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# Relationships Between Wearer Assessment and the Instrumental Measurement of the Handle and Prickle of Knitted Wool Fabrics

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## Abstract

The relationships between wearer assessed comfort and objectively measured comfort and handle parameters were investigated using 19 pure wool single jersey garments made of single ply yarns. Wearer trials were used to determine prickle discomfort, and whether wearers "liked" the garments. Fabrics then were objectively evaluated using the Wool HandleMeter, which measures seven primary handle attributes; and the Wool ComfortMeter (WCM), to predict a wearer's perception of fabric-evoked prickle. Wearer responses and the relationships within and between objective measurements and the effect of fibre, yarn and fabrics attributes were analysed by general linear modelling. Mean fibre diameter, fibre diameter coefficient of variation, yarn count, fabric thickness, fabric density, fabric mass per unit area and decatising affected one or more handle parameters. The best model for predicting wearer prickle discomfort accounted for 90.9% of the variance and included only terms for the WCM and WCM$^2$. The WCM was a good predictor whereas mean fibre diameter was a poor predictor of whether wearers "liked" garments. Wearer assessment of prickle and whether or not wearers "liked" fabrics were independent of fabric handle assessment. The results indicate that the handle and comfort properties of lightweight, wool jersey fabrics can be quantified accurately using the Wool HandleMeter and the Wool ComfortMeter. For fabric handle, fibre and yarn characteristics were less important than changes in the properties of the fabric.

**Key Word:** next to skin, sensory evaluations, wearer, fabric handle, objective assessment, comfort, fabric design

## Introduction

Objective measurements of woven fabric can be used to predict the aesthetic qualities perceived by human touch. Considerable efforts have been put into developing and quantifying the mechanical properties relevant to aspects of handle for woven fabric. The KES-F (Kawabata Evaluation System for Fabrics) and FAST (Fabric Assurance by Simple Testing) are probably the most widely used instruments to measure low stress properties of textiles. The KES-F system was designed to define the role played by different mechanical properties of fabrics on tactile sensations [1]. In contrast, FAST measures low stress properties to identify potential problems in the manufacturing of garments made from lightweight woven fabrics [2].

Knitted fabrics are preferred over woven fabrics for their lower cost of production, easy care and comfort features, especially for informal wear. However, quantifying the mechanical and physical properties of knitted fabrics relevant to fabric handle and wearer properties has received little attention [3,4]. Thus the assessment of such fabric properties is usually limited to subjective evaluation and the vagaries associated with individual interpretation and preferences. Mahar et al. [5] reviewed the subject of fabric handle and its measurement and commented that despite there being less finishing processes regularly used on weft knitted fabric compared with woven fabric, there is still the potential to improve supply chain communication with the introduction of objective measurement of fabric properties related to the subjective tactile properties of knitted fabrics.

The major issue for consumers of knitwear composed of wool is the prickle or itch sensation that over 50% of people in key markets associate with wool. Recent research evaluated a range of 48 light weight knitted fabrics, mostly composed of wool but including cotton, polyester and cashmere. Design variables included different constructions, fibre diameter and fabric mass per unit area to determine a range of wearer responses including prickle discomfort [6,7]. The prickle discomfort assessed by wearers has been analysed in relation to fibre and yarn characteristics, knitting specifications and measurements made using the Wool ComfortMeter to determine the relationships between the subjective and measured parameters [7].

In associated research, the Wool ComfortMeter instrument has been developed to establish a rapid, instrumental approach for predicting a wearer's perception of fabric-evoked prickle. The Wool ComfortMeter uses a measurement wire mounted in a recording head, which scans the surface of the fabric, interacting with fibres protruding from the fabric surface [8]. The results produced are sensitive to variations in the spatial density of stiff fibre ends protruding from the fabric surface such that coarser fibres and more prickly fabrics result in higher Wool ComfortMeter measurements which indicate less desirable fabrics [7,9]. Various fibre, yarn and fabric parameters of knitwear have been demonstrated to be important for the prediction of the wearer prickle response including mean fibre diameter, wool fibre curvature (crimp), type of fibre (cotton, wool/cashmere blend ratio), yarn linear density, yarn elongation, knitting structure, tightness factor (loop length), fabric thickness, fabric mass per unit area and fabric finishing treatment [7,10-12].

The Wool HandleMeter is a recently developed device to measure the handle parameters of knitted single jersey fabric [13-15]. The Wool HandleMeter is based on the ring test whereby a circular fabric sample is pushed or pulled through a circular orifice and the recorded forces related to KESF handle values [16], fabric mass per unit area, bending rigidity and bending hysteresis [17]. Pan and Yen [18] related the force by displacement curves to 16 fabric mechanical properties measured by the KESF system. The development of the PhabrOmeter Fabric Evaluation System (NU Cybertek Inc., Davis, CA, USA) [19], allowed the automatic performance of the ring test on a variety of fibrous sheets [20] and the determination of the "relative hand value", "drape index" and "wrinkle recovery rate". The Wool HandleMeter uses the same principle of pushing a circular fabric sample through a nozzle as the Phabrometer, however, the associated force by displacement curve is quantified by a set of 8 objective parameters and these are used to predict a set of 7 bipolar handle attributes suitable to describe light weight single jersey knitted fabrics. These descriptors were shown to be sufficient to describe the primary tactile attributes of lightweight single jersey fabrics as determined by a panel of experts [13-15]. While those reports provided a robust demonstration of the potential of the Wool HandleMeter to assess a range of fabrics, some of the unexplained variance from the analysis is likely to be related to some of the non-wool fabrics. As the main purpose for the development of both the Wool HandleMeter and the Wool ComfortMeter was to evaluate the comfort and handle properties of lightweight wool knitwear, the earlier analysis may not provide precise assessment of the performance of these new instruments for the assessment of knitted pure wool fabrics worn next to skin.

