

Yetanawork Teyeme^{1,2}, Benny Malengier¹, Tamrat Tesfaye², Simona Vasile³, Lieva Van Langenhove¹

¹ Ghent University, Faculty of Engineering and Architecture, Department of Materials, Textiles and Chemical Engineering, Technologiepark 907, 9052 Zwijnaarde (UGent), Belgium

² Bahir Dar University, Ethiopian Institute of Textile and Fashion Technology, Haile Silase Rode, 6000 Bahir Dar, Ethiopia

³ Fashion and Textiles Innovation Lab+, HOGENT University of Applied Sciences and Arts, Buchtenstraat 11, 9051 Ghent Belgium

Comfort Evaluation of Cyclists Jerseys Using Wear Trial Test

Vrednotenje udobnosti kolesarskih dresov s testom poskusnega nošenja

Short scientific article/Kratki znanstveni prispevek

Received/Prispelo 5-2020 • Accepted/Sprejeto 10-2020

Corresponding author/Korespondenčna avtorica:

Yetanawork Teyeme

E-mail: YetanaworkWubneh.Teyeme@UGent.be

ORCID: 0000-0003-1530-3613

Abstract

The aim of this study was to evaluate the wear comfort of four commercially available cycling outfits and understand various subjective parameters of garments through consumer perception, which will enable the design and development of an optimized outfit. A questionnaire was developed specifically to address various key aspects such as tactile sensation, garment fit with reference to size, garment assembly, garment aesthetics (style and shape), comfort (before, during and after wearing) and overall satisfaction (relating to design of the garment and style). Three outfits were fabricated from polyester fabric and one from polyamide/elastane (80%/20%) fabric. They were assessed by four male professional cyclists (age 22–25) at various stages of a test protocol of 45 minutes total duration, of which 20 minutes was flat cycling. The four tested garments showed greater differences between the sensorial comfort perceptions than thermophysiological comfort. The sensorial comfort sensation was found to be mainly correlated with fabric properties, fit, construction techniques and moisture sensation, whereas the thermophysiological comfort was found to be affected by the fabric characteristics, the test environment conditions and level of activity. Additionally, manual measurements showed great brand-based differences between garments of the same specified size M (medium). Overall, the polyamide/elastane jersey was perceived as a better cycling outfit than the polyester outfit. The results of this study provide guidance for the optimal design and development of professional cyclist outfits.

Keywords: cycling garment, sensorial comfort, thermophysiological comfort, subjective wear trial

Izvleček

Cilj raziskave je oceniti udobnost nošenja štirih tržno dostopnih kolesarskih oblačil in razumevanje različnih subjektivnih parametrov zaznavanja oblačil potrošnikov pri uporabi, kar bo omogočilo oblikovanje in razvoj optimiziranega oblačila. Izdelan je bil poseben vprašalnik za obravnavo različnih ključnih vidikov, kot so občutek otipa, prileganje oblačila glede na velikost, sestavljanje oblačila, estetika oblačila (slog, oblika), udobje pred, med in po nošenju ter splošno zadovoljstvo, povezano z dizajnom oblačila in slogom. Tri obleke so bile izdelane iz poliestrske tkanine, ena pa iz mešanice poliamida in elastana (80 %/20 %). Ocenili so jih štiri moški poklicni kolesarji (stari od 22 do 25 let) v različnih fazah testnega proto-

kola, ki je skupaj trajal 45 minut, od tega je bilo 20 minut kolesarjenja po ravnem. Štiri preizkušena oblačila so pokazala večje razlike v otipu kot v toplotnofiziološkem udobju. Ugotovljeno je bilo, da je čutno udobje v glavnem odvisno od lastnosti tkanine, prileganja oblačila, konstrukcijskih rešitev in občutenja vlage, medtem ko na toplotnofiziološko udobje poleg značilnosti tkanine vplivajo razmere v preskusnem okolju in stopnja aktivnosti. Poleg tega so meritve pokazale velike razlike v dimenzijah med oblačili različnih blagovnih znamk, a enake velikosti M (srednje). Na splošno je bil za kolesarje bolje ocenjen dres iz mešanice poliamid/elastana kot dres iz poliestra. Rezultati te študije dajejo smernice za optimalno zasnovo in razvoj dresa za poklicne kolesarje.

Ključne besede: kolesarsko oblačilo, senzorično udobje, toplotnofiziološko udobje, subjektivno poskusno nošenje

1 Introduction

Clothing comfort is an essential aspect of users' performance and is taken into consideration as a quality characteristic while choosing a particular garment [1]. Clothing comfort is, however, an extremely complex subject and is the result of many interactions between physical, psychological, and physiological factors [2–4]. Sports apparel not only requires comfort, but also functionality. At the same time, these garments must have excellent thermophysiological properties adapted to a particular sport discipline [5]. Thermophysiological comfort, also referred to as thermal comfort, is crucially important for sportswear worn next to skin, where rapid heat transfer, moisture vapor and liquid moisture transfer from skin to the outer fabric surface is required [2]. These factors are influenced by the thermophysiological conditions of the human body [6–8].

Cycling is one of the most popular sports and can be performed in many different weather conditions. Therefore, the expectations that cyclists have in terms of the comfort of athletic apparel have increased. Clothing comfort includes all the comfort sensations produced by a garment [1, 9, 10]. Many studies have been conducted in relation to cycling clothing, in particular taking into consideration ergonomic issues and the effect of compression on performance and recovery [11–13]. Other fields of research cover injury reduction [14, 15], the design of cycling clothing [16, 17], and aerodynamic behaviour and various other aspects of comfort [18–23]. However, previous studies showed that cycling apparel requires further investigation.

Comfort can be a psychological state, a physical sensation or both simultaneously [24]. Most importantly, the development of clothing should consider the anatomical features of individuals (anthropometric data), and biomechanical and functional features (skills and physical limitations while performing occupational or sport activities) [25] and hence tend

to be complex and iterative. These factors can overlap and correlate significantly with the subjective evaluation performed and provided by users, especially regarding usability, wearability and safety.

Clothing designed specifically for certain functionalities (i.e. a cycling garment worn next to the skin) has been shown to cause heat stress, and reduce the task efficiency as well as the range-of-motion of the wearer [26]. The process of design therefore begins by first establishing the many requirements of the user. An extra concern for cyclists is low back pain, the most prevalent injury and a problem for their health [26–29], and several garments have been developed to assist with fatigue and improve motor function. However, athlete compliance is likely to be affected due to the discomfort and inconvenience of these garments.

