

Garment Design and Engineering for Hospital Use

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Abstract. Garments used in hospitals play an important role in user's comfort and health. This paper presents the developments of a patented design technology for medical garments aimed at users, caregivers, and health care providers. Traditional gowns lacking comfort and protection affect the patient's dignity. Similarly, patients often use their own garments, which are not designed to provide the best comfort and protection if sensing capacity is affected. Additionally, they can interfere with caregivers' daily tasks. The proposed pajamas consider these needs and allow an effective interaction between patient and caregiver without compromising the person's self-esteem. The selection of functional textile fibers and the use of seamless production processes allow the design of products advantageous in the prevention of wounds and pressure ulcers, as pressure points are reduced and the micro-climate of the skin is managed in a more effective way, enhancing the levels of sensorial, physiological and ergonomic comfort.

Keywords: Comfort · Protection · Medical garments design

1 Introduction

Textiles have a significant impact on the comfort and recovery of patients in hospital settings. With the right choice of materials, it is possible to manage temperature and humidity, which constitute some of the biggest challenges in maintaining skin integrity, to manage mechanical forces, namely pressure, friction, and shear, and to aid in comfort, with properties such as draping behavior and bending stiffness [1]. This alone is crucial to ensure that patients are not only comfortable, but also benefit from the best possible textile properties that can speed their recovery and prevent additional complications, such as pressure ulcers [2]. Moreover, the effect of appropriate clothing on self-esteem should not be underestimated, as well as the positive effects of high self-esteem on the healing process [3]. Therefore, it is important to determine which

properties are desirable in a textile to be used in hospital settings, and how to integrate these properties in a single fabric while keeping in mind costs, comfort, and usability for the user and caregiver.

There are several textile properties important when designing such a garment. Some of them relate to the actual prevention of comorbidities, namely mechanical and thermal properties, while others are more associated with the comfort of the user, such as handle qualities. Yet others pertain to both categories – thermal properties, for example, are crucial in that they influence the management of temperature and humidity, thus helping in maintaining skin integrity, but at the same time are highly correlated with the comfort of the user, which is naturally vital for any garment [4].

2 Materials and Methods

Nine different materials were first tested for several textile properties, namely mass per unit area, thickness, drape, stiffness, friction, compression, tensile, and shear (using KES), air permeability, water vapor, permeability, vertical wicking resistance to impact water penetration, all Alambeta's thermal parameters, and, finally, a thermal manikin was used to determine thermal insulation.

Careful analysis of these data allowed us to select the material that displayed the best overall properties (80% polyamide and 20% elastane), which was in turn used to manufacture a garment. It was decided that a pajama would be most useful across settings – people wear them at home, and hospitals and nursing homes either provide patients with their own pajamas/gowns or allow them to bring in their own. Moreover, a pajama could be used by both bed-ridden and wheelchair bound people, as well as those who are recuperating from surgery or illness. Finally, the same materials and structure can be used in the future to manufacture other products like bed sheets.

Two types of pajama were produced in seamless looms, in order to reduce the number of seams and their impact in the amount of pressure between the patient's body and the support surface – a single-piece and a two-piece. The reasoning was that bed-ridden people could use the single-piece garment, which would theoretically facilitate caregivers' work, by allowing easy access to several parts of the body by means of several zippers, while at the same time maintaining the user's comfort and dignity, since it would eliminate the need to completely expose the entire body just to examine, for example, skin integrity at the buttocks. The amount of zippers was also intended to aid caregivers in dressing and undressing the patient, thus reducing time spent (and associated costs) and freeing staff for other tasks. Extreme care was taken so that all zippers were completely protected to ensure that no harm was done to the person's skin. All zippers and seams were placed on the front, thus guaranteeing that they did not cause undue pressure on the back and side areas of the body typically in contact with the support surface (see Fig. 1 for an overview of a manikin wearing the single-piece).

The two-piece pajama was intended to be used by patients with a relatively good degree of mobility capable of dressing and undressing themselves. The upper part featured one single zipper on the front, whereas the back remained seam and zipper-free, as with the single-piece. The length of the upper part was deliberately kept



Fig. 1. Thermal manikin wearing the single-piece pajama.

short, so as to ensure that there were no unnecessary creases and folds when the user sat or laid down, which would create needless pressure points. The lower part of the pajama had two zippers at the front that allow the user to easily dress and undress, since the pants completely open up. A person could, for example, set the pants on top of the bed, open both zippers, place themselves on top of the trousers and simply zip up until they are fully dressed. This was designed to be used even by paraplegics that retain upper body strength and mobility.

