Comfortable next-to-skin wool

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Next-to-skin garments form an important market segment for wool; however, there is a common misconception that wool is not suitable in these garments as it is uncomfortable, prickly or itchy. Some people even claim to have an allergic reaction when wearing woollen garments.

Research at CSIRO has clarified why some wool garments are comfortable next to the skin and yet other garments are uncomfortable. As a result of this research, it is now possible to design/engineer wool fabrics and garments to meet consumers' requirements for next-to-skin comfort.

Skin discomfort is not wool-specific or allergy related

Extensive studies at CSIRO and DWI in Germany have been unable to establish any correlation between the results of dermatological tests for wool allergy with actual responses from wearing wool garments. To interpret this lack of correlation, these studies have identified that the extracts used in the dermatological allergy tests contain significant amounts of salts, consistent with an extract from greasy, unprocessed wool. Moreover, positive skin reactions were isolated as arising specifically from these salts and only occurred in the rare cases of people exhibiting *Urticaria factitia* (allergic skin rash caused by the body's over reaction to substances it encounters, such as friction with clothing). These salts are removed during normal scouring and textile processing. Thus, while the current commercial dermatology tests of wool might be of value for people in contact with greasy wool (such as shearers), it is now clear that their application to the wider community of people wearing cleaned and processed wool goods is flawed.

Another study at CSIRO has produced independent evidence of the mechanical, rather than allergenic, basis for discomfort. This study found that skin comfort is not fibre specific –a broad range of experimental garments made from acrylic fibres (chemically very different from wool) induced exactly the same 'skin comfort' responses as garments made from wool with the same fibre diameter characteristics.

Understanding skin comfort as a mechanical effect and the role of fibre diameter

A couple of simple concepts lead to an understanding of skin comfort of wool garments:

- As a biological material, wool samples always contain a mixture of fibres of different thicknesses or diameters as depicted in Figure 1. As well as the average diameter value, the spread in diameter values is commonly reported in one of two ways, namely the standard deviation (SD) or the coefficient of variation of diameter (CV_D).

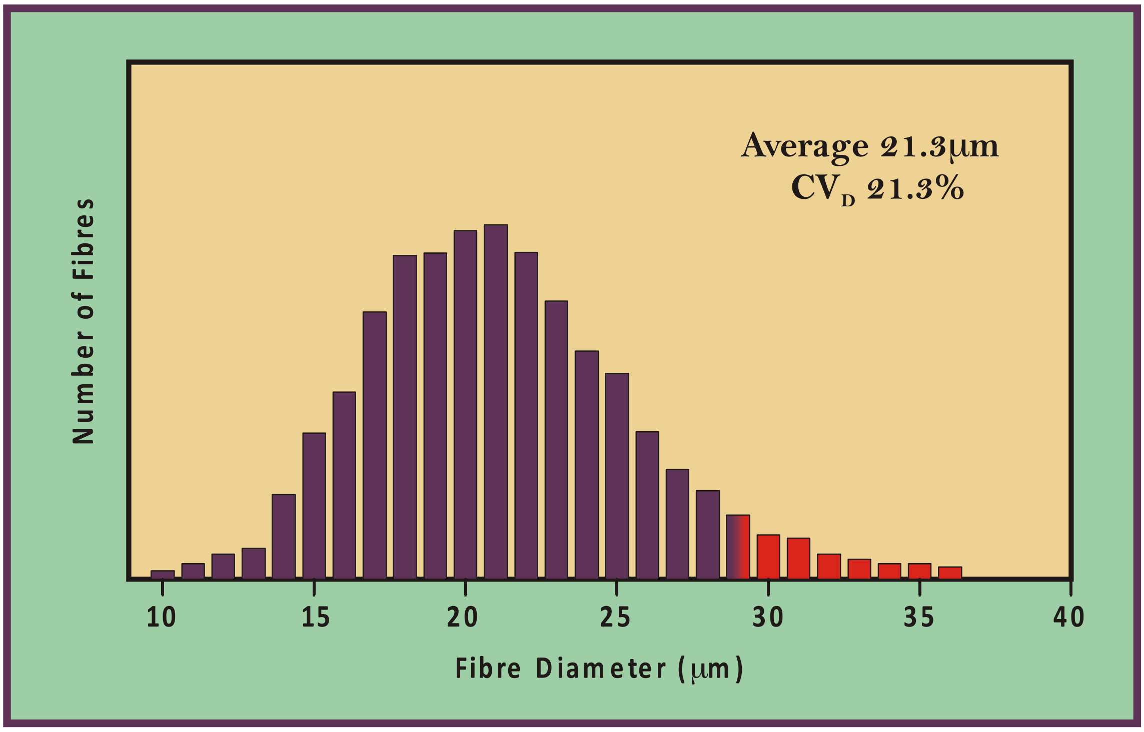


Figure 1: An example of the measurement of fibre diameter characteristics of a wool sample.