A wear trial deploying various evaluation techniques was set up to investigate the functional and comfort requirements of users. The findings of comfort need and the effects of various garment attributes from different wear trials will provide insight into the design and development of proper garment criteria that are required to satisfy an athlete's critical ergonomic needs, and acting upon these insights will eventually improve their performance. The purpose of this study was to quantify the wearers' perceived comfort responses to existing cycling garments in order to identify the influential garment attributes.

2 Materials and methods

2.1 Materials

2.1.1 Test garments

In this study, four commercially available cyclist outfit garments were obtained from A.S. Adventure Ghent, Belgium. All samples were short-sleeved, medium size T-shirts/jerseys. The selected garments were differentiated by fabric composition and structure as shown in Table 1.

Table 1: Fabric composition and structural parameters of selected garments A–D

Garment code	Fibre composition	Garment size	Fabric structure	Courses (cm)	Wales (cm)	Thickness (mm)	Air permeability (mm/s)
A	100% PES ^{a)}	M ^{d)}	1x1 rib	20	19	0.40	929.5
B	100% PES	M	Interlock with 1x1 rib	25	18	0.44	1,515.0
C	80% PA ^{b)} /20%EL ^{c)}	M	1x1 rib	24	16	0.53	1,150.0
D	100% PES	M	1x1 rib with 3D knitted	20	16	0.69	1,262.5

^{a)} polyester; ^{b)} polyamide; ^{c)} elastane; ^{d)} medium

2.1.2 Test subjects

Four male professional cyclists aged between 22 and 25 years from Bahir Dar, Ethiopia were selected to participate as human subjects in the wear trial test of the study. All subjects were healthy volunteers who exercised regularly. Each subject was given one experimental garment over a given time span.

The participants were informed beforehand about the scope of the test, procedure and risks [31, 32]. Informed consent was signed by all subjects, but they were not informed about the details of the clothing materials in order to avoid any influence on their subjective ratings. However, subjects were invited to have a pre-trial before formal trials to determine their individual cycling intensity and understanding of the questions and the procedures involved.

2.2 Methods

2.2.1 Fabric characterization

Fabric analysis was performed on the four different styles of purchased jerseys, including fibre compositions, knit structure, stitch density, thickness and air permeability. The thickness of the fabrics was measured according to ASTM D1777 using a MESDANLAB Digital thickness tester. The air permeability properties of the fabrics were measured using an FX 3300 air permeability tester according to the ISO 9237 standard with a 100 Pa air pressure difference and a 20 mm² test area.

2.2.2 Garment design and size measurement comparison

Garment design: To determine the recommended fit, the sizing charts provided by each retailer were taken from the relevant websites [33–37]. These charts stated the recommended size of the wearer at the chest for a small, medium and large size sample. These were observed further to assess the significance of the measurements recorded and garment assembling for the selected samples.

Garment size measurements: Each sample was measured to highlight differences in garment size and shape, according to the four brands A, B, C and D.

2.3 Wear trials

2.3.1 Subjective assessment of comfort

A variety of methods is typically applied to assess comfort in trials. Some studies use a combination of methods, including one or more questionnaire items. Likert-type rating scales and numeric rating scales have been used [38, 39]. Of these scales, some were oriented to assess “comfort” and “discomfort”, while some were bipolar [13, 14, 19, 37]. In this study, Likert rating scales with different scales were used to assess the subjective perception of the subject. Likert scaling is a unidimensional scaling method useful when measuring latent constructs, i.e. the characteristics of people, such as attitudes, feelings and opinions.

2.3.2 Environmental conditions and test protocol

To gather data about parameters affecting the thermal comfort status of the test persons, temperature, wind speed and relative humidity measurements were recorded objectively (Table 2). The measurements were carried out using the mobile app Live weather forecast widget, which provides daily weather forecasting. All tests in the scope of wear trials were conducted in actual working field environments from 6 am to 9 am, when the sun is still very low, in order to limit the effect of solar radiation. The experimental protocol was approved by Bahir Dar University, Ethiopian Institute of Textile and Fashion Technology Institutional Review Board (IRB) (10th November 2018).

Test subjects followed an exercise protocol consisting of four activities for 45 minutes: the subjects first wore the T-shirt and then they rested with it for 5 minutes in the test environment prior to the conducting of the next test. The subjects then warmed up by doing stretching for 10 minutes according to their normal

Table 2: Environmental conditions during the field trial

Test day	Outside temperature (°C)	Relative air humidity (%)	Wind speed (km/h)	Avg. cycling speed (km/h)
1 st	17	74	1.1	27.8
2 nd	16	96	0	25.4
3 rd	10	48	1.8	29
4 th	10	48	0	29.5

stretching routine. Next, the subjects started cycling trials consisting of a 20 minutes flat ride, followed by cooling down (recovery) for 10 minutes (see Figure 1).

2.3.3 Response and validation

We used the rating system described by Wong et al. [41, 42] and a specially designed questionnaire, as well as an assessment scale defined by ISO 10551:2004 [43] and ISO 7730:2005 [44]. At the end of each trial phase, each participant was asked about their psychological state and thermophysiological comfort, and this was recorded by rating thermal comfort and sensations, such as moisture perception, thermal sensation, and overall physiological and psychological comfort during the cycling period.

The first evaluation was made during the initial touch of the fabric, during the first minute when the subjects handled and wore the garment. During exercise, subjective ratings of comfort and discomfort of the T-shirts, broadly relating to thermal and tactile experience, were recorded. The subjects were instructed at each questioning to concentrate on the area of their upper bodies. The explanation of and judgment between the various sensations and the rating scale were discussed with subjects in advance of the experiments. After each trial, the subjects were asked to compare the overall comfort of the four tested T-shirts they had worn for the trial and re-state their preference. The rating scales are shown in Table 3.