All zippers on both pajamas opened from both sides. This helped in exposing only the body area that needed to be exposed, which contributed to the comfort of the user, since it protected against cold, and also helped with psychological comfort, since it made total exposure unnecessary. Figure 2 shows such an example, with a patient undergoing EMG (electromyography) physical therapy on a leg – using our pajama allows the therapist to create only a small opening needed for the procedure, while keeping the rest of the body clothed and, consequently, keeping the user comfortable. Finally, all zippers ended with two small buttons to further ensure a closed thermal environment.



Fig. 2. Patient undergoing EMG physical therapy while taking advantage of our pajama's zippers.

Finally, there was one last feature, which, although not directly linked to the user's thermophysiological comfort or other functional properties, was crucial for the patients' overall confidence, and self-esteem. Our pajama's material allows for the easy attachment of Velcro. As such, we manufactured a few pieces of clothing without the back and with Velcro at specific sites. This allowed us to attach clothing to the front of the pajama without compromising the user's back. While maintaining our pajama's functional features, this simple attachment allowed patients to appear dressed in different clothing, just as any healthy person appears. Clothing is incredibly easy to attach and remove, and has a huge impact on the patient's self-esteem. Figure 3 shows such an example, with a patient appearing to wear a denim vest that in reality has no back and is only attached with Velcro to the pajama.



Fig. 3. Patient wearing a denim vest attached to the pajama with Velcro

3 Clinical Setup

All studies took place at the Vizela UCCI (Unidade de Cuidados Continuados e Intensivos – Continued and Intensive Care Unit), which housed 60 patients with varying degrees of mobility and independence.

The objective of this experiment was twofold: firstly, we wanted to compare our pajama with the participants' usual pajama, and secondly we wanted feedback on the pajama's comfort for the user, and ease of use for the caregiver.

It was decided that the single-piece would be used for participants with a low level of independence, whereas more independent patients used the two-piece. The reasoning was that the two-piece would be easier, especially for when participants needed to use the bathroom, whereas feedback from caregivers was badly needed for the one-piece, especially to find out whether the pajama was suitable for hygiene procedures.

Several pieces of equipment were used to collect data: Tekscan's pressure mat, experimental force and temperature sensors (SensingCushion), and several questionnaires.

Three types of trials were conducted: one with the participants sitting down on a wheelchair (see Fig. 4), a second one where participants sat on a type of recliner (see Fig. 4), and finally a third one where participants were lying down on a bed



Fig. 4. Trial on the wheelchair on the left. Trial on the recliner on the right.

(see Fig. 5). The protocol used was slightly different for each trial, to accommodate for the differences in setting. Still, all participants wore our pajama for a full night. This helped participants judge its comfort and allowed caregivers to work with the pajama for a significant number of hours, thus allowing for a more informed decision on its merits. All trials were conducted in the participants' rooms.



Fig. 5. Trial lying down supine.

Our sample was comprised of six participants, whose characteristics can be found in Table 1. All signed a consent form, except for those with a compromised cognitive status, who were authorized by their next of kin to take part in our experiment.

After wearing our pajama for one night, participants began each trial either with our pajamas or their own.

For trials on the wheelchair, the pressure mat and SensingCushion were placed on top of the wheelchair. Participants then sat down for 5 min. During this first session a semi-structured interview was conducted to find out the participants' opinions on the pajama.

Secondly, the exact same procedure was repeated with the participant sitting on a recliner. Naturally, no interview took place, since it had already been done.

Table 1. Sample characteristics.

| P | Size | Body mass (kg) | Pathology | Level of independence | Incontinence | Pajama |
|---|------|----------------|-----------|-----------------------|-------------------------|-----------|
| 1 | M | 67 | CVA | Semi-independent | No | Two-piece |
| 2 | L | 79 | CVA | Independent | No | Two-piece |
| 3 | M | 82 | CVA | Semi-independent | No | Two-piece |
| 4 | M | 65 | CVA | Dependent | Diaper | One-piece |
| 5 | L | 71 | CVA | Independent | No | Two-piece |
| 6 | S | 62 | CVA | Dependent | Urinary catheterization | One-piece |

Finally, the pressure mat was placed on the participants’ beds, without the SensingCushion. They then laid down for 5 min in each position – supine, lying on their left side, and lying on their right side.

