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The Wool ComfortMeter and the Wool HandleMeter, new opportunities for wool.

By

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SUMMARY

Two instruments have been developed by the Sheep CRC that provide the tools for a new standard in comfort and handle for the next generation of next-to-skin wool knitwear.

The Wool ComfortMeter and Wool HandleMeter provide a rapid, accurate and objective measure of two important characteristics of wool knitwear that are currently determined by subjective assessment.

The Wool HandleMeter allows the prediction of a set of handle attribute values that can quantify the hand feel of a lightweight jersey fabric. The instrument uses the principle of pushing a fabric sample through a ring. The force displacement curve associated with the fabric test is characterised and used to define each fabric. These values were then compared to the average handle values, as determined by a group of experts, of a large set of lightweight knitted fabrics. Algorithms were developed that enable the instrument to more accurately predict each of seven handle attributes than an individual expert.

The Wool ComfortMeter provides a measure of the fibres that are protruding from the surface of the fabric that are responsible for the itchy sensation caused by some knitwear. The results from the instrument have been compared to the results from extensive wearer trials to provide an understanding of the relationship between the instrument value and the comfort perceptions of wearers. The results have shown a very clear relationship between the instrument and wearer trials.

INTRODUCTION

Wool is renowned throughout the world as the fibre of choice for next-to-skin applications. In the active sports markets particularly, brands stocking merino next-to-skin knitwear have benefited from the consumers’ willingness to pay a premium to benefit from wool’s attributes of superior handle, breathability and moisture management. However, variations in product quality have sometimes left consumers with mixed feelings. Wool has been let down due to perceived garment prickle or inconsistent hand feel. This is because currently garment specifications on skin comfort and handle are based on subjective human estimation.

The successful manufacture, sale and suitability of lightweight knitwear for next-to-skin applications rely heavily on an assessment of the next to skin comfort of the garment and an assessment of the hand feel (handle) of the garment. Both of these assessments are subjective and therefore prone to the variation associated with the individual judges and between the judges making the assessment. To add further importance to these garment characteristics the supply chain also relies on fabric handle as a means of...
assessing garment quality, and the assessment of softness to evaluate the skin comfort of a garment. The accurate and repeatable measure of these two subjective fabric characteristics will be the first step in creating the new standard in skin comfort and handle for the next generation of wool, next-to-skin garments.

Fabric Handle Measurement

Peirce (1930) introduced the notion that attributes of fabric handle were related to measurable fabric properties. The idea being that the sensations of roughness, smoothness, harshness, pliability, thickness etc. were linked to values for fabric tensile properties, lateral compression, surface frictional properties, fabric bending properties and fabric shear properties. This was the basis for most research and instrument developments.

The very few commercially available instruments to “measure” fabric handle prior to the release of the Kawabata instruments (Kawabata 1980) in the late 1970s were made to measure specific low stress, fabric mechanical properties mainly compression, bending, shear and extension. Also the majority of these instrument were designed for lightweight, woven, apparel fabrics. The review by Bishop (1996) gives a good account of the decades of work that were responsible for the development and refinement of instruments to measure fabric low strain mechanical properties.

The review by Mahar et. al. (2013) gives a brief account of the early developments but provides a more comprehensive account of recent developments in fabric measurements as they relate to the prediction of fabric handle. In the last 15 years 3 instruments have become available: the Griff-Tester (Hennrich, Seidel and Rieder, 1999), the PhabrOmeter ((Pan, 2006), http://www.nucybertek.com) and the SDL Atlas Fabric Touch Tester (http://www.sdlatlas.com). The first two use the principle of pulling or pushing a circular sample of fabric through an orifice and monitoring the resultant force-displacement relationship. These evaluate a complex combination of low stress, fabric mechanical properties. The latter instrument measures a range of fabric physical and thermal properties on a single instrument. These instruments are universal in their application and can be applied to many textile substrates.