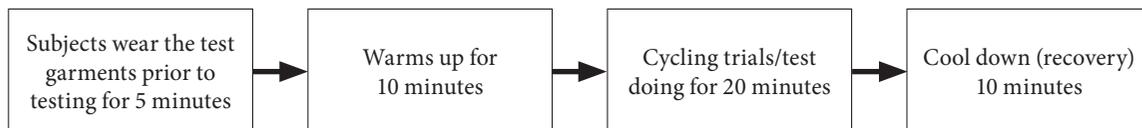


Figure 1: Flow diagram of exercise protocol

Table 3: Rating scales

Comfort	Evaluation criteria	Scale	Remark
Psychological	Clothing size fit	5-point scale	1 (too loose) ... 5 (tight fit)
	Stretchiness	9-point scale	1 (very stretchable) ... 9 (non-stretchy)
	Overall garment look	9-point scale	1 (like very much) ... 9 (dislike)
Thermal	Skin sweat sensation	5-point scale	1 (neutral) ... 5 (extremely wet)
	Skin temperature sensation	7-point scale	1 (cold) ... 7 (hot)
Sensorial	Stiffness and sticky sensation against the skin	9-point scale	1 (not at all) ... 9 (extremely strong)
Ergonomic	Easy of body movements while cycling with ensemble	5-point scale	1 (very stiff) ... 5 (very flexible)
	Level of ease in performing duties	7-point scale	1 (very easy) ... 7 (very difficult)
	Degree of comfort	9-point scale	1 (extremely uncomfortable) ... 9 (extremely comfortable)
	Overall fit of ensemble for the purpose	7-point scale	1 (very poorly) ... 7 (very well)

2.3.4 Statistical analysis

IBM SPSS 21 statistics and Microsoft Excel software were used to analyse the results. Coefficient of variation and mean were used to quantify the variation of various subjective, physiological and objective comfort parameters.

3 Results and discussion

3.1 Fabric characterization

All fibre compositions were taken directly from the care label. Samples, A, B and D were made of polyester and sample C was made of a combination of polyamide and elastane. Polyamide is a strong fibre that has excellent elastic recovery behaviour after stretching [45]. These properties are very important and crucial for (compression) sportswear garments due to the frequent strain on the fabric during use (wearing and washing). Polyester, on the other hand, is characterized by maintaining the stability of its structure, and offering excellent heat resistance and good moisture transport properties. It does not easily extend and has a low cost [46]. However, in the case of

garments that require stretching, nylon is better than polyester, while polyester is favoured over nylon for maintaining stability. Fabric thickness, air permeability, structure and stitch density of fabrics A–D are presented in Table 1. Fabric (A) has the lowest air permeability value (929.5 mm/s) but is the thinnest fabric. Air permeability varied significantly between fabric A and fabric B (1,515 mm/s), with thicknesses of 0.44 mm and 0.40 mm and different structures, respectively. Fabrics A and C contained different compositions of 100% PES (fabric A) and 80% PA/20% EL (fabric C), with a 1x1 rib structure. The 1x1 rib with 3D knitted sample D was the thickest (0.69 mm) and demonstrated lower air permeability than fabric B and a lower fabric density than samples A, B and C.

3.2 Garment design and size measurement comparison

Design detail and size measurements were compared for the four brands of test garment purchased. There were variations in the design in each type. Detailed features of each garment sample are shown in the Figure 2.



Figure 2: Photo of sample garments A (a), B (b), C (c) & D (d)

3.2.1 Garment size measurements

Each sample was measured to highlight differences in garment size and shape, according to the four brands A, B, C and D. Figure 3 shows the points at which the

samples were measured and Table 4 details the manual measurements (cm) taken for the four samples. The measurements listed show variations between ready to wear samples of the same size (medium).

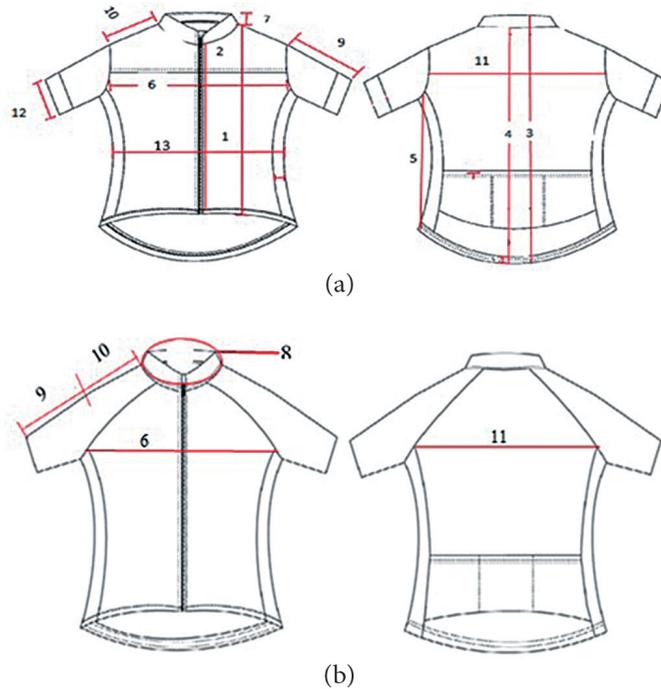


Figure 3: Measurement points of sample garments: a) A, D; b) B, C

Table 4: Measurements variation of garment samples A, B, C, D

Serial number	Measurement point	A (cm)	B (cm)	C (cm)	D (cm)	Mean \pm SD ^{a)} (cm)	CV ^{b)} (%)
1	Full length front	63.5	63.5	59.5	63	62.4 \pm 1.9	3.10
2	Centre front length	54	54	52	53	53.3 \pm 1	1.80
3	Back full length	76.5	71	70	77.5	73.8 \pm 3.8	5.15
4	Centre back length	72.5	68	66	73.5	70.0 \pm 3.6	5.12
5	Side seam length	45	46	43	46	45.0 \pm 1.4	3.14
6	Across chest (seam to seam) front	46	49	45	48	47.0 \pm 1.8	3.88
7	Collar stand length	41	42	40	47	42.5 \pm 3.1	7.32
8	Collar stand width (neck circumference)	4	3	4	4	3.8 \pm 0.5	13.33
9	Sleeve length	24	23.5	35	35	29.4 \pm 6.5	22.12
10	Shoulder length	12.5	13.5	14	9	12.3 \pm 2.3	18.41
11	Across back	42	42	40.5	47	42.9 \pm 2.8	6.62
12	Cuff length straight (1/2)	14.5	13.5	11	14	13.3 \pm 1.6	11.73
13	Waist length front	46	44	40	44	43.5 \pm 2.5	5.79

^{a)} standard deviation; ^{b)} coefficient of variation

This variations in the measures of the different brands for what should nominally be the same medium size are remarkable. The size seems to be derived from the same recommended chest size and waist size (centre front length has a CV of 1.8%, full front a CV of 3.1% and across chest a CV of 3.88%). The large CV for other measures (for example CV of 11.73% for cuff length) is thought to affect the fit of the garment. In particular, the chest size measure affects the pressure distributed by the garments when worn, especially if the wearer of the garment is towards the upper limit of the suggested size measurement.