During the production of light weight single jersey fabrics and garments some processes are used to improve the handle and dimensional stability, which can also make the garments more attractive to the consumer. These processes can include crabbing, milling, pressing, decatising, shrink proofing and the addition of chemical softeners. The results of some of these processes are only temporary. In the case of non-substantive chemical softeners the effect can often be removed after a single aqueous washing operation. Effects from processes such as pressing may be diminished once the fabric is wet, while the effects of others such as milling and decatising can have a longer lasting effect [21]. When evaluating the handle of a garment or fabric, both the temporary and long term handle attributes (i.e. before and after washing) are important. The temporary effects have their impact during the initial “touching” of the garment and can be important in the initial purchase decision. However, over the longer term, and after many wearing and washings, an overall perception of the handle of a garment will develop and this perception will be responsible for influencing the decision to purchase a similar garment.

The main purpose of this paper is to investigate the relationships between the wearer trial prickle discomfort, and whether wearers “liked” the garments, with the handle properties, as assessed by the Wool HandleMeter. Initially, however, the relationships between the Wool HandleMeter measurements and the fibre, yarn and fabric properties are quantified to explore if these Wool HandleMeter measurements are predictable. This work differs from earlier reports in two ways: firstly the fabrics are restricted to those composed only of pure wool and only knitted with single ply yarns; and secondly the value of using the Wool HandleMeter is investigated. Using this set of fabrics the relationship between the prickle discomfort scores and whether wearers “liked” the garments are also quantified using the Wool ComfortMeter measurements and these results are then compared with the results using the Wool HandleMeter measurements.

## Materials and methods

### *Experimental Design and Wearer Trial Assessment*

A subset of 19 fabrics was selected from the 48 fabrics tested in wearer trials previously reported [7], on the basis of being pure wool single jersey fabrics knitted with single ply yarn and characteristic of lightweight next-to-skin knitwear. These fabrics also met the range suitable for the Wool HandleMeter which is: single jersey; fabric thickness less than 0.9 mm; mass per unit area between 140 and 220 g/m$^2$. Details of the fabrics used are provided in Appendix 1.

The wearer trial protocol has been fully described elsewhere [6] and is summarised below. Garments of standard sizes and known construction were evaluated under a set protocol in a range of controlled environments. Each test routine lasted 1.5 hours and each fabric was evaluated by approximately 25 participants. The test protocol consisted of 5 sequential stages: 1, pre-trial acclimatisation in an office environment (23°C and 45% relative humidity (RH)) when no measurements were made; 2, 15 minutes with the test garment being worn in an office environment (23°C and 45% RH); 3, 15 minutes in hot environment (40°C, 24% RH); 4, hot active session in hot environment (40°C, 24% RH), where the participant spent 15 minutes on a treadmill, including walking at a leisurely pace on the level and walking on an incline at 5º; and 5, return to office environment, where the final 15 minutes were spent [6]. The temperature and RH were set to achieve a temperature change but not a (absolute) water vapour pressure change between the change room and the environmental chamber [6]. Wearers scored prickle sensations of garments on a scale of 1 to 9. The assessment responses were: 1, not detected; 2, just detected/ threshold; 3, slightly detected; 5, moderately detected; 7, very detected; 9, extremely detected. At the conclusion of the wearer trial each wearer was asked if they "liked" the garment. These "like" intentions were determined as a percentage of wearers who indicated a "like" response. An average weighted wearer prickle assessment was determined over the last 4 stages of the protocol and between trials by the use of linked garments [6].

Female wearers, in the 25-35 age group, were drawn from the local urban community [6]. They were untrained, unskilled wearers selected by an independent market research company using a carefully constructed screening process. The wearer group had a family income greater than AUD$35,000 (before tax) who were fit enough to undertake the trial and who had no aversion to wearing wool garments. Wearers were restricted to those having a body mass index (BMI) between 18.5 and 30. Pregnant wearers and those without English as their first language were excluded. Over the extended time period of the 12 trials some of the wearers were either not able to participate in some trials or to continue to participate at all due to circumstances external to the trial constraints. This natural progression ensured a large sample of wearers was used for testing and that the trials did not suffer from wearer fatigue. One hundred and sixteen wearers participated in the evaluation of the garments studied in this report.

### *Fabric evaluation and fibre testing*

The Wool HandleMeter provides values for seven primary handle parameters and an assessment of overall handle (Table 1). For each Wool HandleMeter parameter, the predicted value varies between 1 and 10, with 1 associated with the first term for the parameter and 10 being associated with the last term for the parameter. These handle parameters, fabric thickness (mm), fabric mass per unit area ($g/m^2$), fabric density (mass/fabric thickness, $g/m^2/mm$) and all fibre measurements were undertaken at the Australian Wool Testing Authority, North Melbourne, Victoria, Australia according to the draft test method [22] and ISO 5084-1996. Three subsamples of each fabric were used for all tests.