- Fibre ends in contact with the skin during wear, as depicted in Figure 2, invariably protrude above the fabric surface in a garment and during wear these fibre ends will be pressed against the skin.

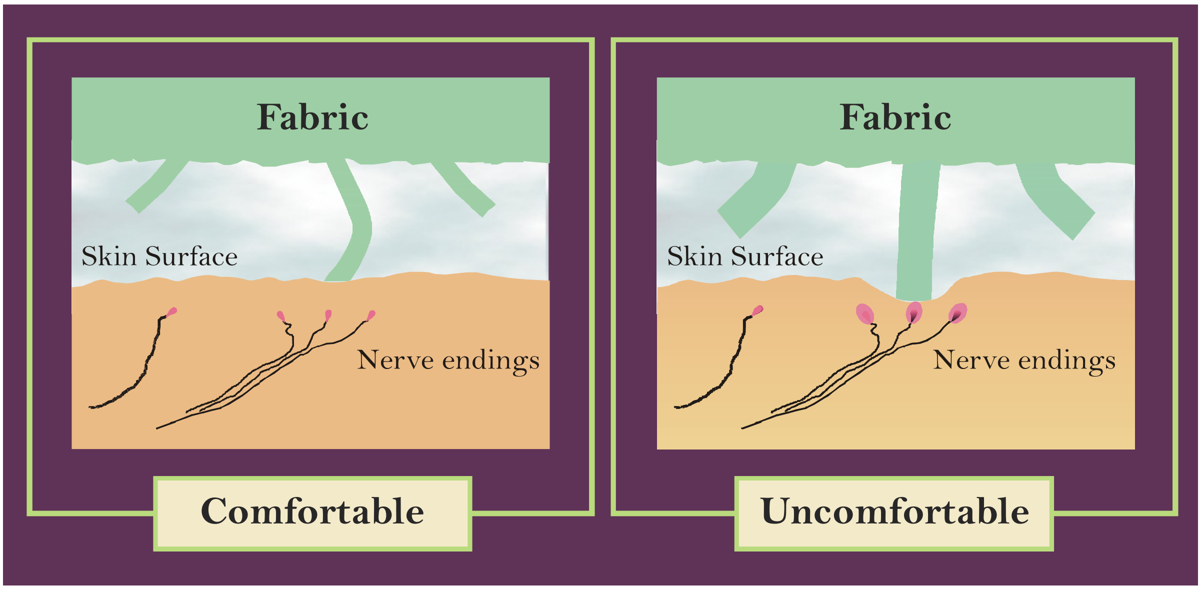


Figure 2: The interaction between fabrics and the skin during wear.

These short protruding fibre ends on the inside surface of a next-to-skin garment obey the laws of physics, that is, under compression between the fabric and the skin surface, they remain rigid up to a threshold force but are unable to sustain a larger force, and buckle. The threshold force for buckling is highly dependent on fibre diameter. For some wools and fabric constructions the buckling forces for the coarser diameter fibres in the naturally occurring diameter distribution (that is, shaded schematically red in Figure 1) are sufficient to trigger nerve ends under the skin and cause discomfort. This mechanism is depicted in Figure 2.

For convenience, in the standard test (certified by IWTO) of the diameter characteristics of a sample of wool, the percentage of fibres less than 30 μm, as illustrated in Figure 1, is sometimes referred to as the Comfort Factor. It can be a useful ranking tool to predict the relative skin comfort of different wools when used in a particular fabric construction and garment.

Detailed physiological studies of nerve responses conducted by CSIRO have confirmed this mechanism. For example, Figure 3 shows the results of a study of the acceptability of two different pure wool fabric types as a function of varying average fibre diameter. In this Figure the knitted samples were 14-gauge single jersey fabrics finished with a simple steam relaxation after knitting and the plain weave trousering fabric was finished with a minimum routine (semi-decatised for three minutes, neutral dolly scour at 40°C for 15 minutes, semi-decatised for 30 seconds). Note that in each series as the average fibre diameter is reduced the comfort level increases in line with the reduction in the number of coarse fibre ends. For a given mean fibre diameter the woven fabrics were, in general, less comfortable than the single jersey fabrics. This is consistent with the buckling mechanism as the protruding fibre ends in the plain-weave fabrics would be expected to be much shorter than in the knitted fabrics and, hence, would be expected to exert more force, even without cropping.

There are two further important effects in fabric skin comfort. These relate to the wearer's skin. Like the variability in wool, there is also a lot of variability in the thickness and stiffness of people's skin. If you have thin, soft skin, it will be more sensitive to discomfort, whereas if you are 'thick skinned', your skin will be less sensitive. A further effect is that increased temperature and moisture softens the skin and increases the sensitivity to discomfort.

