EVOLUTION OF THE IN-SHOE TEMPERATURE DURING WALKING AND RUNNING

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ABSTRACT

Regarding a conception of a new sport shoe, the study of the foot-shoe heating constitutes an important step in the study of the thermal comfort and of the athletic performances. Indeed, the friction of the foot on the ground produces heat and induces a non-homogenous elevation of the temperature in the foot. This elevation varies accordingly to the movement and to the capacity of the shoe to evacuate the heat. In order to evaluate the in-shoe local heating and its connection with the local friction, we devised an experimental set-up aimed at analysing the temperature and the plantar pressures evolutions during race with two velocities: low and high. The temperatures are measured in 3 points between the rubber and the leather soles of the shoes with miniature K-thermocouples: the heel, the plantar-arch and the plantar foot. The relevant temporal trends are given during initial standing, race and final standing during the runner recuperation phase. Results showed that during walking, the temperature of the heel has a more important evolution that the 2 other zones. On the other hand, during the race, the plantar of the foot is more solicited. This result is due to the kinematics variation of the movement.

KEY WORDS
Walking, race, biomechanics, in-shoe temperature, plantar pressure

1. Introduction

The human body maintains his temperature roughly around 37°C and regulates it using all his active metabolic tissue. When a lengthy muscular effort is produced, it produces an important sweat loss with a combination of salt and water. This allows for the evaluation of the heat produced during the effort maintaining a constant temperature. The mechanical output of the muscle for a human being is very low, with in average 75 to 80% of the spent energy transformed in heat. With such a rate and therefore an internal temperature that could reach extreme values, the organism could not survive in the absence of regulating mechanisms. This way, the evaporation contributes mainly to maintain the internal temperature at a maximum level of 39 to 40°C, even in a hot environment and during lengthy efforts. Indeed, it is the evaporation of the sweat at the surface of the skin that allows the elimination of the heat (around 580 kcal per litre of evaporated sweat) [1]. The release of heat by conduction between the foot and the ground (only point of contact) through the shoe is also important in the mechanisms of thermo regulation.

The thermo comfort is generally associated with a neutral or almost neutral thermo sensation on the entire body. This sensation depends on the body temperature which is influenced by environmental factors (air temperature, relative humidity, speed of air…) as well as the individual’s personal factors (metabolism and clothing). The physiological processes contribute to maintain the temperature and the humidity of the skin below a maximum value. The comfort seems to be reached when the body temperatures are constant with a minimal physiological regulating effort [2 – 7].

The experiences done by Zotterman [3] showed how skin temperature rises during different phases of warm up and cooling of the foot. That study pointed out the evolution in intensity of the warm and cold sensations during those phases. The skin, initially at 25°C, was firstly warmed up to 35°C at a rate of 0,45°C.min-1. The sensation went from cold to warm. The skin was then cooled down to 25°C at a rate of -0,87°C.min-1, a cool sensation came when the skin reached around 30°C. However, this temperature induced a sensation of heat during the warm up phase. According to whether the skin is warming up or cooling down, an equivalent temperature caused in one case heat and in the other case cold. In other terms, the sensation depended on the temperature as well as the direction of the flow entering or through the skin. Maluf [8] for the clinical population developed a device to measure temperature, pressure and humidity. He indicates that the multisensory data acquisition device can be used for a long-term, continuous monitoring of in-shoe plantar pressure, temperature and humidity for clinical patient including diabetes.

2. The exchanges of heat in a shoe

The shoe provides a more or less important thermo protection for the foot according to its design. Indeed,
there are heat losses due to the conduction through the soles, by the convection and the radiation of the surfaces of the shoe. The convection caused by the ventilation of the openings, as well as the evaporation, is the principal mode of heat transfer between the foot and the environment. The isolation properties of a shoe depend on its shape, its structure, and the materials that form the different layers [4].

The goal of this study was to devise an experimental protocol aimed at analysing both temperature and plantar pressure evolutions during walking and running and evaluate how the temperature elevates at different points of support of the foot during the movement.

3. Materials and methods

The goal of this study is to measure the elevation of the temperature at different points of support of the foot during the movement.

The following test was carried out with 2 different speeds (4 and 16km/h) of running on a subject of 28 years old and athletic: the subject wore a pair of shoes and maintained a standing position for 2 minutes. Then, he placed himself on a treadmill and ran at a set pace for 4 minutes. Finally, he replaced himself in standing position for another 4 minutes. This step allowed us to follow the complete evolution of the field of temperature before, during, and after the race, during the three phases: static, effort, and recuperation.