**Table 1** Description of each Wool HandleMeter parameter (derived Wang et al. [15])

| Parameter | Descriptor and Definition of Scale |
|---|---|
| Clean/Hairy | Surface property: 1, extremely clean; 10, brushed/raised (very hairy). |
| Greasy/Dry | Surface property: 1, excessive finish (greasy); 10, extremely dry. |
| Rough/Smooth | Surface property: 1, very very rough; 10, extremely smooth. |
| Hard/Soft | Flexural property: 1, extremely hard; 10, extremely soft. |
| Loose/Tight | Flexural property: 1, extremely loose; 10, extremely tight. |
| Cool/Warm | Perceived temperature: 1, extremely cool; 10, extremely warm. |
| Light/Heavy | Bulk property: 1, extremely light; 10 extremely heavy. |
| Overall Handle | Overall fabric handle: 1, poor; 10, excellent. |

The fabric samples measured on the Wool HandleMeter were cut from garments that had been used in the wearer trials. The garments were selected on the basis that they had been worn twice during the trials [7]. All garments were initially washed three times on a gentle cycle in a domestic washing machine according to the Woolmark Test Method TM 31 [23], and dried flat prior to use in the wearer trials. To remove any non-substantive chemicals and softeners that might cause skin irritation to the wearers garments were also washed and dried flat between sessions [6]. Prior to handle measurements, garments were therefore laundered five times removing any temporary chemical and mechanical handle modifications. Therefore, the handle evaluation quantified the long-term, durable handle aspects of each fabric that were related to raw material and permanent processing effects.

Wool ComfortMeter measurement was undertaken at Deakin University using the draft test method [24]. In brief, whole garments were turned inside out, hung vertically and the fabric was lightly and evenly steamed using vertical movements of a Personal Hand Steamer. Garments were conditioned at 20°C and 65% relative humidity for 24 hours prior to testing. Testing was conducted on each whole garment at two places on the front panel and three places on the back panel, subjected to 10 passes of the Wool ComfortMeter recording head. Then, the average of the five measurements were determined for each garment.

The mean fibre diameter (MFD, μm); coefficient of variation of fibre diameter (CVD, %), incidence of fibres at each diameter (%); fibre curvature and fibre curvature standard deviation (SD, °/mm) were measured using the Laserscan [25] with 10,000 fibre measurements on yarn samples taken from each garments. The percentage of fibres which exceeded 25 µm, 26 µm and each successive fibre diameter up to 40 µm, were determined using the fibre diameter distribution counts (% fibres > specified diameter).

***Statistical analysis***

The units for analysis were the individual fabric means ($n$ =19). For each handle parameter from the Wool HandleMeter, a parsimonious general linear model with normal errors was developed, in a forward stepwise manner, using GenStat 15.2 for Windows [26] to determine the relationship between each handle parameter and fibre, yarn and fabric properties. Terms for fabric finishing treatments were also tested. The most adequate model was developed with terms being added or rejected on the basis of $F$-tests ($p < 0.05$). For significant variates, the product of these variates were also tested on the basis of *F*-tests ($p < 0.05$). Models were tested for curvature by testing the square of significant variates, such as fabric and fibre properties. Once the final models were determined, the marginal significance of each term in the final model and the marginal significance of rejected terms were determined. Terms for fabric finishing treatment were: total easy care ($n = 13$); mercerised ($n = 2$); decatised, ($n = 4$). To quantify the dependence of each Wool HandleMeter parameter upon MFD, the percentage variance accounted for by MFD was determined using a linear model with only MFD, and secondly, the reduction in percentage variance accounted were determined when all terms involving fibre diameter were dropped from the final multiple regression models. Correlation coefficients (*r*) were determined between wearer trial assessments (fabric prickle and the wearers "liking" of the garment), Wool HandleMeter parameters and the Wool ComfortMeter measurements [26].

A parsimonious general linear model with normal errors was developed to determine the relationship between the average weighted prickle scores from the wearer trials and attributes of constituent fibres, yarns and fabrics, and Wool ComfortMeter measurement. For regression models using the Wool ComfortMeter, the prickle scores did not require transformation as the residual variation did not increase as the mean score increased. For regression models relating prickle scores with MFD, data required $\log_{10}$ transformation prior to analysis, to avoid the amount of residual variation increasing as the mean score increased. The model development was the same as previously described. General linear models, that included only prescribed subsets of the parameters in the parsimonious model, were fitted and compared using percentage variance accounted for [26]. The relationship between the percentage of wearers "liking" a garment with Wool ComfortMeter measurements was best predicted by an inverse s-shaped logistic curve [26].

## Results

The mean, standard deviation (SD) and range of selected fibre, yarn and fabric handle parameters are presented in Table 2. The MFD of the wools ranged between 13.8 and 21.2 µm. The fabric mass per unit area ranged between 156 and 219 g/m$^2$. Most handle parameters from the Wool HandleMeter showed a range of 2 - 3 units. The weighted prickle scores ranged between 1.50 and 3.77. For the tested garments, wearers showed a range in "like" from 17% to 92%.