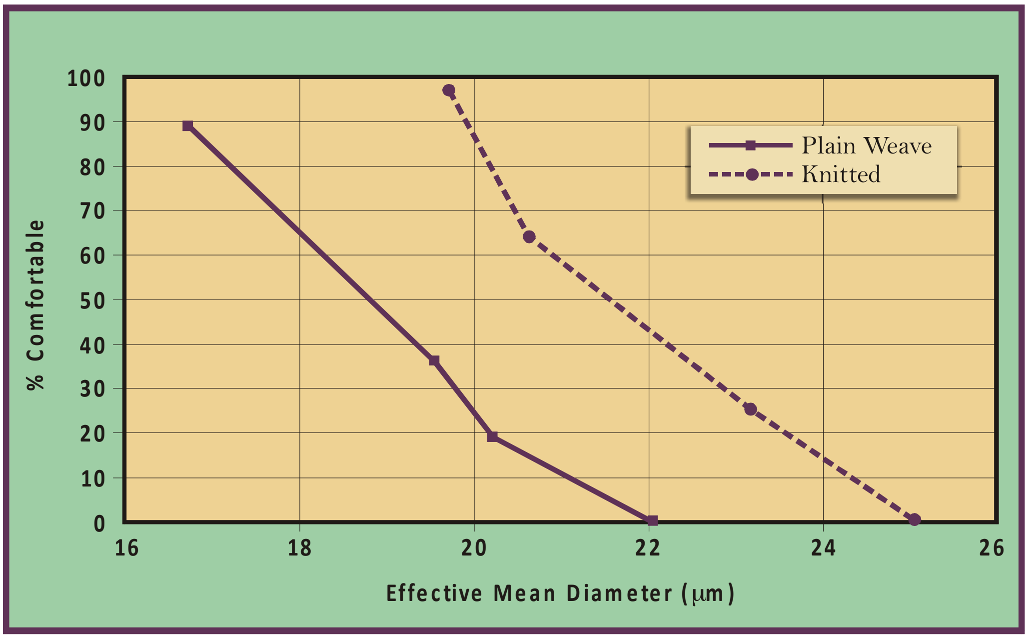


Figure 3: An assessment of skin comfort for both single jersey and plain-weave fabrics as a function of effective mean diameter. The results are plotted as the percentage of positive responses.

Relative Importance of other fibre, yarn and fabric parameters

As indicated, the skin comfort of a wool fabric is related to the density of coarse fibre ends per unit area of fabric. This depends primarily on the wool diameter characteristics, but other factors also show smaller effects. A CSIRO study of the comfort of 14-gauge single jersey worsted wool fabrics demonstrated that:

- for a given yarn and fabric type the density of fibre ends decreases with increasing fibre length in the top
- increasing cover factor will increase fabric weight per unit area and consequently increase the density of fibre ends.

The relative effect of different parameters is listed in the Table 1. Mean fibre diameter is by far the most important parameter, being approximately three times as important as coefficient of variation of diameter, mean fibre length or cover factor. For a given cover factor, skin comfort was found to be independent of yarn count.

Property	Relative Importance
FIBRE DIAMETER	
(mean diameter) 1 µm	10
(CV_D) 1% point	3
COVER FACTOR	
0.15 $tex^{1/2}$ mm^{-1}	4
HAUTEUR	
5mm	-2
YARN LINEAR DENSITY	
In the range 60 tex to 100 tex	0

Table 1: The relative importance of changes in different parameters on the skin comfort of knitwear. (The negative value for Hauteur signifies that increasing Hauteur (a measure of fibre length) increases skin comfort, whereas an increase in all the other variables leads to a decrease in skin comfort).

Summary

1. Next-to-skin fabric discomfort is not due to allergy, nor is it specific to wool. It is due to coarse fibre ends pressing against the skin during wear.
2. Fine Australian wools are comfortable and suitable for next-to-skin wear.
3. For single jersey fabrics, absolute skin comfort can be predicted from fibre and fabric parameters.
4. For commercial tops, mean fibre diameter is the most important parameter determining skin comfort.
5. Skin comfort depends on fabric type, with plain-weave fabrics being more likely to lead to discomfort than single jersey fabrics.