These variations in measurement between the sample garments illustrate the need for more detailed sizing recommendations for users to ensure correct fit and consequently sufficient compression. It is also believed that these variations in grading could affect the pressure distributed across sizes. It must be taken into consideration that only one medium size sample was measured per brand. This helps to highlight the differences between garments when consumers purchase them.

Generally, it should be noted that while significant differences in grading were highlighted by these measurements, only one sample of one size was examined. Therefore, some of the measurements taken may be unrepresentative as a whole and the result of mistakes in production. The relationship between the size of the garments and the fibre content will again be of interest when looking at the pressure distribution of the samples. Where the samples have the same recommended torso size but show varying chest measurements, the effect of this on the compression will also be highly interesting. Therefore, further research to investigate these differences in grading on a much larger number of samples may be helpful.

3.3 Subjective assessment of comfort perception during cycling

3.3.1 Psychological responses

Subjects were required to assess the overall look, stretchiness and clothing fit by handling and putting the garments on respectively. This was their initial preference of the sample before starting the exercise. Out of the four samples tested (Figure 4), assessments of the perceived stretchability/non-stretchability property of the garments generally fell in the “neutral” category (4–5) for sample C, B and D. In fact, these three samples are not similar by fabric type (such as fabric structure, fibre composition and thickness), as shown in Table 1. Therefore, the assessment

of stretchy/non-stretchy did not differ significantly by structure, fibre composition or thickness, and provides evidence that the perception of garment stretchability is not affected solely by fabric type.

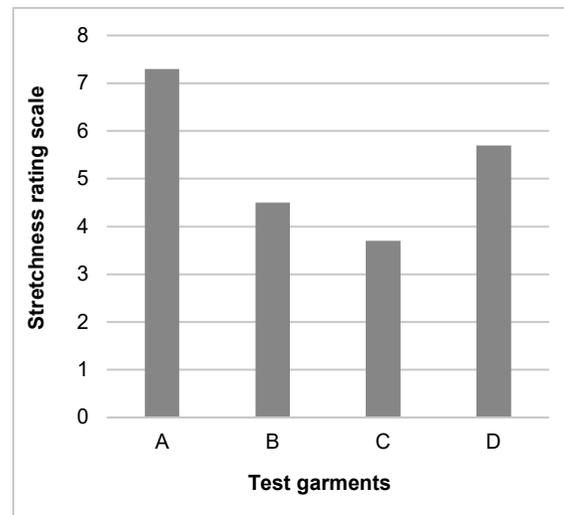


Figure 4: Average value of stretchiness, 9-point scale: 1 (very stretchable) ... 9 (non-stretchy)

In addition, for sample A, the fabric stretchability was rated “moderately non-stretchy”, while it was rated as “loose” in terms of tightness/looseness of the garment fit to the body. This agrees with garment size measurements (Table 4), which are above the average for almost all measurement points considered. Similarly, the same “loose” fit assessment was given to garment D, while garments B and C were rated as “normal/moderate” (Figure 5). The fabrics of these garments were different in terms of composition and

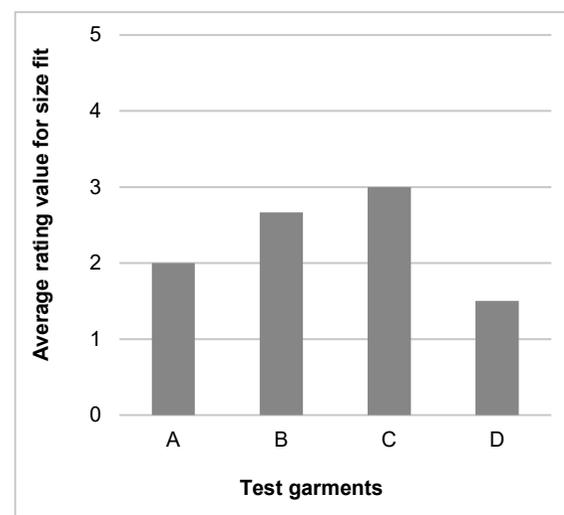


Figure 5: Average value of clothing size fit, 5-point scale: 1 (too loose) ... 5 (tight fit)

other properties (Table 1), and it is therefore unlikely that this minor difference in fit could have contributed to greater discomfort during wear. The results further indicated that garment C constructed from polyamide and elastane material (Table 1) is liked more than the other samples (Figure 6).

We concluded from the pre-test ratings of the psychological responses “clothing size fit”, “stretchiness” and “overall look” that the polyamide-elastane garment C was more accepted than the polyester garments A and D, and slightly more accepted than garment B, which coincides with the slightly better fit of garment C than garment B, while garments A and D were on the loose side. Garment B was, however, considered more stretchy than garment C, so a good fit and adequate stretching contribute to better acceptance. Thus, the difference between the garments observed on these subjective dimensions under pre-test conditions may be due to the characteristics of the fabrics from which the garments were constructed, as well as the design, assembly and overall appearance/look of the ensemble.

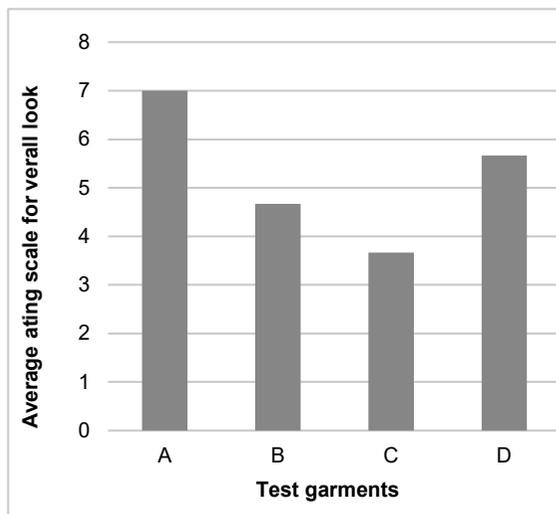


Figure 6: Overall look: how well the garment is liked/disliked, 9-point scale: 1 (well liked) ... 9 (disliked)

Thermal transmission is thought to be one of the most important factors affecting clothing comfort [47, 48]. The thermal insulation of clothing is affected by many physical factors, such as fabric thickness, the amount of body surface area covered by the garment, garment design (looseness and tightness) and number of fabric layers [46].