**Table 2** Mean, standard deviation (SD) and range of fibre and fabric properties (*n* = 19)

| Variables | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|
| Mean fibre diameter (µm) | 17.7 | 2.29 | 13.8 | 21.2 |
| Fibre diameter coefficient of variation (%) | 22.2 | 2.03 | 19.1 | 26.0 |
| Fibre curvature (°/mm) | 133 | 25.1 | 92 | 188 |
| Percent fibres > 27 µm | 3.0 | 2.99 | 0.5 | 12.4 |
| Percent fibres > 30 µm | 1.5 | 1.60 | 0.2 | 7.0 |
| Yarn linear density (tex) | 24 | 2.7 | 17 | 25 |
| Fabric mass/unit area (g/m$^2$) | 182 | 19.4 | 156 | 219 |
| Fabric thickness (mm) | 0.69 | 0.094 | 0.55 | 0.85 |
| Fabric density (g/m$^2$/mm thickness) | 267 | 27.0 | 232 | 316 |
| Wool HandleMeter parameter | | | | |
| Clean/Hairy | 5.7 | 0.70 | 4.1 | 7.0 |
| Greasy/Dry | 6.6 | 0.67 | 5.4 | 7.9 |
| Rough/Smooth | 5.2 | 0.79 | 4.0 | 7.1 |
| Hard/Soft | 6.1 | 0.50 | 5.3 | 7.1 |
| Loose/Tight | 5.2 | 0.24 | 4.7 | 5.5 |
| Cool/Warm | 5.9 | 0.51 | 5.1 | 6.7 |
| Light/Heavy | 5.0 | 0.66 | 3.7 | 5.9 |
| Overall Handle | 5.37 | 0.66 | 4.5 | 7.0 |
| Average weighted prickle score | 2.23 | 0.627 | 1.50 | 3.77 |
| Wearers who "liked" garments (%) | 57 | 23.8 | 17 | 92 |
| Wool ComfortMeter | 381 | 214.2 | 35 | 817 |

Fabric mass per unit area and fabric thickness generally declined as MFD increased ($p$ = 0.031, $r$ = -0.45, and $p$ = 0.002, $r$ = -0.65, respectively). Fabric mass per unit area generally increased as fabric thickness increased ($p$ = 0.001, $r$ = 0.65). Fabric density generally declined as fabric thickness increased ($p$ = 0.004, $r$ = -0.60).

***Prediction of Wool HandleMeter parameters***

Significant terms and their *p*-value for the prediction of each handle parameter are summarised in Table 3. For Clean/Hairy, there was a negative linear response to fabric density, thus increasing fabric density reduced the feeling of hairiness (- 0.025 unit/ g/ $m^2$ /mm). Fabric density alone accounted for 53.5% of the variance but the model with a term for decatised finish accounted for 69.8% of the variance. Fabrics with a decatised finish were assessed as having a cleaner feel (- 0.8 unit) compared with fabrics with a standard non-decatised finish. It seems that the compressing and setting of the fabric by decatising, which would be expected to change the orientation of surface fibres but not reduce the physical presence of these fibres, has resulted in a cleaner feel.

For Greasy/Dry, there was a positive linear response to both fabric thickness and MFD with both thicker fabrics (+ 3.67 units/1 mm) and coarser fibre (+ 0.13 unit/1 µm) resulting in fabrics feeling drier. A decatised finish produced a drier handle (+ 1.2 units). Fabric thickness alone accounted for 64.3% of the variance, and MFD alone accounted for 17.4% of the variance with the final model accounting for 78.8% of the variance (Table 3).

For Rough/Smooth, increasing fabric thickness and MFD resulted in separate linear decreases in fabric smoothness (1.2 units per 0.1 mm in thickness; 0.13 unit per 1 µm, respectively) but this response was modified by a linear increase in fabric smoothness, with increases in fabric mass per unit area (0.23 unit per 10 g/$m^2$). Fabric thickness alone accounted for 57.3% of the variance and the final model accounted for 83.6% of total variance (Table 3).

For Hard/Soft, there were linear decreases in softness as fabric thickness (- 6.1 units per 1.0 mm increase) and MFD (- 0.09 unit/1 µm) increased, with thicker fabrics and coarser wool producing fabrics that felt harder. Increasing fabric thickness by the range observed in the test samples (0.3 mm, Table 2) resulted in the predicted softness declining by 1.8 units. Increasing MFD by the range observed in the test samples (7 µm) resulted in predicted hardness increasing by 0.6 unit. Fabric thickness alone accounted for 77.7% of the variance, MFD alone accounted for 9.2% of the variance, and the final model accounted for 86.1% of the variance (Table 3).

For Loose/Tight, there was a narrow range in values of 0.8 (Table 2), most likely as a consequence of our narrowing of the range of fabrics to those knitted on a 24 gauge knitting machine and maintaining a consistent cover factor of about 1.28. CVD alone explained 29.3% of the variance, and CVD with fabric mass per unit area explained 50.3% of the variance, and the final model included an interaction between fabric mass per unit area and CVD which explained 63.9% of the variance (Table 3). For fabrics with a mass per unit area of 165 $g/m^2$, the feeling of tightness increased with increasing CVD but for fabrics with mass per unit area of 190 $g/m^2$ there was little change in fabric loose/tight feeling. At a CVD of 19%, fabrics of 190 $g/m^2$ felt about 0.5 unit tighter than those of 165 $g/m^2$ with differences diminishing as CVD increased to 23%.

For Cool/Warm, there was a linear increase in the feeling of warmth as fabric thickness increased and a small negative decrease as fabric density increased. Alone, fabric thickness accounted for 76.7% of the variance and the final model 88.7% of the variance (Table 3). After adjustment for fabric density, over the range in fabric thickness in this study (Table 2), a 0.3 mm increase in fabric thickness increased the feeling of warmth by 1 unit. Increasing fabric density from 240 to 300 $g/m^2/mm$ equated to a decline in Cool/Warm by 0.5 unit.