Further reading:

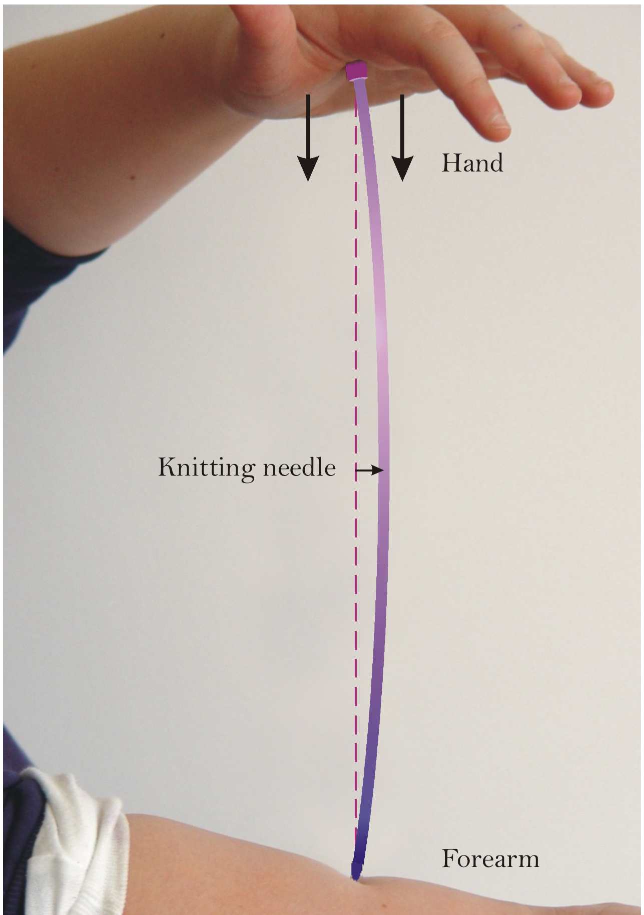
Garnsworthy, R.K., Gully, R.L., Kandiah, R.P., Kenins, P., Mayfield, R.J. and Westerman, R.A. (1988) *Understanding the Causes of Prickle and Itch from Skin Contact of Fabrics*, CSIRO Division of Wool Technology Report No. 64,. Also published in *Australiasian Textiles* 8 (4), 26/29, 1988.

Naylor, G.R.S. and Phillips. D.G. (1995) Skin Comfort of Wool Fabrics. in *Proc. Int. Wool Text. Res. Conf. (Biella)*, 2, pp. 203–209. Also published in *Top-Tech '96: papers.* CSIRO Division of Wool Technology, 1996.

Skin Comfort

Plastic knitting needles can be used to simulate the effect of short fibre ends pressing against the skin. You will need two knitting needles for this experiment, one thin and one a little thicker, all made from the same plastic (for example, 3 mm and 4.5 mm sized 30 cm long plastic knitting needles). First try pressing a thin knitting needle against your arm as illustrated. Remember to hold the top of the knitting needle with your open palm as in Figure 4 — don't grasp it. Note that as you push harder the knitting needle begins to bend and buckle. It is impossible to exert enough force to cause pain. Repeat this now with a thicker (4.5 mm) needle. Note that it is now much harder to make the knitting needle buckle and it now hurts long before the knitting needle buckles.

The knitting needles act just like the wool fibre ends that protrude above a fabric surface and press against the skin during wear as shown in Figure 2. The thin fibre ends readily bend and buckle when pressed against the skin during wear (like the thin knitting needle) and you are unaware of them. In the case of an uncomfortable garment, some of the coarser fibre ends, towards the right hand end of Figure 1, are able to press hard enough against your skin during wear to trigger nerve ending lying just below the skin surface. The triggered nerve sends an electrical signal to the brain. If your brain receives several of these signals from the same local area of the skin, it interprets them as an unpleasant itchy, scratchy or prickly sensation (more like the thicker knitting needle).



Demonstrating Skin Comfort

Skin comfort of wool fabrics*

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Summary

Skin comfort was measured for a range of single jersey fabrics made from worsted spun yarn of either wool or acrylic fibres. Skin comfort was found to be independent of fibre type. Relative comfort can be predicted from the density of coarse fibre ends per unit area of fabric with the percentage of fibre ends greater than about 32 μm being the key factor. This quantitative predictive model also accounts for the effect of fibre length, yarn linear density and fabric cover factor. Single jersey fabrics made from fine wool were found to be comfortable and suitable for next-to-skin wear. The level of acceptability decreased from approximately 90% for a 20.5 μm commercial top to about 50% for a 23.5 μm commercial top. These studies confirm that skin comfort is not chemical or allergy related.

Skin comfort was also found to be highly dependant on fabric type due to differences in the fabric surface characteristics. Plain-weave trouser fabrics are less comfortable than single jersey fabrics made from the same wool. For the same level of skin comfort, plain-weave fabrics require wool approximately 3 μm finer than that of single jersey fabrics.

