Determination of insulation properties of functional clothing using core body temperature gradients as quantification parameter

Jonathan Bulut*, Marius Janta, Veit Senner, Johannes Kreuzer

Technische Universität München, Boltzmannstraße 15, 85747 Garching, Germany

Received 15 April 2013; revised 6 May 2013; accepted 20 May 2013

Abstract

Increasing quality requirements for functional sports- and work wear make their development more demanding as complex interaction between human physiology and clothing is to be taken adequately into account. Previous test designs, often based on subjective perceptions, make a convincing comparison difficult. Material-specific laboratory tests only offer limited validity regarding effects on physiological and ergonomic properties. Principal objective of the study is to compare two different types of down jackets with respect to their effect on core body temperature during physical activity and inactivity. Both jackets were filled with different lining, one with chemically modified down called “QuixDown” (QD), the other one with conventional down (CD). A climatic chamber test with two activity sessions and a break in between was performed. Subjects were physically active on a bike ergometer at moderate level. A total of n = 26 (12m, 14f) healthy and physically active subjects between 18 and 35 years of age were randomly divided into control (CG) and treatment group (TG). TG was equipped with the QD, control group with the CD jacket. To ensure identical loading intensity for the test the individual anaerobic threshold of each subject had been determined in a pretest. Each person was equipped with an in-ear thermometer for measuring the core body temperature at the acoustic meatus. With QD jacket the subject’s core body temperature dropped less during the break between both activity sessions than when wearing the CD jacket (p < 0.05, η² = 0.124). No statistical significance could be shown in gender (p = 0.22, η² = 0.02) and interaction jacket/gender (p = 0.56, η² = 0). The chemically modified down insulation seems to offer better thermal insulation than conventional down.

© 2013 The Authors. Published by Elsevier Ltd. Open access under CC BY-NC-ND license.
Selection and peer-review under responsibility of the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University

Keywords: Functional clothing; sports wear, insulation; core body temperature

E-mail address: jonathan.bulut@tum.de
1. Introduction

High performance materials used for modern functional clothing go through laboratory tests to certificate mechanical and chemical resilience plus skin compatibility. Together with parameters for insulation and water vapour permeability the clothing’s application range can be determined. This is essential for exploring the fabric’s technical properties. However, this procedure only offers limited validity regarding effects on physiological and ergonomic properties, especially at variable physical load or under harsh or changing environmental conditions.

Technological progress of mobile measuring devices opens up new possibilities for objective test designs regarding the complex interaction between human physiology and clothing. These possibilities are not only confined to laboratory tests, but can also be used for indoor and outdoor field tests. The aim is to complement or even substitute previous test designs, often based on subjective perceptions, which make a convincing comparison difficult, by those including objective analysis and metrical data.

Principal objective of the study is to compare the insulation characteristics of two different types of down jackets with respect to their effect on the course of core body temperature during physical activity and inactivity. Aim of the test is to prove whether course of core body temperature represents a suitable parameter for evaluation of functional clothing.

<table>
<thead>
<tr>
<th>Nomenclature</th>
</tr>
</thead>
<tbody>
<tr>
<td>QD</td>
</tr>
<tr>
<td>QuixDown™ (chemically modified down with water-repellent characteristics)</td>
</tr>
<tr>
<td>CD</td>
</tr>
<tr>
<td>conventional down</td>
</tr>
<tr>
<td>TG</td>
</tr>
<tr>
<td>treatment group</td>
</tr>
<tr>
<td>CG</td>
</tr>
<tr>
<td>control group</td>
</tr>
<tr>
<td>SD</td>
</tr>
<tr>
<td>standard deviation</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>mean</td>
</tr>
</tbody>
</table>

2. Experimental section

2.1. Background

Thermoregulation of human beings ensures that a core body temperature of about 37 °C is kept within narrow limits. Thermogenesis is resultant from basal metabolism, physical activity and environmental conditions. Depending on these conditions warmth is to be used for stabilizing the core body temperature or to be dissipated. A small part is dissipated by breathing air and the biggest part by heat dissipation through the skin [1], [2], which is shown in a thermography picture taken during a pretest (Fig. 1).
Beyond physical protection functional wear is supposed to support body’s thermoregulation or at least not to interfere with it. It should offer maximum water vapour permeability for sweat escape and insulate body heat at cold ambient temperatures whereas minimum resistance against heat dissipation at warm environmental conditions is required.

Both jackets used in the test were optically equal, but filled with different insulation material: One jacket was filled with a new chemically modified down, called “QuixDown” (QD), the other with conventional down (CD). Unlike conventional down QD is water-repellent and not supposed to lose its insulation function upon contact with moisture such as sweat. To compare the jacket’s insulation characteristics core body temperature gradients are compared to each other.

2.2. Experimental setup and hypotheses

A total of \( n = 26 \) randomly chosen test persons interested in sports aged between 18 and 35 years at good health, 12 male and 14 female, participated in this single blind study. The test was performed in a climatic chamber with two sessions of each 30 min of physical activity on a bike ergometer and a 15 min break in between.