For Light/Heavy, there was a positive linear increase as both fabric thickness increased (8.6 units per 1 mm) and yarn count increased (0.4 unit per 10 tex increase), that is thicker fabrics and higher tex yarns were associated with heavier fabric feeling. A decatised finish produced a lighter handle (- 0.8 unit). Most of the variance was associated with changes in fabric

**Table 3** Significant terms showing their *p*-values and variance accounted for and residual s.d. by models of Wool HandleMeter parameters (*n* = 19)

| | Wool HandleMeter parameter | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Property type | | Surface | | Flexural | | Perceived | Bulk | Overall |
| Model terms | Clean/ Hairy | Greasy/ Dry | Rough/ Smooth | Hard/ Soft | Loose/ Tight | Cool/ Warm | Light/ Heavy | Overall Handle |
| Mean fibre diameter | | 0.017 | 0.009 | 0.004 | | | | 0.003 |
| Coefficient of variation of fibre diameter (CVD) | | | | | 0.002 | | | |
| Yarn count | | | | | | | 0.023 | |
| Fabric thickness | | 0.013 | < 0.001 | < 0.001 | | < 0.001 | < 0.001 | |
| Fabric density | < 0.001 | | | | | < 0.001 | | < 0.001 |
| Fabric mass per unit area | | | < 0.001 | | 0.011 | | | < 0.001 |
| Product CVD and fabric mass per unit area | | | | | 0.018 | | | |
| Term for Decatised finish | 0.015 | 0.003 | | | | | < 0.001 | |
| Correlation coefficient (*r*) | -0.84 | 0.89 | -0.91 | -0.93 | 0.80 | 0.94 | 0.96 | 0.90 |
| Variance accounted (%) | 69.8 | 78.8 | 83.6 | 86.1 | 63.9 | 88.7 | 92.6 | 80.9 |
| Residual s.d. | 0.39 | 0.31 | 0.32 | 0.19 | 0.14 | 0.17 | 0.18 | 0.29 |

thickness (78.2%), while yarn count alone accounted for 29.7% of the variance and the final model accounted for 92.6% of the variance (Table 3).

For Overall Handle, increasing fabric density improved Overall Handle while increasing MFD (- 0.14 unit per 1 μm) and mass per unit area (- 0.20 unit per 10 $g/m^2$) reduced the Overall Handle. Fabric density alone accounted for 58.7% of total variance, and the final model accounted for 80.9% of total variance (Table 3).

The dependence of each Wool HandleMeter parameter is quantified in terms of variance accounted for by MFD in Table 4. As a single term, MFD was only related to three parameters, Greasy/Dry, Cool/Warm and Light/Heavy, and then at only the lowest acceptable level of significance ($p < 0.05$). However, MFD was only significant in the final model for one of these parameters, Greasy/Dry (Table 3). Four Wool HandleMeter parameters included MFD in their final models (Table 3). When MFD was removed from the final model for Greasy/Dry, Hard/Soft and Rough/Smooth, the models accounted for 8% less variance and for Overall Handle, the model accounted for 14.4% less variance (Table 4).

**Table 4**. The percentage variance accounted for by mean fibre diameter in linear models for Wool HandleMeter parameters of wool fabrics when used as the sole term or when terms involving fibre diameter were dropped from the final multiple regression model as shown in Table 3 ($n$ = 19).

| Wool HandleMeter parameter | MFD as sole term | *p*-value | Reduction in percentage variance accounted for when MFD dropped from final model |
|---|---|---|---|
| Clean/Hairy | 0 | 0.66 | - |
| Greasy/Dry | 17.4 | 0.043 | 8.2 |
| Rough/Smooth | 2.6 | 0.24 | 8.2 |
| Hard/Soft | 9.2 | 0.11 | 8.4 |
| Loose/Tight | 0 | 0.85 | - |
| Cool/Warm | 38.8[a] | 0.020[a] | - |
| Light/Heavy | 21.2 | 0.027 | - |
| Overall Handle | 0 | 0.57 | 14.4 |

[a] this relates to the square term

### Wearer assessments and Wool HandleMeter measurements

The correlations between the wearer trial perceptions of fabric prickle, the percentage of wearers who" liked" the garment and each Wool HandleMeter parameter are shown in Table 5. There was no significant association between Overall Handle and if wearers "liked" the garment (Table 5) or between Overall Handle and the level of wearer assessed prickle (Table 5, Figure 1). There was little relationship between other handle parameters and levels of garment prickle or if wearers "liked" the garment. Only the Light/Heavy handle parameter showed significant correlations ($p < 0.05$) with "like". Light/Heavy was also negatively correlated with wearer prickle score.

**Table 5** The correlation (*r*) between wearer trial perceptions of fabric prickle and overall preference for the garment (like percentage) and the Wool HandleMeter assessment, with the statistical significance of the correlation coefficient (*n* = 19)

| Wool HandleMeter parameter | Wearer like % | *p*-value | Weighted wearer prickle | *p*-value |
|---|---|---|---|---|
| Clean/Hairy | -0.02 | 0.94 | 0.02 | 0.92 |
| Greasy/Dry | 0.24 | 0.32 | -0.28 | 0.25 |
| Rough/Smooth | -0.13 | 0.59 | 0.19 | 0.43 |
| Hard/Soft | -0.23 | 0.34 | 0.29 | 0.23 |
| Loose/Tight | -0.09 | 0.71 | 0.08 | 0.74 |
| Cool/Warm | 0.34 | 0.15 | -0.36 | 0.13 |
| Light/Heavy | 0.47 | 0.044 | -0.52 | 0.024 |
| Overall Handle | -0.08 | 0.75 | 0.17 | 0.48 |