The subjective measurements were collected during field trials during the warmup and cycling immediately after recovery stages. The test data was split and

grouped over the first two days 1 and 2 and last two cold/dry days (Table 2) in order to show whether the environment influences the results or not. All clothing trials were performed in the actual working field environment (cold and warm) at an average temperature of between 10 °C and 16.5 °C, a relative humidity of between 48% and 85%, and a wind speed of 0.9 and 0.6 km/h, respectively. The average age, height and weight of the subjects were 22.8 ± 1.0 years, 173.8 ± 10.7 cm and 61.6 ± 4.5 kg, respectively as described in Table 1. Each subject tested all four of the garments on separate occasions.

Thermal-sweat sensation: Professional cyclists train much more intensively, and the wetness level and expectations are therefore completely different for recreational cyclists. Physiological effects during different activity levels (such as seated, exercising and recovery condition) of the test were mostly related to moisture properties (Figures 7–9). The different garment fabrics did have effects on thermal perception and comfort, as well as on the moisture related perceptions of the wearer.

The various subjective thermal-wet sensations changed in different ways during exercise under different climatic condition. Figures 7 and 8 illustrate the results. Most of the garment-related moisture sensation increased significantly with activity (Figure 7), but the warm skin temperature sensation (Figure 8) showed a decreasing trend over time in the start/recovery stage. In general, we see from the mean skin temperature of the test subjects while wearing the test

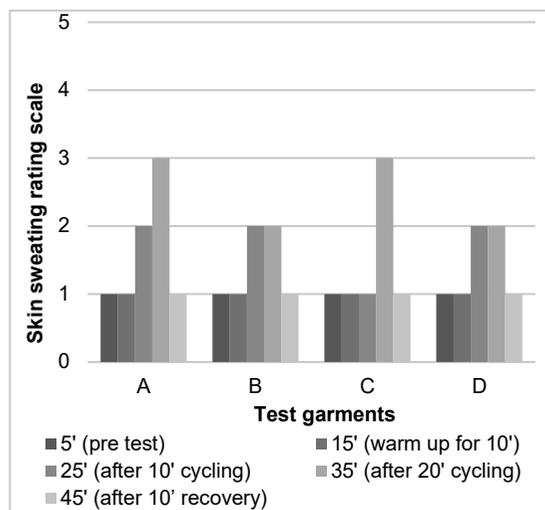


Figure 7: Average skin sweating sensation of test subjects while wearing analysed test garments under different activity level, 5-point scale: 1 (neutral) ... 5 (extremely wet)

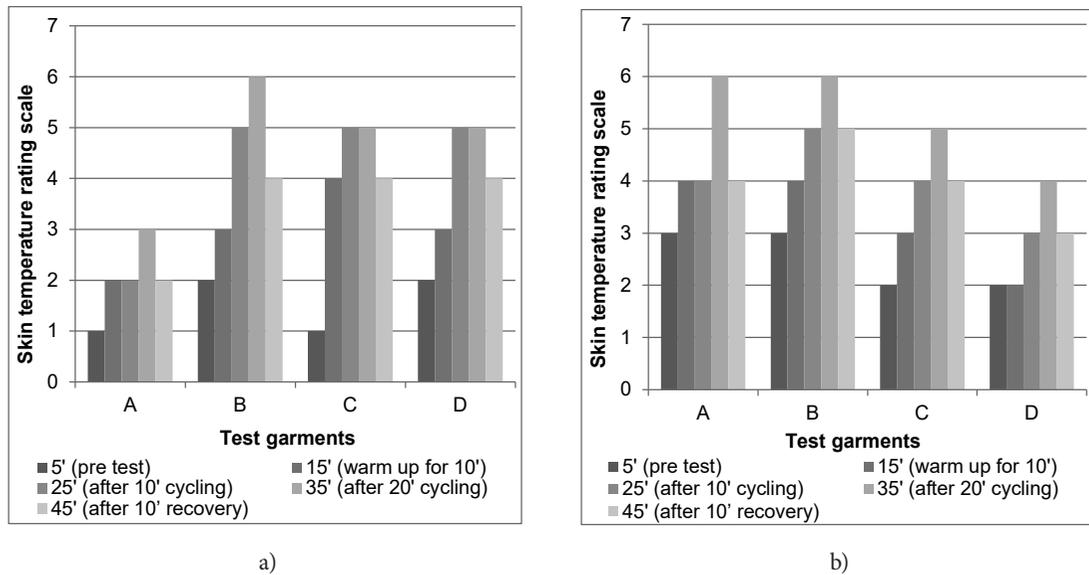


Figure 8: Mean skin temperature sensation of test subjects while wearing analysed sample test garments under different activity level: a) in cold and b) in warm climatic conditions; 7–point scale: 1 (cold) ... 7 (hot)

garments in the warm and cold climatic conditions (Figure 8 a–b) that garment B resulted in greater perception of heat in both conditions, and garment A resulted in greater perception of skin wetness than garment B, but less in heat sensation in cold conditions after 20 minutes of cycling. The subjects had similar neutral skin temperature sensation while wearing garments C and D in cold conditions (Figure 8 a) and they indicated less skin wetness after 20 minutes of cycling while wearing garment D than while wearing garment A (Figure 7).