1. Introduction

Next-to-skin garments are potentially an important market for wool, however there is a common misconception that wool is not suitable in these garments as it is uncomfortable≅, prickly≅ or itchy≅. Some people even claim an allergic reaction when wearing wool garments. Research at CSIRO has shown that these unpleasant sensations are related to the physical dimensions of the fibres rather than being chemical or allergy related (1,2). Short fibre ends protrude from a fabric surface as shown in Figure 1. These fibre ends obey Euler's simple buckling theory, i.e. under compression they remain rigid up to a threshold load but are unable to sustain a larger force and buckle. The threshold force for buckling is proportional to Ed^4/l^2 (where E is the Young's Modulus of the material, d is the diameter and is l the length of the protruding fibre end), i.e. buckling is highly dependant on fibre diameter. For some wools and fabric constructions the buckling force for the coarser diameter fibres in the naturally occurring diameter distribution are sufficient to trigger nerve ends under the skin leading to discomfort.

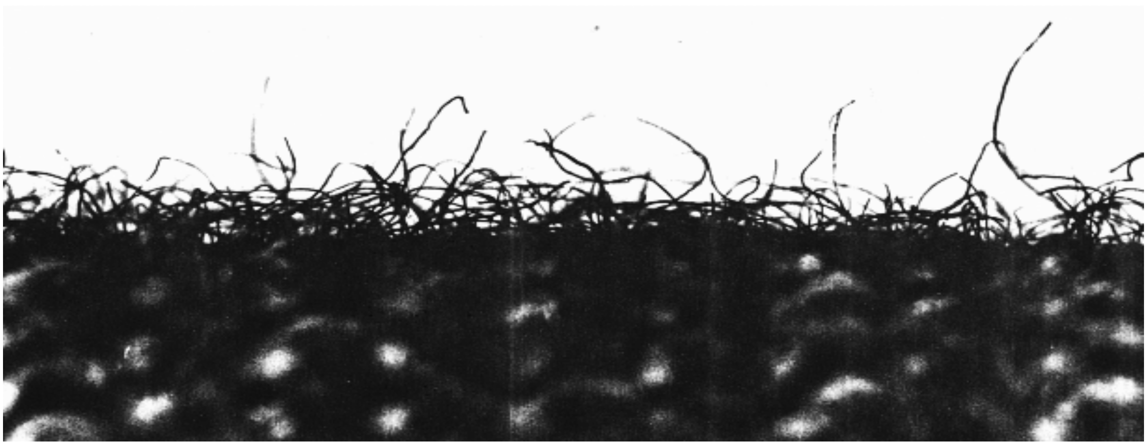

Figure 1: The surface of a single jersey fabric showing the protruding fibre ends.

* Reproduced from Proc. Int. Wool Text. Res. Conf. (Biella), 2, 203-209, 1995.

At the last wool conference (3) it was shown that the subjective forearm test is a useful indicator of skin comfort during wear. Since that conference one focus of the skin comfort research program at CSIRO has been to characterise quantitatively the effect and importance of fibre, yarn and fabric parameters on skin comfort, as guidelines for the industry. This paper summarises the main findings from this work, which are being published in more detail elsewhere (4).

2. Skin comfort is not wool specific

In the study (4), blends of acrylic fibres with different fibre linear densities were used to simulate the naturally occurring diameter distribution of wool. Starting with 3.3 dtex fibre (approximately 19 μm mean diameter), two carefully controlled series of knitted fabrics were produced each with increasing amounts of either 6.7 dtex fibre (approximately 27 μm mean diameter) or 9 dtex (approximately 33 μm mean diameter) fibre. The three parent tops had similar fibre length distributions (Hauteur 80 mm) and the Young's modulus was the same as conditioned wool. The yarn count and twist factor were constant for the series. Forearm prickle studies of the resultant 14 gauge single jersey acrylic samples showed that fabrics containing only fine fibres were comfortable. The feelings of discomfort as previously observed with coarse wool fabrics occurred with some of the acrylic blends containing coarser fibres. Further the intensity of these unpleasant sensations increased as the percentage of coarse fibres in the blend increased.

Figure 2 shows the coarse tail on the diameter distribution of the fibre ends for some of the fabrics. This shows clearly that the shape of the distribution in this region for the two series is quite different. The percentage of coarse fibres for the odd numeral series (blended with the 6.7 dtex acrylic) decreases rapidly with increasing diameter whereas the even numeral series (blended with the 9 dtex acrylic) has a broader tail in the fibre diameter distribution.