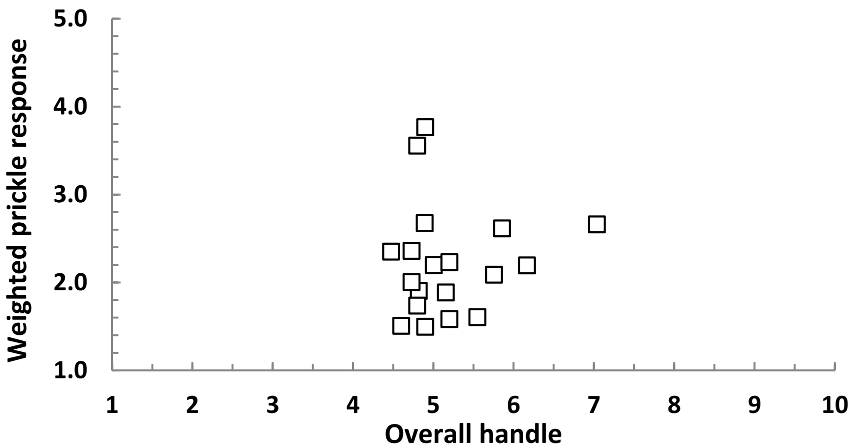


**Figure 1** Relationship between the wearer trial prickle response and the Wool HandleMeter measurement of Overall handle (1 = poor; 10 = excellent) (*n* = 19, *r* = 0.07, *p* > 0.1)

***Wearer assessments and Wool ComfortMeter measurements***

The final model for the prediction of average wearer prickle scores generated from the analysis of all fibre, yarn and fabric measurements and from Wool ComfortMeter measurement (WCM) is shown in Equation 1, with standard errors shown in brackets;

Prickle score =

$$1.55\ (\pm 0.119) + 49\times 10^{-6}\ (\pm 644\times 10^{-6})\ \text{WCM} + 3.51\times 10^{-6}\ (\pm 0.82\times 10^{-6})\ \text{WCM}^2 \quad (1)$$

The multiple correlation coefficient was 0.95, the percentage of variance accounted for was 90.9% and the residual SD was 0.189. The major share of variation, 81.7% of total variation and 90% of the variation accounted for by the model, could be attributed to differences due to Wool ComfortMeter value without the square term ($p = 6.9 \times 10^{-8}$). The addition of the term for $\text{WCM}^2$ ($p = 0.00057$) accounted for a further 9.2% of variance (Table 6).

**Table 6** Variance in the wearer assessed prickle scores accounted for by terms involving mean fibre diameter (MFD) and Wool ComfortMeter measurement (WCM)

| Terms in model involving | Residual SD | Residual variance | % variance accounted for by model |
|---|---|---|---|
| None | 0.627 | 0.393 | 0 |
| MFD[a] | 0.378 | 0.143 | 63.7 |
| WCM | 0.269 | 0.072 | 81.7 |
| WCM and MFD[b] | 0.273 | 0.075 | 81.0 |
| WCM and $\text{WCM}^2$ | 0.189 | 0.036 | 90.9 |

[a] If data was $\log_{10}$ transformed % variance accounted increased to 73.0.
[b] MFD was not significant in this model ($p = 0.52$)

The relationship between the wearer prickle response and the Wool ComfortMeter measurement of fabrics is shown in Figure 2. Low wearer prickle scores were associated with low Wool ComfortMeter measurement.

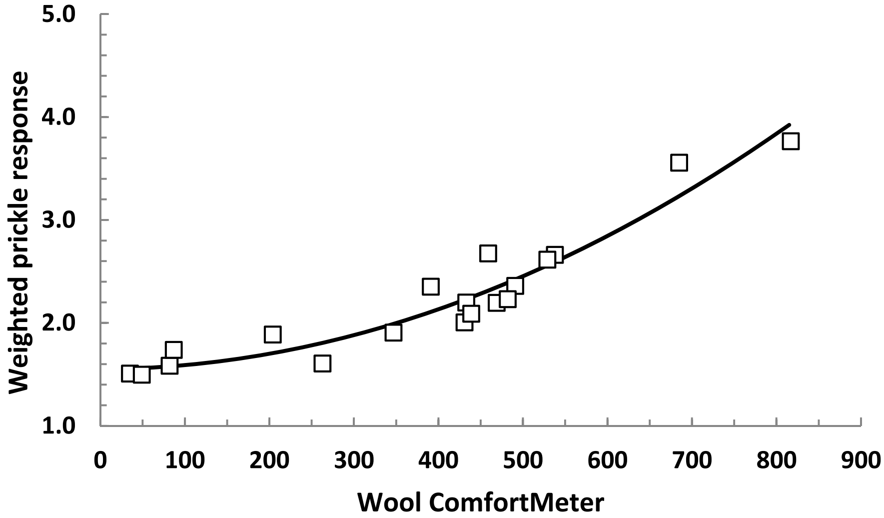


**Figure 2** Relationship between the average weighted prickle scores of wearers of single jersey knitted garments composed of wool and the Wool ComfortMeter measurement of garments ($n$ = 19, $r$ = 0.95, $p$ < 0.001)

Once the Wool ComfortMeter measurement had been accounted for, MFD was not a significant term in the final model ($p$ = 0.72). Other non-significant terms were: yarn count ($p$ = 0.26); fabric density ($p$ = 0.16); fabric mass per unit area ($p$ = 0.50); CVD ($p$ = 0.34); fibre curvature ($p$ = 0.86); fibre curvature SD ($p$ = 0.59); spinning fineness ($p$ = 0.95); percentage of fibres coarser than 27 µm ($p$ = 0.37) or 30 µm ($p$ = 0.21). Fabric finishing treatments were also not significant: total easy care finish ($p$ = 0.85), mercerised ($p$ = 0.70) and decatised ($p$ = 0.40).