Fabric Skin Comfort Measurement

The measurement of fabric evoked prickle, as it relates to the next-to-skin comfort of consumers, has not had a commercial instrument available to measure fabric or garments. The industry in general has relied on the assumption that if a fabric feels soft it will provide good skin comfort. The only objective measurement associated with fabric evoked prickle is usually performed on greasy wool or wool tops and is a measure of the percentage of measured fibres less than 30 um in diameter known as the Comfort Factor. The origin of this value came from work which demonstrated that fibre ends protruding from the fabric surface acted like a simple column under compression and those fibres able to push against the skin with a force of about 0.75 mN or greater, without buckling, were capable of evoking a prickle response in human subjects. (Garnsworthy et al., 1988). It was estimated that a wool fibre protruding 2 mm above the fabric surface with a fibre diameter of approximately 30 μm would meet this criterion (Naylor et al., 1992; Veitch & Naylor, 1992).

The Wool ComfortMeter & Wool HandleMeter

In response to the specific needs for the next generation of lightweight, next to skin wool garments two instruments, The Wool ComfortMeter™ and Wool HandleMeter™, have been developed. They allow the measurement and accurate prediction of the skin comfort of a garment, specifically the perception of fabric evoked prickle, and a rating for the key handle attributes of lightweight jersey fabric including softness and smoothness. The Wool ComfortMeter and Wool HandleMeter were developed by the Cooperative Research Centre for Sheep Industry Innovation (Sheep CRC) in conjunction with the CSIRO, Australian Wool Innovation (AWI), AWTA, Deakin University, the Department of Agriculture and Food WA (DAFWA) and Curtin University.

The development of both instruments followed similar paths. Both developed protocols for the accurate subjective evaluation of the properties of interest. Both then collected extensive amounts of subjective data on a wide range of next to skin fabrics. In parallel to this, instruments were developed that measured physical attributes of the fabric that directly related to prickle and handle. Finally, models were developed that enable the prediction of prickle and handle from the measured fabric data.
The Wool HandleMeter

The assessment of handle is such a complex, subjective task that attempts to develop a commercial instrument, to predict such a value from measured fabric properties, has proved difficult and even harder to get widespread commercial adoption. The Kawabata system (Kawabata 1980) came closest to an accepted commercial evaluation system and one possible reason for this was because it focussed on a single class of fabrics, light weight men’s suiting. In doing so it limited the range of fabric physical characteristics that had to be covered by the predictive models and this in turn limited the interactions of the measured physical properties and the subjective perception of handle. This principle was applied to the development of the Wool HandleMeter. The predictive models could be kept accurate because they are currently only applicable to lightweight single jersey fabrics (Wang et. al. 2012, Mahar et. al 2013).

The first activity was to develop a language of handle terms that could be understood by the majority of the people involved with handling lightweight jersey fabrics. Eight (8) groups of expert assessors were surveyed to develop a list of terms to describe light weight jersey fabrics. From an original total of 89 terms a list of 7 terms were agreed to as the most important (Wang et. al. 2012, Wang et. al. 2013). The consistent message was that surface, flexural, mass/bulk and warm/cool properties were widely considered the most important. The results also highlighted that fact that there are slight variations amongst the experienced judges in the relative importance attached to stretch, resilience and loftiness/bulk. On the basis of the overall survey results, the following words and bi-polar word-pairs were adopted to describe next-to-skin fabric handle:

- Smooth – Rough (Surface property);
- Soft – Hard/Harsh (Flexural property);
- Clean – Hairy (Surface property);
- Cool – Warm (Perceived temperature);
- Tight – Loose (Flexural property).
- Heavy – Light (Perceived weight)
- Dry – Oily (Quality Control descriptor to determine high levels of softener)

The instrument design was based on the proven principle of pushing a fabric sample through a ring while a weight is applied (Pan 2006; Wang et al. 2008). The associated force displacement curve can be accurately described using various measures of the height, width and slope of the curve. Figure 1 shows the range of curve description parameters that have been used to quantify each curve. This gives a set of values that independently describe each fabric and it is these values that will be used to develop the models to predict the subjective handle traits.

![Figure 1. Defining parameters of the fabric force / displacement curve](image-url)
The shape of the force displacement curve is a result of the complex fabric deformation occurring during the test. Wang et al (2008) divided the curve up into 3 sections. Figure 2 shows a general curve for a lightweight jersey fabric and the following list assigns the dominant fabric properties associated with each part of the curve.