The measurements of temperature were carried out using type K thermocouples (Chromel-Alumel), of diameter 0.25mm, placed between the principal sole (polyethylene) and the cleanliness sole (material), on the median axe of the shoe. The thermocouples were connected to a high frequency power station of acquisition (INET 200) (Fig. 1 b). During the experimental tests, the temperatures in 3 different zones of the foot were recorded in 3 different zones of the foot: the heel (HL corresponding to the initial contact during walking), the plantar-arch (PA corresponding to the Mid-stance phase) and the plantar foot (PF corresponding to the push-off phase). The shoe is a size 43 and its length is 26,9cm. The first thermocouple is placed at 5.5cm from the front edge of the shoe, the second at 16.2cm and the third at 24.7cm. (Fig. 1 a and b).

4. Results and Discussions

4.1 Temperature at rest (initial 2 minutes standing)

Let’s note on figure 2 that the temperatures recorded in the foot areas are different. Indeed, the temperature is 22.2°C at the level of the heel and 23.3°C at the level of the sole. It is higher at the level of the arch of the foot (24.6°C). The contact zones of the foot with the sole are therefore colder than the arch of the foot, the central zone of the foot. This result can be explained by the heat loss that happened by conduction in the areas of direct contact with the sole. Indeed, the hollow of the arch of the foot is not a support point of the foot; it is not therefore in direct contact with the sole. Let’s note that the 3 temperatures remain almost constant throughout those 2 minutes.

![Figure 1 (a) Placement of the sensors for the measurement of temperature](image)

![Figure 1 (b) Experimental device for the acquisition of temperatures and pressure data](image)

![Figure 2 Walking: The temperatures are measured in 3 points between the rubber and the leather soles of the shoes with miniature K-thermocouples: the heel (HL corresponding to the initial contact during walking), the plantar-arch (PA corresponding to the Mid-stance phase) and the plantar foot (PF corresponding to the push-off phase)](image)
4.2 Temperature during the movement (4 minutes walk/run)

The graph reported in figure 3 shows the elevation of the temperatures of the 3 zones of measurement during test 1, corresponding to a walking speed (4 km/h). The most important elevation is located in the heel. Indeed, after 4 minutes, the heel temperature increases of roughly 2°C, though the temperature of the sole increases by 1.6°C and the temperature of the arch of the foot increases by 1.2°C.

In test 2, corresponding to a running race at a speed of (16 km/h), the temperature of the sole increased by roughly 6°C when the temperature if the heel increases by 4.5°C (Figure 4). Contrary to the walk, the warm up was more important for the sole than for the heel. The arch always had the weakest temperature elevation (roughly 3°C here).

This difference in the zones of maximum warm up between the two tests is due to the difference of the support zones during the movement of the foot that proceeds in three steps: the reception, the intermediate support and the thrust. During the walk, the heel contributes more than the sole in the reception to the ground and to the intermediate support. The time during which the heel is in contact with the ground is longer than the one of the contact sole-ground. However, due to the posture of the body of the runner during the race (slightly leaning forward), it is the sole of the foot that insure the reception and the thrust.

4.3 Temperature after movement (final 4 minutes standing)

Between the 6th and the 10th minute of each test, the runner stands up on both feet during 4 minutes of recuperation after effort. Here again, the temperatures have been recorded during this phase because it is important to quantify the capacity of a shoe to evacuate the heat during the effort and also during the phase of recuperation.

The drawings 4 and 5 show that, for both test, the temperature at the level of the sole and the arch of the foot decrease slightly during the phase of recuperation, go through a minimum (reached at roughly one minute after the end of the effort), then increase again. However, the temperature of the heel decreases all along the 4 minutes in both tests. It decreases of 0.5°C in test 1, and of 1.5°C in test 2, under the effect of the release of the heat by conduction of the foot towards the ground through the different soles of the shoe. Measurements of sole pressure with the Zebris platform showed that the contact between the foot and the sole is more important in the heel in a static position.
5. Conclusion

The study of the evolution of the temperature in the system foot-shoe system highlighted the presence of a local warm up that differed according to the speed of the race, and depending on the zones of support during the effort. The temperature increase was higher in the heel while walking. However the most important elevation occurred in the plantar foot during the race. These warm ups were due to the modification of the movement kinetics between the running and the walking, and consequently to the different zones of friction between the foot and the sole. During the phase of recuperation after the effort, the heat is liberated more easily throughout the sole below the heel than the arch of the foot or the sole. This is explained by the loss of heat stored by the sole during the effort. Main limitation of the present study is the number of subjects took into consideration. In fact, one shoe and one subject permit to give only temperature evolution trends that are not necessary repeatable to other subjects. Future perspectives in this respect will be the sample widening to compare the evolution for the temperature for different shoes and subjects. A parametric study of the evolution of the temperature, of the humidity and of the reaction of the metabolism (skin burn, lack of comfort…) according to the material and the shape of the shoe is in process. It should allow a complete characterisation of the interaction shoe-foot in the different situations of physical exercise. As perspective in our future work we wish quantify the humidity evolutions during the movement.

References