It should be noted that only independent or semi-dependent participants underwent all trials. Those who were completely dependent only participated in the lying down trial, due to the natural constraints of their health status. Moreover, no interview was undertaken with these participants due to their decreased mental status.

Finally, caregivers who worked with our participants were asked to answer a brief questionnaire on the usability of our pajama.

4 Results

For the wheelchair trials our pajama performed best in 3 out of 4 participants, and in the recliner trials it performed best twice, worse once, and roughly the same the remaining trial. Figure 6 shows temperature over time for one participant where our pajama

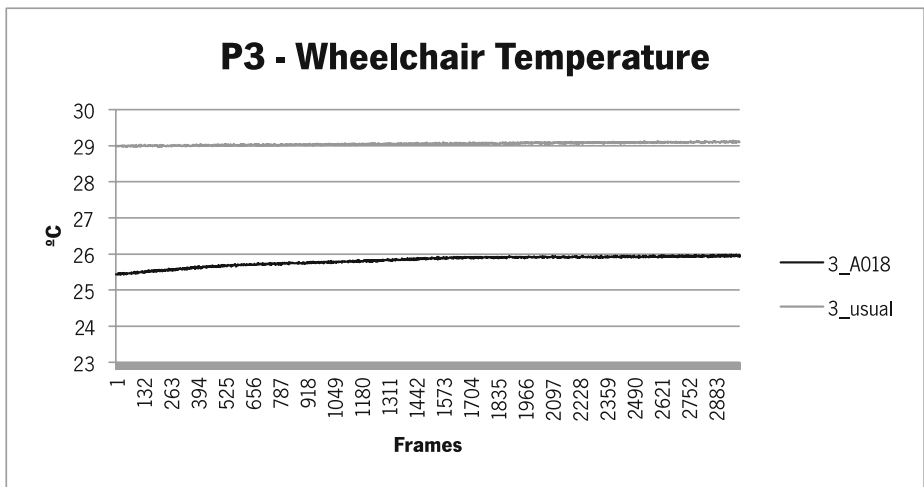


Fig. 6. Temperature (in °C) over time for participant 3 sitting on the wheelchair.

performed best: the participant’s usual pajama’s average temperature was 29.05 °C against only 25.81 °C with our pajama, which corresponded to an average difference of 3.24 °C.

As for pressure data, an unexpected error in the calibration file left us only with data for two participants sitting on the recliner, with our pajama showing better performance on one occasion, with lower pressure values than the participants’ pajama. Figures 7 and 8 show peak pressure at the ischia (in g/cm²) for both pajamas.

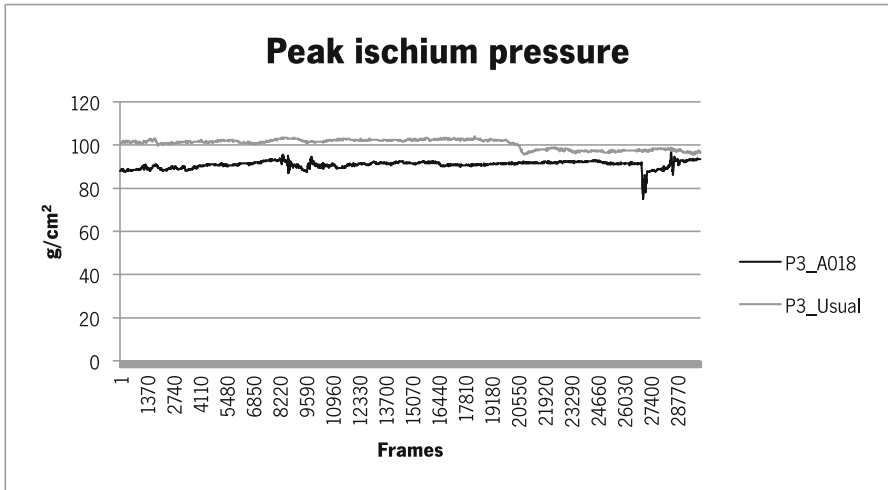


Fig. 7. Peak ischium pressure (in g/cm²) for participant 3 wearing both pajamas.