1) Bending and biaxial extension (S1);
2) Creasing (S2); and,
3) Dynamic friction (S3).

![Knitted Jersey Fabric](image)

Figure 2. The general form of the force displacement curve produced by the Wool HandleMeter with the 3 regions of interest identified.

To calibrate The Wool HandleMeter a set of 52 knitted fabrics in the fabric mass/unit area range from 140gm\(^2\) to 210gm\(^2\) was assembled for assessment by experienced judges. The fabrics were mainly pure wool and predominantly single jersey, and generally regarded as suitable for next-to-skin wear (Wang et al. 2012). Twelve (12) assessors experienced in handling fabrics were asked to rate the fabrics for overall fabric handle and the seven (7) adopted handle descriptors. Judges were asked to assess the fabrics according to their usual method and rate them according to a scale defined by a set of written descriptions (Wang et al. 2013).

In brief the scale went from a value of 1 for an extreme expression of the first word to a value of 10 for an extreme expression of the second word in the description. E.g. for Rough – Smooth it would be:

1 Extremely Rough ; 2 Very Rough ; 3 Rough ; 4 Average Roughness ; 5 Neutral Roughness ; 6 Average Smoothness ; 7 Good Smoothness ; 8 Very Smooth ; 9 Very Very Smooth ; 10 Extremely Smooth.

The twelve assessors displayed high sensitivity and strong agreement amongst themselves in assessing Overall Handle, the seven fabric handle descriptors. The other findings were that softness and smoothness were the handle characteristics that most strongly influenced the Overall Handle assessment of fabrics. Of the other handle descriptors 'Heavy – Light', 'Loose – Tight' and 'Dry – Clean' also had firm relationships with Overall Handle. However, 'Hairy – Clean' and 'Warm – Cool' assessments had relatively poor linear relationships with Overall Handle.

The results in Table 1 show the correlation coefficients between the individual judges assessment of 52 single jersey fabrics and the average assessment of all judges. These results demonstrate that a reasonable degree of consensus exists about fabric handle assessments by all the judges. The key handle attributes of softness, smoothness and Overall handle have correlation coefficients in excess of 0.7. However, the results also demonstrate that there is variation amongst the assessors in their assessments. These two outcomes lend support to the development of a system to quantify fabric tactile attributes based on instrumental measurement of fabric properties. The measurement based system will build on the consensus while removing the individual assessor-based variability.
Table 1. The correlation coefficients of the individual judges assessments against that of the average of all judges.

A series of models were developed relating the shape of the force displacement curves of the fabrics, as defined by the various descriptive parameters shown in Figure 1, to the average handle attribute values of all 12 judges (Wang et. al. 2012, Wang et.al 2013). The resultant models are able to explain approximately 70% to 80% of the variances for all adopted handle attributes and 92.5% of the variance for Overall Handle (Wang & Mahar 2010). Figure 3 shows the example for softness demonstrating the model explains 70% of the variance associated with the subjective assessment of softness for a diverse group of 52 lightweight, single jersey fabrics.

![Graph showing an example of the accuracy of the objective prediction for softness.](image-url)
A validation trial using the same 12 judges was then carried out covering a separate set of 21 fabrics to confirm the accuracy of the models. This trial demonstrated the models were applicable to a new set of single jersey fabrics and also showed that 86% of the original prediction precision remained (Wang et al 2012).

<table>
<thead>
<tr>
<th>Overall Handle</th>
<th>Rough - Smooth</th>
<th>Hairy - Clean</th>
<th>Hard - Soft</th>
<th>Warm - Cool</th>
<th>Heavy - Light</th>
<th>Loose - Tight</th>
<th>Greasy - Dry</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 assessors</td>
<td>1.1</td>
<td>0.9</td>
<td>1.0</td>
<td>0.9</td>
<td>0.8</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td>1 assessor</td>
<td>3.8</td>
<td>3.1</td>
<td>3.2</td>
<td>2.9</td>
<td>2.5</td>
<td>2.6</td>
<td>3.3</td>
</tr>
<tr>
<td>Objective Prediction</td>
<td>3.0</td>
<td>2.3</td>
<td>1.3</td>
<td>2.4</td>
<td>1.0</td>
<td>1.5</td>
<td>1.1</td>
</tr>
<tr>
<td>Prediction - 1 assessor</td>
<td>-0.8</td>
<td>-0.7</td>
<td>-1.9</td>
<td>-0.5</td>
<td>-1.5</td>
<td>-1.1</td>
<td>-2.2</td>
</tr>
</tbody>
</table>