From these results, we can also deduce that the loose garments A and D result in lower skin temperature sensation in hot conditions during recovery, with the loosest garment D resulting in the lowest skin temperature perception overall in warm conditions. However, for aerodynamic reasons, cyclists want to avoid loose garments. Among the good fitting garments B and C, garment C demonstrated the best temperature properties (i.e. lowest skin temperature sensation in warm conditions), but a higher sweat sensation rating after 20 minutes of cycling than garment B. This showed that the polyester garment B had a lower moisture uptake from the skin than the polyamide/elastane fabric C. It is important to note that even during the warmup, garment A was perceived as cold in cold conditions, while this was the case for garment D in warm conditions, demonstrating that a looser fit results in more training activity required to warm up. Considering the deviation from the neutral

4 scale in skin temperature sensation during the warmup and cycling phases, garment C performs best in cold conditions (Figure 8a), followed by garment D.

Sensorial comfort: With regard to skin contact attributes in terms of the perceived sticky sensation of the skin, garment A and B were assessed as moderately sticky, one score higher than C, and two scores above the loosest garment D (i.e. where less fabric comes into contact with the skin) as shown in Figure 10. Not much variation was identified between the garments in terms of stiffness, with all recording a score close to the value of 4, meaning all give a moderately stiff touch sensation.

Ergonomic comfort: Considering the degree of comfort, garment B rated as neutral (score of 5) whereas garment C was rated as very comfortable (score of 8) and was also perceived as normal (score of 3) for ease of body movements while cycling (Figure 9) and making it easier (score of 2) to perform duties. To a lesser extent, the less stiff garment B (Figure 10) was also perceived as somewhat easy for performing duties (score of 3). When we compared overall fit for the purpose of the garment, garment D was assessed as fitting poorly for the desired purpose (score of 2) and difficult to perform the task (score of 4).

These differences in the skin feel sensations of the garments, combined with the perceived pre-test differences among the garments for “feel” and “comfort”

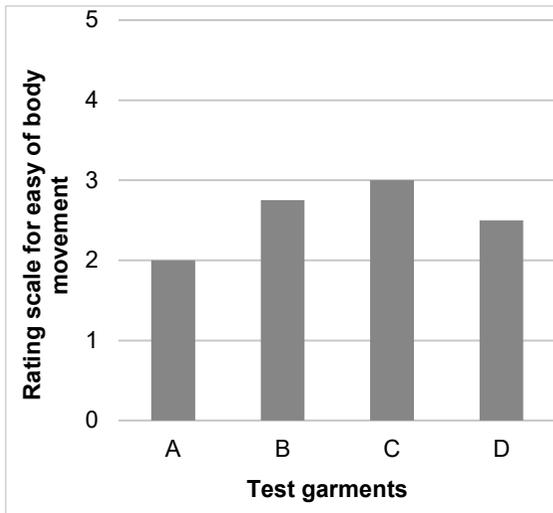


Figure 9: Average value of ease of body movements while cycling with ensemble, 5-point scale: 1 (very stiff) ... 5 (very flexible)

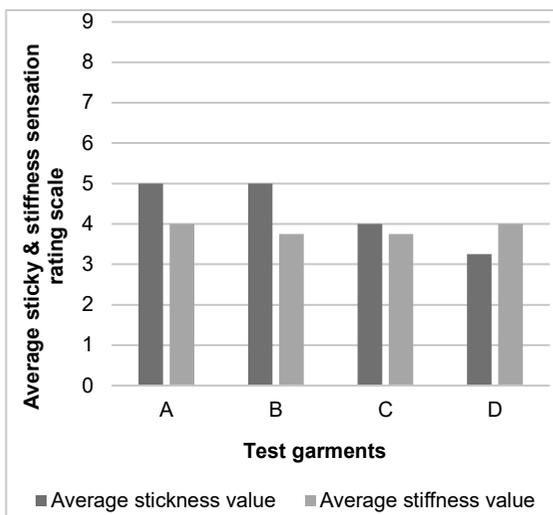


Figure 10: Average stickiness and stiffness sensation against the skin for the duration of whole activity phase, 9-point scale: 1 (not at all) ... 9 (extremely strong)

suggest that the tactile characteristics of the fabrics contributed, along with the moisture and thermal sensations, to the overall assessment of the comfort of the garments during the study. The overall findings for the comparative comfort of the garments were consistent with the expected response that the considered polyamide/elastane fabric (C) tends to be more comfortable, with excellent elasticity and recovery behaviour, while polyester fabrics A-B-D are more likely to produce discomfort. This assumption

was made during a pre-test questionnaire in which the subjects generally expressed the most favourable opinion regarding the 80/20 polyamide/elastane fabric (C) and the least favourable opinion regarding the 100% polyester fabric (D) with respect to fabric-skin contact sensation. This pre-test also ensured that all garments, regardless of the fabric from which they were constructed, fit the participants equally well in various body areas. Adapting the polyester garment construction in such a way that it has a good stretchability and can thus be made to fit tighter (garment B) is highly preferred by the cyclists over the other polyester fabrics (A and D), but nevertheless remains less preferred than the polyamide garment, with a higher stickiness, lower fit and higher skin temperature sensation. Though the sweat perception of fabric B was better (lower) than fabric C after 20 minutes of cycling, this brings less weight for cyclists who expect a certain level of sweat during sport [30].

4 Conclusion

Significant brand-based differences between garments of the same specified size M were observed and overall, the polyamide/elastane jersey was perceived as the best. The results suggest that thermal and moisture sensations of different T-shirts primarily relate to the different physiological state of subjects (i.e. perception of skin temperature and wetness). On the other hand, tactile sensations were found to differ between the subjects wearing different jersey, whilst differences in these sensations did not change over time (exercise), nor show any significant difference between warm and cold conditions. It therefore seems that the tactile and fit sensations were mainly determined by fabric-skin-contact, not by the environmental conditions or exercise. This suggests that the overall preferences of the subjects for clothing worn next to the skin, in both thermal conditions of these trials, were mainly determined by the tactile and fit sensations and not by the thermal-wet sensations. The result shows that sensations of comfort-discomfort in clothing worn next to the skin can be influenced by several factors, including the environment and the physiological state of the wearers, as well as the type of fibre used in manufacturing the fabrics and garment fit. The interaction between the factors is also important, and overall acceptability of a garment is not easily predicted by simple handling tests. The cyclists do seem to prefer

tight fitting garments with enough stretch. The results of this study provide guidance for the optimal design and development of cyclist outfits.