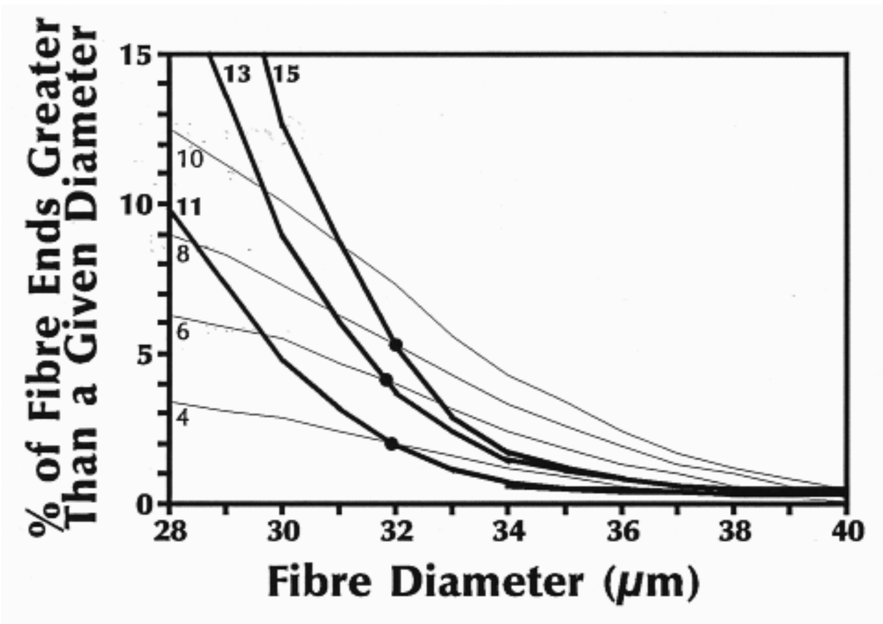

Figure 2: The coarse fibre end characteristics of two sets of blended acrylic. The cross-over points of samples with the same level of skin comfort has been highlighted by a dot.

The skin comfort of samples from both series was compared using a paired comparison protocol asking the subject to identify the more comfortable of the pair. For a sample pair with equivalent skin comfort a 50:50 split in the results is expected, that is, in 36 test comparisons, 18 choices would be selected as more comfortable. The results are summarised in Table I using one set of acrylic samples as reference samples. (These reference samples had previously been shown to represent a graded series of comfort levels from very comfortable to quite uncomfortable (4)). From Table I the members of the acrylic pairs (11,4), (11,6), (13,6) and (15,8) have equivalent skin comfort. Returning to Figure 2 the cross-over points of three of these pairs cluster around 32 μm with one point a little lower at 30 μm. In other words despite the different shapes in the diameter distributions, on three independent experiments samples with the same level of comfort have the same percentage of fibre ends greater than about 32 μm. This is strong evidence in favour of the model that the uncomfortable sensations arise from the physical stimulation of nerve endings by fibre ends which act like Euler rods with buckling loads greater than a threshold value. For this fabric type, the critical buckling load translates to a critical fibre end diameter of around 32 μm.

REFERENCE SAMPLES	ACRYLIC SAMPLES			WOOL SAMPLES	
	11	13	15	DQN2160	DQN2312
2 (comfortable)	26**	35**	36**	33**	-
4	18	28**	31**	23	-
6	16	22	25*	13	35**
8	6**	11**	19	11*	27**
10	5**	-	4**	-	14
12	1**	-	-	-	8**
14 (very uncomfortable)	2**	-	-	-	-

*Table I: Results of paired comparisons of the fabric-evoked prickle of test samples relative to reference acrylic samples. The score represents the number of times out of 36 that the test sample was chosen as more prickly than the corresponding reference sample. Scores that are statistically different from the null hypothesis of equal prickliness are markets with * or ** corresponding to the 5% to 1% significant level respectively using the sign test.*

Further comparisons of the skin comfort of wool and acrylic single jersey fabrics of the same yarn and knit construction showed that samples with similar skin comfort properties have similar coarse fibre diameter characteristics independent of the fibre type. For example, Table I includes the results of skin comfort tests of two wool samples DQN2160 and DQN2312 relative to the reference acrylic set. The paired comparison results show that the skin comfort of DQN2160 lies between that of acrylic samples 4 and 6. DQN2312 has skin comfort properties similar to acrylic sample No 10. Figure 3 shows the corresponding fibre diameter properties of these samples. The curve for DQN2160 lies between that of reference sample numbers 4 and 6 and the curve for DQN2360 lies very close to that for reference sample No 10. This data is consistent with the hypothesis that skin comfort properties are related to the percentage of fibres above a value around 32 μm.

This is strong evidence that the discomfort sensations are not allergy related; that is, they are not inherently specific to a particular fibre type. Rather, the unpleasant sensations are related to the density of coarse fibre ends in contact with the skin.

3. Relative importance of other fibre, yarn and fabric parameters

The density of coarse fibre ends per unit area of fabric depends not only on the fibre diameter characteristics but also on other fibre, yarn and fabric parameters. Two examples follow:

(a) for a given yarn and fabric type the density of fibre ends decreases with increasing fibre length in the top

(b) increasing cover factor will increase fabric weight/area and consequently increase the density of fibre ends.

