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# DEVELOPMENT OF AN ARTIFICIAL MULTIFUNCTIONAL FOOT

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## KEYWORDS

Footwear, thermal comfort, prototype, sweating, thermal insulation

## ABSTRACT

The main purpose of this PhD project is the development of a multifunctional artificial foot, capable of duplicate a human foot in a laboratory environment, in order to evaluate and to simulate the footwear's performance under certain conditions. This foot is used as a laboratory prototype and is multisegmented, in order that each section is controlled independently in terms of heat generation and sweating rate, hence we can simulate more accurately the real behavior of a human foot. The device produces thermal insulation values that will help designing footwear with better skills in thermal comfort, as well as will replace human volunteers in thermal comfort perception tests, which are very subjective due to the human factor. The prototype is already in tests stage, and preliminary results indicate thermal insulation values which are within the range of expected values produced either by other foot thermal manikins or by human volunteers tests. This fact suggests this prototype can be used in future thermal comfort assays.

## INTRODUCTION

Human thermal regulation is mainly done by the extremities like feet and hands, footwear as an essential role in maintaining the thermal balance of the body (Strickland et al., 1997).
The cold perception on feet as a correlation with low skin temperatures, due to perspiration. The shoe may have a proper thermal insulation, but when the foot begins getting cold, it generates discomfort. In situations of low temperatures and high humidity, moisture will condensate easier, which will induce a faster foot cooling (Taylor et al., 2006).
Unfortunately, most of the footwear is quite impermeable to moisture in addition to a high thermal resistance, two factors that contribute to deep variations on the temperature of foot's skin (Kuklane, 1999; Yuhong and Zhihua, 2001).
In this context, the design and development of a human foot prototype, capable of simulating thermal gradients and sweating rates close to the ones occurring physiologically in the human body, is a great improvement and competitive advantage in the process of testing footwear and developing or improving materials whose effect is important in the wet/wicked perception and consequently in the individuals' thermal confort.

## RESULTS AND DISCUSSION

It was developed a prototype with 7 independent segments, each one with own temperature and sweating rate control. Each segment has its specific heating power as well as terminals for water release into its surface. There is a total of 7 sweating terminals distributed all over the prototype's surface, allowing sweating rates from 0,20-15 mL/h. It was also designed a software capable of controlling and interacting with this artificial foot.

As we can see in Table 1, the thermal insulation values obtained for a bare foot assay with our prototype's equation (2) are quite different from those calculated with SATRA calculus formula (1).

$$I_i = \frac{a_i}{A}\frac{\left(T_{sup,\,i}-T_o\right).a_i}{Q_i} \tag{1}$$

$$I_i = \frac{\left(\frac{hca_i(a_i+ca_i)}{2}\right)\left(T_{sup,i}-T_o\right)-\frac{Q_i a_i(1+c)}{2}}{Q_i h(ca_i)} \tag{2}$$

Table 1–Thermal insulation values for each segment calculed based on equations (1) and (2)

| Segment | Heat Power (W) | Segment area (m^2) | Temperature (ºC) | Thermal insulation SATRA (m^2.ºC/W) | Thermal Insulation Bionic (m^2.ºC/W) |
|---|---|---|---|---|---|
| 1 | 0,03681 | 0,002025 | 33 | 0,006 | 0,008 |
| 2 | 0,4165 | 0,01105 | 33 | 0,015 | 0,100 |
| 3 | 0,08575 | 0,005453 | 33 | 0,017 | 0,020 |
| 4 | 0,098 | 0,007387 | 33 | 0,028 | 0,058 |
| 5 | 0,1715 | 0,00851 | 33 | 0,021 | 0,025 |
| 6 | 0,196 | 0,01518 | 33 | 0,059 | 0,065 |
| 7 | 0,343 | 0,010137 | 33 | 0,015 | 0,090 |

However, it is important to say that the two equations are different and that, according to the reference range (0,05-0,13 $m^2$.ºC/W) of interlaboratory tests on thermal models (Kuklane et al, 2003), only 1/7 segments by Satra equation fit the reference range, while 4/7 segments by Bionic equation fit the same range.

## CONCLUSIONS

The novel aspects of this prototype, comparing it with other similar models already developed, are its anthropometric shape and dimensions, which make these assays much more realistic and accurate. This allows they approach to the results obtained with human volunteers, without the subjective bias factor. Furthermore, this thermal foot model allows that footwear tests are done either in a dry mode or in a sweat mode (in this case the prototype releases water in flow rates adjustable by the human sweating rates).
However, more experiences must be conducted with footwear. Besides, the equation for thermal insulation (2) is passible of being reformulated in order to make the results more accurate and close to the ones referenced in the interlaboratory tests.

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## AUTHORS BIOGRAPHY

**JOÃO DUARTE P. ALMEIDA** was born in Forjães, Esposende and went to the University of Minho in Braga, where he studied biomedical engineering and obtained his MSc in 2007. He post graduated in Legal Medicine in the Faculty of Medicine of the University of Porto in 2008 before moving in 2009 to the CTCP (Centro Tecnológico do Calçado de Portugal) in SãoJoão da Madeira where he is developing his PhD thesis, under supervision of Prof. Pedro Lobarinhas and Prof. Luís Ferreira da Silva from the Department of Mechanical Engineering of theUniversity of Minho.