Table 2. The 95% Confidence Limits for the assessment and prediction of the eight (8) handle characteristics of the 52 next-to-skin fabrics

Table 2 provides further evidence of the improved precision of the measured handle values compared to the assessed handle values. It provides a comparison of the 95% confidence limits of the assessed and measured handle predictions and demonstrates that the models are more consistent than a single assessor when it comes to assessing the handle of lightweight jersey fabrics (Mahar and Wang 2010).

The Wool ComfortMeter

A protocol was developed (Stanton 2010 ; Stanton et al., 2013) to enable the collection of subjective skin comfort data from a large number of wearers. The protocol and analysis methods are reported in detail elsewhere. However, in brief, long sleeved, crewe neck, T shirts of standard sizes and construction were manufactured from 48 selected fabrics. These garments were evaluated by female wearers in a range of controlled environments. The test protocol lasted for approximately 90 minutes and consisted of 5 stages: a 30 minute pre-trial acclimatisation ; a 15 minute cool / passive stage (23°C, 45% RH) ; a 15 minute hot / passive stage (40°C, 24% RH) ; a 15 minute hot / active stage (40°C, 24% RH) and a return to a cool / passive stage (23°C, 45% RH. The passive stages consisted of 5 minutes standing, 5 minutes gently moving the arms and 5 minutes sitting. The active stage involved walking on a treadmill for 15 minutes. The first 5 minutes with the treadmill platform level, the second 5 minutes with the platform inclined 5° and the last 5 minutes with the platform level.

The female wearers were asked to rate a total of 11 sensations covering tactile, thermal and moisture attributes, on a scale of 1 (not detected) to 9 (extremely detected). The ratings were made 15 times by each participant during each trial. Three ratings were taken at the very beginning of each stage associated with a temperature change. Within each temperature stage a rating was taken at 5 minute intervals to correspond with the completion of each different activity. For each fabric the mean prickle rating from all wearers were used to analyse the data. The full list of garments and analysis procedures are exactly as described previously (McGregor et al., 2013 ; Stanton et al., 2013)
The wearer trials used a minimum of 25 wearers and a maximum of 43 wearers to evaluate each fabric. This resulted in about 14,000 wearer ratings being analysed for prickle. The fabrics used a range of fibre properties, especially fibre diameter, aimed at evoking a significant change in wearer comfort response. Fabrics made from wool covered a mean fibre diameter range from 13.8 um to 21.2 um. The majority of fabrics were however, in the range 18.5um to 20.5 um. The trial also included 2 fabrics made from cotton, 2 fabrics made from polyester, 1 fabric made from a wool 70% cashmere 30% blend and a pure cashmere fabric. Nine (9) separate wearer trials were done as part of this study. Each wearer trial included a link garment which was used in number of other trials. Assuming garment differences would not differ between trials, using a link garment made it possible to calculate comparable results for garments tested in different trials. This then allowed all fabrics from each trial to be analysed together. The wearer trial fabric assessments were analysed to provide aggregative responses across a population of wearers (Stanton et al., 2013).

Figure 4 shows the average wearer response to 4 fabrics from the trial at each rating period. The key outcomes from the wearer trials were the demonstration that fabrics could be readily differentiated by the participants and that the conditions and activities of the participants significantly influenced the perceptions of prickle (Stanton 2010; Tester 2010; McGregor et al. 2013). It should be acknowledged that the individual responses of different wearers varied for the same fabric. The coefficient of variation for the wearer response for a given fabric in any period averaged about 50%. This meant that when the fabric prickle rating was low (average rating < 2) there was good agreement with more than 80% of wearers rating 1 or 2. However, for high rating fabrics (average rating >4) it was not uncommon to have individual ratings covering all values. This suggests that individuals are similar in their threshold perceptions but have very different tolerances to the prickle sensation.