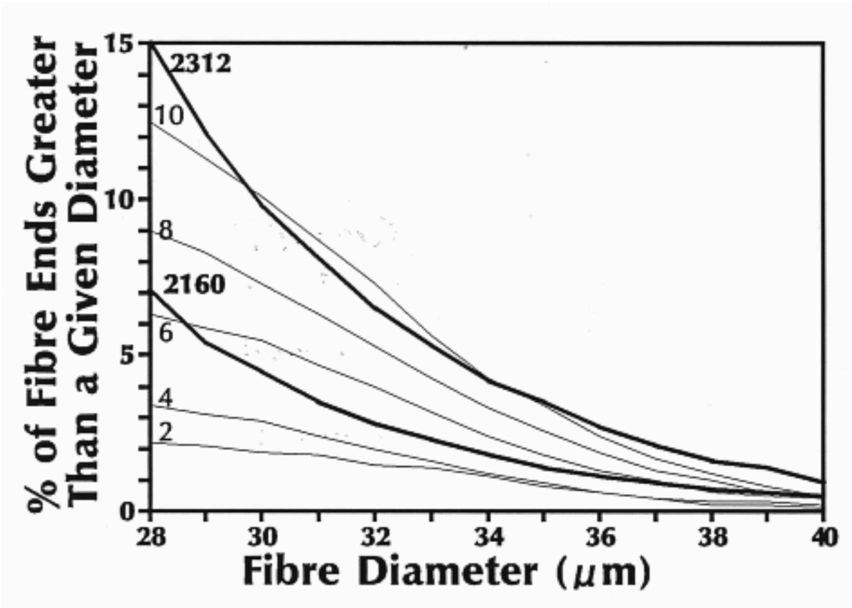

Figure 3: The coarse fibre end characteristics of two wool samples (DQN2160 and DQN2312) relative to that for the reference set of blended acrylic samples.

Detailed paired comparison experiments (4) have shown that the effects of fibre length, yarn count and fabric cover factor on the skin comfort of 14 gauge single jersey fabrics can all be accounted for quantitively by a model describing the fibre end density.

Summarising again the detailed studies by Naylor et al (4), and considering the practical range of these variables, they can be ranked in terms of their relative importance for skin comfort as shown in Table II. Mean fibre diameter is by far the most important parameter, being approximately three times as important as coefficient of variation of diameter, mean fibre length or cover factor. For a given cover factor, skin comfort was found to be independent of yarn count.

PROPERTY	RELATIVE IMPORTANCE
FIBRE DIAMETER	
(mean diameter) 1:m	
(CV_D) 1% point	10
COVER FACTOR	3
0.15 tex^2mm^{-1}	
HAUTEUR	4
5 mm	
YARN LINEAR DENSITY	-2
In the range 60 tex to 100 tex	0

Table II: The relative importance of changes in different parameters on the skin comfort of knitwear. (The negative value for Hauteur signifies that increasing Hauteur increases skin comfort whereas an increase in all the other variables leads to a decrease in skin comfort).

4. Absolute fabric acceptability

All the proceeding results were obtained with knitted fabrics using subjective paired comparison protocols to obtain the relative ranking of the skin comfort. To obtain absolute measures of skin comfort for both knitted and woven fabrics, fabrics made into full length sleeves were assessed subjectively while being worn next to the skin. Judges were asked to respond to the question: Is this sleeve comfortable; would you want to wear it?

In the case of the knitted fabrics, 21 gauge fully fashioned sleeves were assessed by a regular team of A trained and sensitive adult judges. Figure 4 shows the results. A study of commercially available tops has shown that the coarse fibre end diameter characteristics of these tops can be accurately predicted from the mean diameter (6). Using this relationship the skin comfort results are plotted in Figure 4 against the mean diameter of commonly available commercial tops with the same coarse fibre end characteristics as test samples, called the effective mean diameter. These results show clearly that fine Australian wools are comfortable and suitable for next-to-skin wear. Discomfort only arises with coarser wools typically above 22 micrometres.

Further experiments (4) were made to assess the skin comfort of plain-weave trouser fabrics finished with a minimum routine (semi-decatised for three minutes, neutral dolly scour at 40°C for 15 minutes, semi-decatised for 30 seconds). Equivalent studies to those shown in Table I indicate that for a given mean fibre diameter the woven fabrics were in general less comfortable than the single jersey fabrics. This is consistent with Eulers buckling theory as the protruding fibre ends in the plain-weave fabrics would be expected to be much shorter than in the knitted fabrics, and hence stiffer, even without cropping.

The absolute skin comfort of typical worsted spun plain-weave trouser fabrics was also evaluated in a similar manner to the knitted fabrics and the results are included in Figure 4. For equivalent skin comfort the woven fabrics need to be made from a wool approximately 3 μm finer than that used for the single jersey fabric.