Acknowledgements

This paper was supported by the CoE project funded through KFW project no. 51235 (PE 479—Higher Education) under grant no. MBZ/201166305 in collaboration with the Ethiopian government. The authors are grateful to all the volunteer subjects who participated in this study. The authors also give special thanks to Mr Abrham D., Abdella S. and Mr Sufyian D. (EiTEX, Bahir Dar University) for their assistance during the field test.

References

1. BIVAINYTĖ A., MIKUČIONIENĖ, D. Investigation on the dynamic water absorption of double-layered weft knitted fabrics. *Fibres & Textiles in Eastern Europe*, 2011, **19**(6), 64–70.
2. BHATIA, D., MALHOTRA, U. Thermo-physiological wear comfort of clothing: an overview. *Journal of Textile Science & Engineering*, 2016, **6**(2), 1–6, doi: 10.4172/2165-8064.1000250.
3. GUPTA, D. Design and engineering of functional clothing. *Indian Journal of Fibre & Textile Research*, 2011, **36**(4), 327–335.
4. MIN, L., DONG-PING, L. WEI-YUAN, Z., XIAO-ZHONG, T. A multiple regression model for predicting comfort sensation of knitted fabric in sports condition based on objective properties. In *2009 Second International Conference on Information and Computing Science (ICIC)*, Edited by Hong-Guang Bao et al. Los Alamitos : IEEE Computer Society, 2009, 372–375, doi: 10.1109/ICIC.2009.299.
5. KANAKARAJ, P., RAMACHANDRAN, R. Active knit fabrics - functional needs of sportswear application. *Journal of Textile and Apparel, Technology and Management*, 2015, **9**(2), 1–11.
6. ASHDOWN, S.P. Improving body movement comfort in apparel. In *Improving comfort in clothing. 1st edition*. Edited by G. Song. Cambridge : Woodhead Publishing, 2011, 278–302, doi: 10.1533/9780857090645.2.278.
7. HUNTER, L., FAN, J. Improving the comfort of garments. In *Textiles and fashion: Materials, design and technology*. Edited by Rose Sinclair. Cambridge : Woodhead Publishing, The Textile Institute, 2015, 739–761, doi: 10.1016/B978-1-84569-931-4.00029-5.
8. NICHOLS, D. Practical recommendations for endurance cycling in hot/humid conditions. *Aspetar Sport Medicine Journal*, 2016, 440–445.
9. LI, Y. The science of clothing comfort. *Textile Progress*, 2011, **31**(1-2), 1–135, doi: 10.1080/00405160108688951.
10. BARTELS, V.T. Improving comfort in sports and leisure wear. In *Improving comfort in clothing. 1st ed.* Edited by G. Song. Cambridge : Woodhead Publishing, 2011, pp. 385–411, doi: 10.1016/B978-1-84569-539-2.50015-6.
11. KEMMLER, W., von STENGEL, S., KOCKRITZ, C., MAYHEW, J., WASSERMANN, A., ZAPF, J. Effect of compression stockings running performance in men runners. *Journal of Strength and Conditioning Research*, 2009, **23**(1), 101–105, doi: 10.1519/JSC.0b013e31818eaef3.
12. STANEK, J.M. The effectiveness of compression socks for athletic performance and recovery. *Journal of Sport Rehabilitation*, 2017, **26**(1), 109–114, doi: 10.1123/jsr.2015-0048.
13. VENKATRAMAN, P.D., TYLER, D., FERGUSSON-LEE, L., BOURKE, A. Performance of compression garments for cyclists. In *The Textile Institute's International conference on advances in functional textiles*. Manchester : The Textile Institute, 2013, 2–32, <https://e-space.mmu.ac.uk/id/eprint/601082>.
14. CIPRIANI, D.J., YU, T.S., LYSSANOVA, O. Perceived influence of a compression, posture-cueing shirt on cyclists' ride experience and post-ride recovery. *Journal of Chiropractic Medicine*, 2014, **13**(1), 21–27, doi: 10.1016/j.jcm.2014.01.007.
15. De ROME, L., BOUFOUS, S., GEORGESON, T., SENSERRICK, T., IVERS, R. Cyclists' clothing and reduced risk of injury in crashes. *Accident Analysis & Prevention*, 2014, **73**, 392–398, doi: 10.1016/j.aap.2014.09.022.
16. LIU, K., KAMALHA, E., WANG, J., AGRAWAL, T.K. Optimization design of cycling clothes' patterns based on digital clothing pressures. *Fibers and Polymers*, 2016, **17**(9), 1522–1529, doi: 10.1007/s12221-016-6402-2.
17. CHUNYAN, Q., YUE, H. The review of smart clothing design research based on the concept of 3F + 1I. *International Journal of Business and Social Science*, 2015, **6**(1), 199–209.