As these charts show, participant 3 shows an advantage to our pajama, with an average difference of 9.67 g/cm² and a maximum difference of 22.5 g/cm². On the other hand, the opposite is true for participant 5, with an average difference of 7.52 g/cm² and a maximum of 14.5 g/cm². Still, having only two participants prevents us from drawing any definitive conclusions for this variable.

Finally, we turned to the questionnaires given to the caregivers and semi-structured interviews from the participants.

The questionnaire was based on the System Usability Scale, a widely used tool that quickly and reliably measures the usability of a product, and adapted to our specific needs.

Only two caregivers answered the questionnaires, which made it impossible to perform any statistical analysis on the data. Thus, Table 2 simply presents answers from both caregivers. Where both answered the same, only one cross is displayed, whereas two crosses on the same answer signify different answers.

Both respondents gave similar answers on most items, with the exception of item 2 – one caregiver completely agreed that the pajama was efficient in managing temperature, while the other neither agreed nor disagreed – and item 5 – one caregiver disagreed that the pajama was complicated to use, but the other agreed. With only two

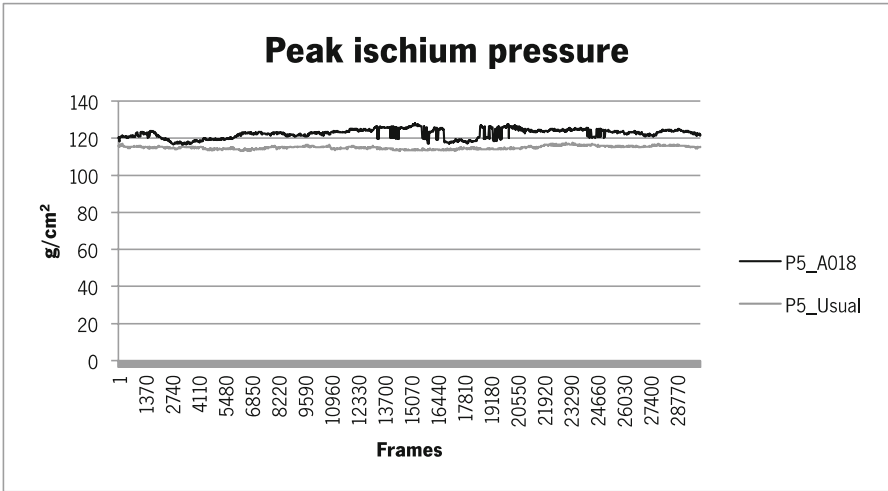


Fig. 8. Peak ischium pressure (in g/cm²) for participant 3 wearing both pajamas.

Table 2. Usability questionnaire for caregivers

| Question | 1 | 2 | 3 | 4 | 5 |
|--|---|---|---|---|---|
| 1. I would not like to work with this pajama in the future | | X | | | |
| 2. The pajama is efficient in managing temperature | | | X | | X |
| 3. The pajama is not efficient in managing humidity | X | X | | | |
| 4. The pajama helps prevent Pressure Ulcers | | | | | X |
| 5. The pajama is complicated to use | | X | | X | |
| 6. The pajama is easy to undress | | | | | X |
| 7. It's difficult to dress the patient in the pajama | X | | | | |
| 8. The pajama allows easy access for user hygiene | | X | X | | |
| 9. The pajama does not make my work easier | | X | | | |
| 10. The pajama improves the user's quality of life | | | | X | X |
| 11. The pajama needs more openings | | | | | X |
| If yes, where: <u>Perineum</u> | | | | | |

participants it was impossible to draw any conclusions when their answers differed so much. Nevertheless, overall both gave a positive review on the pajama. They would both like to work with our pajama in the future, both believed it was effective in managing humidity, and more importantly, both strongly agreed that the pajama helped prevent PUs. Moreover, both strongly agreed the pajama was easy to dress and undress, both agreed the pajama made their work easier, and both agreed it improved the user's quality of life. These were the positive aspects we were able to draw from the questionnaires. On the other hand, neither caregiver agreed that the pajama allowed for easy access to perform hygiene tasks, and both strongly felt the need for more openings, namely in the perineum. After seeing these results we informally talked with the

caregivers, and all were adamant that an opening in the area of the perineum would significantly improve the pajama, since they felt it was hard to change diapers with the current configuration of the one-piece pajama.