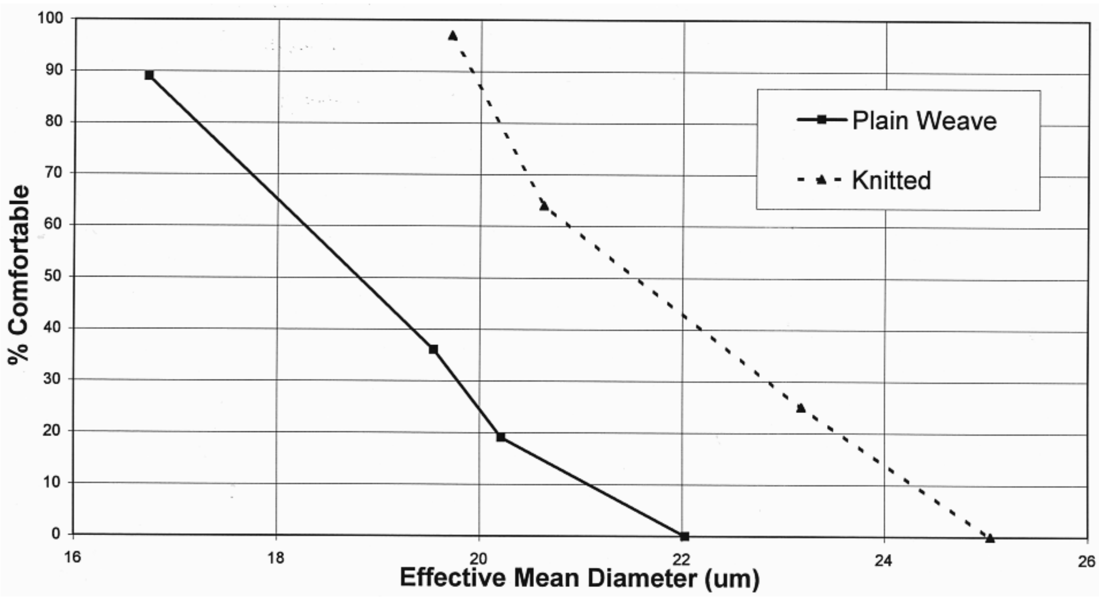

Figure 4: An assessment of the skin comfort of both single jersey and plain-weave fabrics as a function of effective mean diameter. The results are plotted as the percentage of positive responses.

5. Conclusions

The conclusions from the body of work in reference (4) and summarised in this paper are:

1. Next-to-skin fabric discomfort is not an allergy or even a fibre specific phenomena. It is due to coarse fibre ends pressing against the skin during wear.

2. Fine Australian wools are comfortable and suitable for next-to-skin wear.

3. For single jersey fabrics absolute skin comfort can be predicted from fibre and fabric parameters.

4. For commercial tops mean fibre diameter is the most important parameter determining skin comfort.

5. Skin comfort depends on fabric type with plain-weave fabrics being more susceptible to discomfort than single jersey fabrics.

6. Acknowledgments

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7. References

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3. C. J. Veitch, P. Kenins, G. R. S. Naylor, "Comparison between Laboratory Protocol and Simulated Wear Conditions for the Evaluation of Prickle", Proc. 8th Int. Wool Text. Res. Conference (Christchurch), 5, 286-295, 1990.

4. G. R. S. Naylor, et al, "Fabric-Evoked Prickle in Worsted Spun Single Jersey Fabrics", Parts 1, 2 and 3, Text. Res. J. 67, pp288-295, 354-358, 413-416, 1997.

5. G. R. S. Naylor, "The Role of Coarse Fibres on Fabric Prickle Using Blended Acrylic Fibres of Different Diameters", *Wool Tech. Sheep Breed.*, 40 (1), 14-18, 1992.

6. G. R. S. Naylor, et al, "Fibre End Diameter Characteristics of Australian Wool Tops", Proc. 9th Int. Wool Text. Res. Conf. (Biella), 3, 203-209, 1995.

Questions

1. How often is fabric skin comfort/discomfort associated with an allergic response?
    a. Always
    b. Sometimes
    c. Never
    d. There is no evidence of a link
2. Is there a significant range of sensitivities to fabric skin comfort between people?
    a. Yes
    b. No
    c. Perhaps
    d. There is no evidence of any differences between people.
3. Which fibre properties affect fabric skin comfort?
    a. Fibre diameter
    b. Fibre length
    c. Fibre type
    d. Fibre stiffness
    e. All of the above
    f. None of the above
4. Can fabric skin comfort be predicted from raw wool characteristics?
    a. Yes
    b. No
    c. Sometimes
5. Can fabric skin comfort be affected by the following?
    a. Fabric type
    b. Fabric finishing
    c. Skin properties
    d. Physiological state of the wearer
    e. All of the above
    f. None of the above