To ensure identical loading intensity for the test on the bike ergometer the individual anaerobic threshold of each subject had been determined in a pretest. The intensity of a bike ergometer was set on 60 W and raised by 30 W every three minutes, while the test person holds a rotational speed of 80 - 85 min\(^{-1}\). At the end of each three minute period a blood sample was taken out of the lobe. The test was stopped when speed could not be maintained anymore. The intensity in Watt for the ergometer setup in climatic chamber test was determined by analyzing the lactate concentration and evaluating the individual performance curve of each person by software Winlactat using the Mader model. This model with fixed 4 mmol/l anaerobic threshold was chosen as test persons have different sportive backgrounds and a wide ranged level of physical fitness. It could be shown by experience of previous tests that a loading intensity at basic endurance level turned out to be the most reasonable and reliable choice for this ergometer test.
After determination of each participant’s ergometer setup the test was performed in a climatic chamber to ensure constant environmental conditions. Temperature was set at 0 °C, humidity at 70 %rH. To ensure random allocation into treatment (TG) and control group (CG), test persons registered themselves for the offered dates. Therefore, the examiner had no influence on the order, so that the two jacket types QD and CD could be provided alternately on test persons upon appearance without violating randomization. This was necessary to keep TG and CG at nearly same size. Both jacket types QD and CD were optically equal, but coded by manufacturer, so that test persons had no knowledge about different lining material. To minimize influence of disturbance variables all other clothing such as shoes, pants, socks, shirts, gloves and beanies was standardized. Shirts and gloves were provided by the examiner, the rest was checked before test beginning and got replaced, if necessary. Before starting the test each person was equipped with a high-precision in-ear thermometer (CosinusS° sensor with data logger, accuracy ±0.01 K) for measuring the core body temperature at the acoustic meatus (Fig. 2.), which subsequently was sealed by cotton to avoid influence caused by cold ambient air.

After correct fit of sensor, which could be seen on computer screen via live tracking, the bike ergometer was adjusted to size and workload of respective test person determined in the pretest (Fig. 2.).

Fig. 2. (a) In-ear thermometer unit for recording of core body temperature; (b) Test person on bike ergometer in climatic chamber

Main purpose of first activity session is to raise test person’s core body temperature and to generate a humid milieu at the inner side of the jacket to evaluate the water-repellent characteristics of QD and therefore its insulation capability compared to CD lining by comparison of core body temperature drops during the break. An additional humidity/temperature sensor, applied between the inner side of jacket and shirt, serves as a redundant control for validity of the test setup in terms of realistic and plausible temperature ranges. The second activity session as repetition of the first one is for proving the reproducibility of the test setup.

It is to prove whether the following hypotheses can be corroborated:
- Average gradients of core body temperature drop during the break between jacket QD and CD vary significantly
- Average gradients of core body temperature drop during the break between male and female vary significantly
- The interaction between jacket and gender is significant

3. Results

Results of two-way ANOVA show significant influence of jacket type (F (1, 22) = 4.69, p < 0.05, $\omega^2 = 0.124$) on core body temperature drop during the break between both activity sessions. With QD jacket ($M = 0.37 \, K$, $SD = 0.14$) the core body temperature dropped less than with CD jacket ($M = 0.49 \, K$, $SD = 0.14$). Calculated post-hoc power is about 62%. A calculated a-priori sampling plan shows that at least 39 test persons would have been necessary to achieve power of > 80%, provided that effect size would remain the same.

No statistical significance could be shown in gender (F (1, 22) = 1.61, p = 0.22, $\omega^2 = 0.02$) and interaction jacket/gender (F (1, 22) = 0.36, p = 0.56, $\omega^2 \approx 0$).

![Boxplot for core body temperature drop during break between activity sessions](image)

Fig. 3. Boxplot for core body temperature drop during break between activity sessions

Boxplot (Fig. 3.) shows the distribution within both groups QD and CD. SD is nearly the same. The median for CD is higher than the one for QD. Even the first quartile of CD is higher than the median of QD.

No statistically relevant difference between QD and CD could be shown during the activity sessions.
4. Discussion

The test shows that jacket type only shows significant influence on core body temperature drop during the break between both activity sessions with a medium to large-sized effect, according to Cohen’s classification [3], [4]. However, power is lower than 80 % since sample size was not big enough. No statistical significance could be shown in gender and interaction jacket/gender.

Since core body temperature ranges between narrow limits, high-precision devices for measuring the temperature is essential. Compared to the accuracy of the measuring system used in the test, the difference in means of 0.12 K within a time period of 15 min may be considered as plausible. The large differences in effect size between the variables jacket, gender and interaction testify a high differentiation grade, so that differences can adequately be ascribed to the jacket type.

No statistically relevant difference could be shown between QD and CD during activity sessions, as more body heat was produced than ambient air temperature could have cooled down.

The chemically modified down insulation seems to offer better thermal insulation than conventional down, which might be explained by its improved moisture management.

5. Summary

Core body temperature gradients represent a suitable parameter for evaluation of functional clothing. Even though results most closely correspond to the expectations, potential of core body temperature recording by far is not exhausted yet. High reproducibility of portable measuring devices, which are easy-to-handle, allows accurate measurements in laboratory and field tests.

Fields of application can be found in sports and health science and ergonomics, especially where information about complex interaction between human physiology and clothing or environment is required. Core body temperature offers a useful feedback for developers of functional clothing for sports, work and safety purposes. Athletes or workers can be tested while performing their exercise or job under real environmental conditions at variable physical load rather than to be limited on results of laboratory or material tests only. Furthermore field tests for clothes can be performed while collecting objective, metrical data, which makes analysis more reliable compared to test designs based on data from subjective perceptions.

References