Fabric thickness ($p$ = 0.024) was not included in the final model as it was considered a minority effect. If fabric thickness was included in the final model, it increased variance accounted for by 2.3% to a total of 93.2%. The regression coefficient indicated that weighted prickle score declined by 1.66 (s.e. 0.661) for each 1 mm increase in fabric thickness, however the range in fabric thickness in this study was 0.3 mm (Table 2).

MFD is an important factor in determining wearer comfort and accounted for 63.7% of the variance in the weighted prickle response when untransformed data are analysed (Table 6).

The model for the relationship between the logarithm of wearer prickle scores and MFD ($p = 1.9 \times 10^{-6}$) is shown in Equation 2, with standard errors shown in brackets:

$$\text{Log}_{10}\,(\text{Prickle score}) = -\,0.427\ (0.109) + 0.04295\ (0.00609) \times \text{MFD} \;\ldots..(2)$$

The correlation coefficient was 0.85, the percentage of variance accounted for was 73.0% and the residual SD was 0.0591. No additional term related to fibre measurement was significant ($MFD^2$, $p = 0.57$; fibre diameter CV, $p = 0.68$; fibre curvature, $p = 0.14$; fibre curvature SD, $p = 0.33$; spinning fineness, $p = 0.56$; percentage of fibres coarser than 27 µm, $p = 0.15$ or 30 µm, $p = 0.18$).

The relationship between whether wearers "liked" the garments and the Wool ComfortMeter measurement (WCM) was best predicted by an inverse s-shaped logistic curve (Equation 3, $p$-value = $2.6 \times 10^{-7}$). This line of best fit explained 86.3% of the variance in wearer "liking" of the garments, whereas a linear fit explained only 77% of the variance.

$$\text{Wearers who liked garment (\%)} = 17.7 + 66.2/(1+e^{(0.015\times(\text{WCM}-454.4))}) \ldots..(3)$$

The logistic curve and the observed values are shown in Figure 3. This curve had a residual SD of 8.8. This shows that Wool ComfortMeter measurements below 300 were associated with a "like" percentage greater than 80% and measurements above 600 were associated with low "like" percentage of about 20%.

The relationship between whether wearers "liked" the garments and the MFD was best predicted by a linear fit, which explained only 51.1% of the variance, while an inverse s-shaped logistic curve explained 44.9% of the variance in wearer "liking" of the garments.

Since there was a good relationship between garment prickle and Wool ComfortMeter measurement (Figure 2) and a poor relationship between garment prickle and Overall Handle (Figure 1) further investigation was carried out to study the relationship between Wool

ComfortMeter and Overall Handle. The result showed a non-significant relationship between Wool ComfortMeter measurement and Overall Handle (Figure 4, $p > 0.1$).

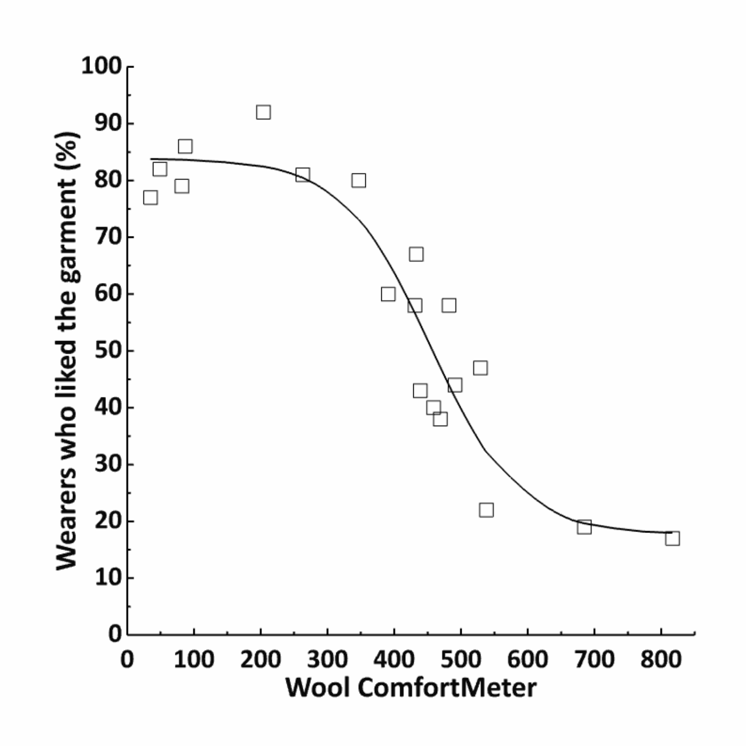


**Figure 3** Relationship between the percentage of wearers who liked a garment and the Wool ComfortMeter measurement of single jersey knitwear. The fitted logistic inverse S-shaped curve explained 86.3% of the variance ($n = 19$, $p < 0.001$)