Finally, when meeting some of the staff informally, one other advantage of our pajama became clear: physiotherapists complained that observing their patients' gait during physiotherapy sessions was a challenge due to their usual baggy garments, which could hinder their recovery. The therapists we talked to mentioned how easier it was for them to observe and correct their patients' gait when they were wearing our tight-fitting pajama. Such an example is shown in Fig. 9 where one of our participants, wearing our pajama, can be seen during a physiotherapy session walking. As is clear from the photo, the participant's legs and gait can be easily evaluated from a distance, much more accurately than if she were wearing her usual trousers or gowns.



Fig. 9. Patient wearing our pajama while undergoing physical therapy.

The patients answered a semi-structured interview while undergoing seated trials. Only four participants answered the interview, since the others' cognitive status did not allow them to do so. The interview was based on a questionnaire focused mainly on comfort.

We began by asking the patients whether the pajama, as compared with their usual pajamas, had in any way influenced their sleep. Two participants stated that they had slept better than usual and attributed this to the pajama, while the other two felt that the pajama had no influence whatsoever in the quality of their sleep. These were encouraging results, since they proved that our pajama did not hinder sleep, and may even have improved sleep for some people.

We then turned to the comfort felt while using the pajama, first asking about overall comfort and then specifying different aspects of comfort, namely thermal comfort. All participants strongly felt they were more comfortable than usual because of the pajama they were wearing. This was extremely important, since the textile tests related to

handle, such as drape, had yielded somewhat poor results for this material, which could have translated into an uncomfortable garment. These responses increased our confidence in the pajama's comfort properties, since all participants rated our pajama as comfortable. None reported any pain or discomfort due to the pajama, although one patient mentioned that he would feel more comfortable if the upper part was longer. This patient had a considerable abdominal perimeter, and the upper part of the pajama was in fact unable to cover the whole belly area. The length of the pajama was intentionally shortened, since we did not want excess material to fold and crease, and thus create pressure points that could lead to discomfort and possibly PUs. However, we do acknowledge this patient's concerns, and believe we can easily fix this by keeping the pajama shorter on the back, but lengthening the front, so that patients can be completely covered while they go about their daily lives. Finally, the same patient mentioned the need for zippers on the arms for the two-part pajama. Again, this is easily fixed. Although increasing the amount of zippers also increases the pajama's cost, we acknowledge that for patients who retain a good degree of mobility having zippers on the arms allows them to more easily dress and undress themselves. We had planned for the two-part pajama to be used for patients who are at home, and therefore are not subjected to daily skin inspections or blood drawing. This would mean they would not need the zippers on the arms as much as those patients who are in care. Still, it is reasonable to assume that users at home still have mobility difficulties, and might find it easier to dress and undress themselves with more zippers.

We then asked participants more specific questions about their thermophysiological comfort. Only one participant felt the pajama had any influence in their thermal comfort – this participant stated that he usually feels cold, and this did not happen with our pajama. The participant attributed this to fact that our pajama is tighter. When asked if they would prefer to feel colder or hotter with our pajama, all participants stated they felt “just right” and would not like to feel neither hotter nor colder. These data clearly reflect the pajama's capacity to manage temperature, since all participants felt there was no need to make any changes on this particular issue.

As for humidity management, all participants agreed that they felt their skin was neither dry nor humid, and all were satisfied with the pajama's ability to manage moisture. All stated that they would not like to see any changes in this regard. However, they all agreed that they felt no change in their skin's humidity, which means that they usually feel comfortable regarding skin moisture, and as such felt no difference with our pajama. These answers did not allow us to validate our claim of humidity management. It would be interesting to have patients who typically perspire wear our pajama for at least one night in order to see if it in any way enhanced their moisture related comfort.

We then presented a list of adjectives that could possibly describe our pajama and asked participants to state whether they felt those adjectives accurately described it. Most participants felt the pajama was neither cold nor warm, but, as they put it, “just right”. The one exception was the participant who usually felt cold, but felt warmer with our pajama. This participant described our pajama as warm. All of them rated the pajama as smooth and soft, as opposed to rough and prickly. This point in particular was important, due to the pajama's material's results on friction and drape tests, which indicated that it might be rough and uncomfortable for the user. Our participants'

answers clearly show that this was not the case, but quite the opposite, thus validating our choice of material. All felt it was made of strong materials, as opposed to delicate, but at the same time all stated it was light, as opposed to heavy. When asked if the pajama was thin or thick, all participants again rated it as “just right”. All these answers pointed to the fact that the participants’ subjective evaluation of the pajama was very positive, especially on its handle properties. As such, when asked about overall agreeability and comfort, all participants rated the pajama as very agreeable and very comfortable.

