Accessed: 22 February 2019)

Vardasca R, Ring F, Plassmann P and Jones C 2012 Termal symmetry of the upper and lower extremities in healthy subjects *Thermol. Int.* **22** 53–60

Vargas J V C *et al* 2009 Normalized methodology for medical infrared imaging *Infrared Phys. Technol.* **52** 42–7

West A M, Schönfisch D, Picard A, Tarrier J, Hodder S and Havenith G 2019 Shoe microclimate: an objective characterisation and subjective evaluation *Appl. Ergon.* **78** 1–12

Yavuz M *et al* 2014 Temperature as a predictive tool for plantar triaxial loading *J. Biomech.* **47** 3767–70

Zaproudina N, Varmavuo V, Airaksinen O and Närhi M 2008 Reproducibility of infrared thermography measurements in healthy individuals *Physiol. Meas.* **29** 515