18. BEDEK, G., SALAÜN, F., MARTINKOVSKA, Z., DEVAUX, E., DUPONT, D. Evaluation of thermal and moisture management properties on knitted fabrics and comparison with a physiological model in warm conditions. *Applied Ergonomics*, 2011, **42**(6), 792–800, doi: 10.1016/j.apergo.2011.01.001
19. ALLSOP, C.A. An evaluation of base layer compression garments for sportswear : Master Thesis. Manchester Metropolitan University, Department of Clothing Design and Technology, 2012, 127 p.
20. De RAEVE, A., VASILE, S. Adapted performance sportswear. In *Proceedings of 7th International Conference 3D Body Scanning Technology*. Ascona : Hometrica Consulting, 2016, 9–15, doi: 10.15221/16.009.
21. SPURKLAND, L., BARDAL, L.M., SÆTRAN, L., OGGIANO, L. Low aerodynamic drag suit for cycling - design and testing. In *icSPORTS 2015 - Proceedings of the 3rd international congress on sport sciences research and technology support*. Edited by Jan Cabri and Pedro Pizarat Correia. Setúbal : Science and Technology Publications, 2015, 86–96, doi: 10.5220/0005589600890096.
22. Özkan, E.T., Meriç, B. Thermophysiological comfort properties of different knitted fabrics used in cycling clothes. *Textile Research Journal*, 2015, **85**(1), 62–70, doi: 10.1177/0040517514530033.
23. UPRETI, Monika, GAHLOT, Manisha. Subjective testing for clothing comfort. *International Journal of Emerging Research in Management and Technology*, 2016, **5**(4), 14–18. Available from <<https://docplayer.net/76723978-Subjective-testing-for-clothing-comfort-1-monika-upreti-2-manisha-gahlot-1.html>>.
24. PEARSON, E.J.M. Comfort and its measurement – a literature review. *Disability and Rehabilitation: Assistive Technology*, 2009, **4**(5), 301–310, doi: 10.1080/17483100902980950.
25. PASCAL, M., VANGSGAARD, S., DE ZEE, M., KRISTIANSEN, M., VERMA, R., KERSTING, U., VILLUMSEN, M., SAMANI, A. Ergonomics in sports and at work. In *11th International symposium on human factors in organisational design & management and the 46 Annual Nordic Ergonomics Society conference (ODAM-NES Copenhagen Denmark)*, 2014, 57–62.
26. ROJA, Zenija, KALKIS, Henrijs, REINHOLDS, Ingars, ROJA, Inara. Physical load among construction workers and analysis with objective ergonomics research method. In *Advances in physical ergonomics and human factors : Proceedings of the AHFE 2016 International conference on physical ergonomics and human factors, July 27-31, 2016, Walt Disney World®, Florida, USA. (Advances in intelligent systems and computing, Vol. 489)*. Edited by Ravindra S. Goonetilleke and Waldemar Karwowski. Heidelberg : Springer International, 2016.
27. CLARSEN, B., KROSSHAUG TRON, T., BAHR, R. Overuse injuries in professional road cyclists. *American Journal of Sports Medicine*, 2010, **38**(12), 2494–2501, doi: 10.1177/0363546510376816.
28. SILBERMAN, M.R. Bicycling injuries. *Current Sports Medicine Reports*, 2013, **12**(5), 337–345, doi: 10.1249/JSR.0b013e3182a4bab7.
29. Van der WALT, A., van RENSBURG, D.C.J., FLETCHER, L., GRANT, C.C., van der WALT, A.J. Non-traumatic injury profile of amateur cyclists. *South African Journal of Sports Medicine*, 2014, **26**(4), 119–122, doi: 10.7196/SAJSM.555.
30. TEYEME, Y.W., MALENGIER, B., TESFAYE, T., CIOCCI, M., VASILE, S., van LANGENHOVE, L. An empirical analysis of potential cyclist injuries and cycling outfit comfort. *Journal of Textile Science & Fashion Technology (JTSFT)*, 2019, **4**(1), 1–10, doi: 10.33552/JTSFT.2019.04.000578.
31. *National statement on ethical conduct in human research 2007* (Updated 2018). Canberra : The National Health and Medical Research Council, the Australian Research Council and Universities Australia. Commonwealth of Australia, 2007, 1–116.
32. MESLIN, E.M. Protecting human subjects from harm through improved risk judgments. *IRB: Ethics & Human Research*, 1990, **12**(1), 7–10, doi: 10.2307/3563683.
33. ARTHUR, D. Sportful BodyFit Pro Race Jersey [online]. Road.cc [cited February 21, 2019]. Available from: <<https://www.road.cc/content/review/226023-sportful-bodyfit-pro-race-jersey>>
34. ATKINS, R. Decathlon cycling jersey [online]. SpyCycle [cited February 21, 2019]. Available from: <<https://www.spycycle.uk/decathlon-cycling-jersey-reviewed>>.
35. Size guide. [online]. ASSOS [cited February 21, 2019]. Available from: <<https://www.assos.com/size-guide>>.
36. Classic cycling [online]. Cycling clothing sizing charts. Help with fit and sizing [cited February 21, 2019]. Available from: <https://classiccycling.com/pages/sizing_charts>.

37. Size guides [online]. Sports direct [cited February 21, 2019]. Available from: <<https://www.sports-direct.com/customerservices/otherinformation/sizguide>>.
38. BRAGANÇA, S., FONTES, L., AREZES, P., EDELMAN, E.R., CARVALHO, M. The impact of work clothing design on workers' comfort. *Procedia Manufacturing*, 2015, **3**, 5889–5896, doi: 10.1016/j.promfg.2015.07.898.
39. KONSTANTINOS, S. Assessment methods for comfort of consumer products at early stages of the development process : PhD Thesis. Technical University of Denmark, Department of Management Engineering, 2015.
40. ALI, A., CAINE, M.P., SNOW, B.G. Graduated compression stockings : physiological and perceptual responses during and after exercise. *Journal of Sport Science*, 2007, **25**(4), 413–419, doi: 10.1080/02640410600718376.
41. WONG, A.S.W., LI, Y., Yeung, P.K.W. Predicting clothing sensory comfort with artificial intelligence hybrid models. *Textile Research Journal*, 2004, **74**(1), 13–19, doi: 10.1177/004051750407400103.
42. WONG, A.S.W., LI, Y. Clothing sensory comfort perception and brand preferences. In *IFFTI International conference 2002 : Fashion and textiles : the new frontiers : design, technology and business*, 1131–1135. Available from: <http://hdl.handle.net/10397/38878>.
43. ISO 10551:2001 (E) Ergonomics of the thermal environment – assessment of the influence of the thermal environment using subjective judgement scales Ergonomie. Geneva : ISO Copyright Office, 2001.
44. ISO 7730:2005 (E) Ergonomics of the thermal environment – analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. Geneva : ISO Copyright Office, 2005.
45. DEOPURA, B.L. Polyamide fibres. In *Polyesters and polyamides*. Edited by B.L. Deopura et al. Cambridge : Woodhead Publishing, 2008, 41–61, doi: 10.1533/9781845694609.1.41.
46. UTTAM, D. Active sportswear fabrics. *International Journal of IT, Engineering and Applied Sciences Research (IJIEASR)*, 2013, **2**(1), 34–40.
47. KAPLAN, S., OKUR, A. Thermal comfort performance of sports garments with objective and subjective measurements. *Indian Journal of Fibre & Textile Research* 2012, **37**(1), 46–54.
48. BARTKOWIAK, G., FRYDRYCH, I., GRESZTA, A. Fabric selection for the reference clothing destined for ergonomics test of protective clothing: physiological comfort point of view. *AUTEX Research Journal*, 2016, **16**(4), 256–261, doi: 10.1515/aut-2016-0037.
49. LI, Y. Computer aided clothing ergonomic design for thermal comfort. *Sigurnost*, 2011, **53**(1), 29–41. Available from: <<https://hrcak.srce.hr/67036>>.