We were also interested in the participants’ opinion on the pajama’s impact on their self-esteem. All participants stated that they felt prettier than usual with our pajama, and further specified that it was in fact the pajama that influenced their self-image. Furthermore, one of the participants mentioned that he preferred the two-piece pajama, not because he felt it was prettier, but because he felt it was more practical. This particular assessment confirms our hypothesis that the two-piece pajama is more useful for patients who retain a relatively good degree of mobility.

Finally, we asked participants whether they liked wearing our pajama, if they preferred it over their usual pajamas, and if they would wear it on a daily basis. All of them strongly agreed that they liked wearing it, preferred it over their usual ones, and would definitely wear them on a daily basis.

Overall, we were very pleased with the results from the users’ questionnaires. All participants reached a very positive evaluation of our pajama on several dimensions, with the exception of humidity management. However, even in this respect the evaluation was not negative, but simply neutral. These were very encouraging results for a widespread use of our pajama in populations who are recovering from illness, but still maintain mobility. Unfortunately, we had no data for patients who were bedridden, since none were cognitively able to answer our questions.

5 Discussion and Conclusion

In sum, this experiment, although not as successful as had been hoped, allowed us to draw some conclusions on our data. Firstly, temperature data showed a clear advantage of our pajama as opposed to the participants’ usual pajamas.

Secondly, pressure data did not allow for any conclusions, since only two trials were available. In these, one showed a better performance from our pajama, with lower peak pressure results, but the other trial showed the opposite. Naturally, this was not sufficient to form any conclusions. Given the fact that the calibration file was inadequate, future experiments must take this into consideration and use a calibration file with a higher saturation point.

Finally, data from the questionnaires and interviews revealed a couple of problems with the pajama – the lack of an opening at the perineum in the single-piece pajama for the caregivers to perform hygiene tasks, and no change in humidity management from the users’ point of view. Moreover, one of the participants mentioned the lack of zippers on the arms as a problem, as well as the top of the two-piece pajama being too short. The first problem will be hard to resolve if we want to keep the back and sides of the pajama free of seams and zippers. The shortcomings of the two-piece pajama, on

the other hand, are easily solvable. Overall, caregivers and users gave a very positive evaluation of the pajama, which makes us confident of a good buyer acceptance should it come to market.

In sum, we successfully manufactured two pajamas (single and two-piece) to be used across settings using seamless knitting materials that reduce pressure points in contact with the user's skin and improve breathability. Moreover, the two-way zippers aid caregivers and users alike (for physiotherapy sessions, for example), and allow for easy dressing and undressing due to their amount and positioning. The enclosing of zippers helps prevent damage to the user's skin, and the absence of zippers and seams on the back and sides minimizes pressure with the support surface. Additionally, its tight-fitting form and shortened upper part on the two-piece ensures that loose fabric does not fold and potentially cause damage. Finally, it is possible to attach a Velcro front garment to enhance psychological comfort.

All in all, we managed to manufacture a pajama with good thermophysiological properties that received very positive evaluations from both caregivers and users, thus achieving our goal of designing a garment that ensures psychophysiological comfort, aids recovery, and helps prevent health complications, such as pressure ulcers.

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References

1. Angelova, R.A.: *Textiles and Human Thermophysiological Comfort in the Indoor Environment*, 1st edn. CRC Press, Boca Raton (2016)
2. Pan, N., Sun, G.: *Functional Textiles for Improved Performance, Protection and Health*, 1st edn. Woodhead Publishing, Oxford (2011)
3. Kamalha, E., Zeng, Y., Mwasiagi, J.I., Kyatuheire, S.: The comfort dimension; a review of perception in clothing. *J. Sens. Stud.* **28**(6), 423–444 (2013)
4. Bartels, V.T.: *Handbook of Medical Textiles*, 1st edn. Woodhead Pub., Oxford (2011)