Figure 4. The average prickle rating of 4 wearer trial fabrics at each rating period. Periods 1 to 4 - Cool Passive; Periods 5 to 8 - Hot Passive; Periods 9 to 11 - Hot Active and Periods 12 to 15 - Cool Passive.

Periods 3, 7 and 14 in the wearer trial are periods where the participants have been asked to remain standing and move their arms around in such a way that the garment is moving relative to the skin. This ensures that there is good active contact between the skin and garment. In almost all cases these periods were related to an increase in the perception of prickle.

Periods 9, 10 and 11 are the periods in the hot room when the wearers are actively exercising. Although period 10 is associated with the most strenuous exercising the perception of prickle continues to increase throughout this period. These periods are also associated with increasing levels of sweating, as measured by the relative humidity of the skin, and increasing skin temperature as measured by
thermocouples on the skin (Stanton 2013). All wearers reached 100% rh by period 11. During periods 12 to 15 the relative humidity of the skin remained at 100% but the skin temperature dropped back from the maxiums at period 11 to almost return to a pre hot period level.

The Wool ComfortMeter was developed as a rapid laboratory method to quantify knitted fabric tactile comfort ratings (Tester, 2010; Ramsay et al., 2012). Its design used the strong relationship between the bending stiffness and the buckling force of fibres protruding from the fabric surface (Veitch and Naylor, 1992). The Wool ComfortMeter uses a measurement string mounted in a recording head which scans a known area of the surface of a fabric. The measurement string is held a fixed height above the fabric surface and is sensitive to protruding fibres that exceed a threshold bending stiffness. The Wool ComfortMeter is therefore able to determine the relative number of fibres, protruding from the fabric surface, able to evoke a prickle response (Ramsay et al. 2012; Naebe et al., 2012c).

All the fabrics used in the wearer trial have been measured using the Wool ComfortMeter. The Wool ComfortMeter value for these 48 fabrics ranged from a low of 13 to a high of 817. The value that the Wool ComfortMeter produces has been shown to be closely related to the average prickle rating of the wearers (Tester 2010; Ramsay et. al. 2012; McGregor and Naebe 2013; McGregor et. al. 2013; Naebe and McGregor 2013; Naebe et. al. 2013a; Naebe et. al. 2013b; Naebe et. al. 2013c). The earliest published comparison of 19 fabrics from the wearer trials showed a linear relationship and the Wool ComfortMeter value could explain 74.2% of the variance of the average wearer rating over all periods for each fabric (Tester 2010). More recently (McGregor et. al. 2013) showed a linear relationship and the Wool ComfortMeter value could explain 69.7% of the variance of the average wearer rating for all 48 fabrics. Furthermore a model was developed that, in addition to the Wool ComfortMeter value, used additional terms including mean fibre diameter, yarn linear density and yarn twist. This model was able to explain about 90% of the variance of the average wearer rating for all 48 fabrics in the wearer trials (McGregor et. al. 2013). This paper went on to say that if some slight detection of prickle response, equivalent to a mean wearer prickle assessment of 2.5, was acceptable then WCM values of up to about 450 would be suitable. A similar conclusion can be drawn from the data presented in (Figure 5).

Figure 5 shows the relationship between the WCM values for the fabrics in the wearer trials and the average prickle rating at period 3 in the wearer trial. Period 3 represents a passive cool period in the wearer trial where participants were asked to stand and move their arms in a range of motions. While this data still has a strong linear relationship, and the Wool ComfortMeter value explains 69% of the variance in the average wearer response, this graph also demonstrates the increase in the rate of change of response that occurs above a value of about 400.
Figure 5. shows the relationship between the WCM values for the garment and the average prickle rating at period 3 in the wearer trial.

**Conclusion**

The Wool HandleMeter and Wool ComfortMeter have been developed to provide an objective measure of two critical fabric characteristics that are currently assessed subjectively. They have been calibrated using large amounts of carefully gathered subjective data and shown to be able to accurately predict the skin comfort perceptions of wearers and the fabric handle values of industry experts. These instruments are now available for the industry to develop the next generation of next-to-skin wool knitwear.
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