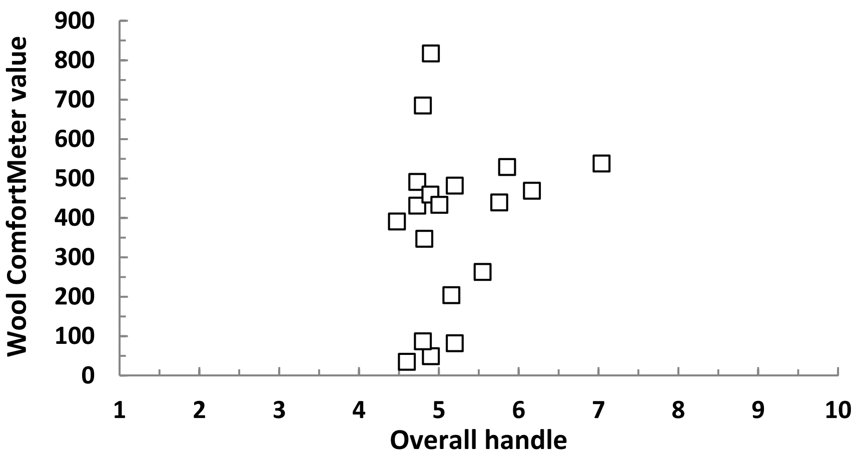


**Figure 4** Relationship between the Wool ComfortMeter measurement and the Wool HandleMeter measurement of Overall Handle (1 = poor; 10 = excellent) ($n = 19$, $r = 0.22$, $p > 0.1$)

## Discussion

### *Prediction of fabric handle*

The results indicate that the Wool HandleMeter can differentiate wool fabrics based on their fundamental aspects and the way these are expressed in the low stress fabric mechanical properties such as bending rigidity, biaxial extension, friction etc. The results also demonstrate that for fabric handle, the fibre and yarn characteristics are less important than changes in the fabric physical properties of thickness, density, mass per unit area and finishing processes (Table 3). Unlike the Wool ComfortMeter measurement, there is no ideal combination of handle attributes for the best fabric, as the desired fabric handle depends upon fashion trends and the desires of the end user.

While the seven specific handle attributes are highly correlated [15], one of the key processes used in developing the Handle prediction algorithms was using principle component analysis to remove the co-linearity that exists between some of the subjective handle terms. The present results demonstrate the effectiveness of this approach as each handle parameter includes a different combination of the fundamental aspects of the knitted fabric (Table 3). Wool HandleMeter predictions were also largely independent of mean fibre diameter (MFD) (Table 4).

### *Influence of fibre, yarn and fabric properties on handle parameters*

Two attributes of fibres affected handle parameters. MFD was shown to affect the prediction of the Greasy/Dry, Rough/Smooth, Hard/Soft and Overall feel of the fabrics but this term only had a small effect within the full prediction models (Table 4). Previous studies on knitted cotton and polyester fabric has shown that the MFD of the component fibres can affect fabric handle, with 1.5 denier polyester fibres producing a material that is more flexible than a 3.5 denier polyester fabric, as indicated by fabric bending and shearing modulus evaluated by the KESF [27].

The fibre diameter coefficient of variation (CVD) affected only the prediction of Loose/Tight (Table 3). CVD has previously been shown to be associated with increasing fabric stiffness in Punto-di-Roma fabrics (MFD range 19.9-25.4 µm, CVD, 22.2-28.0%, fabric mass per unit area ~ 400 g/m$^2$) knitted with 32 tex worsted spun yarns [28]. While these fabrics are outside the range used here for next-to-skin wear, these results support our findings that higher CVD is related to fabrics feeling tighter, although only detected in our fabrics in the range of CVD of 19-23%.

The only yarn property which affected the handle parameters was the yarn linear density which marginally affected Light/Heavy (Table 3). As fabric thickness was the main term in the prediction model for Light/Heavy, it could be expected that yarn linear density would also be included, as coarser yarn counts would be thicker and therefore associated with thicker fabrics. It is possible that yarn twist, yarn hairiness and yarn frictional properties also affect the surface properties of fabrics by affecting fabric friction and fabric roughness but these measurements were not available.

Of the fabric properties, fabric thickness had a positive effect on Cool/Warm, Greasy/Dry and Light/Heavy but had a negative effect on Hard/Soft, and Rough/Smooth (Table 3). As fabric thickness increased the fabric felt warmer, drier, heavier, harder and rougher. Softness and smoothness, probably the two most used terms to describe how a fabric feels, had fabric thickness as the most influential term (Table 3). Smoothness and softness are important in the assessment of Overall Handle [5]. It is therefore not surprising that fabric thickness is the most significant determinant of smoothness and softness and fabric density is the main determinant of Overall Handle.

Fabric density affected Clean/Hairy, Cool/Warm and Overall Handle with a decrease in density associated with a hairier, warmer but less preferred overall feel. The hairier and warmer feel is associated with an increase in the number of fibres on the surface of the fabric. As these fibres are at a much lower packing density than the fibres within the yarn, it would be expected that for a given unit volume of fabric, the greater the proportion of surface fibres and therefore the lower the total fabric density.

Fabric mass per unit area affected Loose/Tight as part of a product term with CVD (Table 3). The role of mass per unit area is understandable as shorter loop lengths and higher cover factor would be associated with increased mass and an increased tight feeling.

The Cool/Warm sensation occurs when the fabric contacts the skin and is related to the fabric surface contour and the surface area in contact with the skin, the greater the contact area the cooler the feel [29]. Fabric thickness and density were the two terms in the prediction model for the Cool/Warm feeling (Table 3). As thickness reduces and density increases it would be expected that there would be more fibre per unit area and therefore a greater area of fibre in contact with the skin.

The decatising treatment is applied with the intent of altering fabric handle [16]. It is a second order effect in the sensations of Clean/Hairy, Greasy/Dry and Light/Heavy with the biggest effect in the Clean/Hairy sensation (Table 3). The decatising process involves a mechanical treatment which combines the influence of heat, moisture and pressure and results in an increase in the plasticity of the fabric [29], a permanent reduction in fabric thickness and the release of residual strains in the fabric. All the garments used in this study were washed five times prior to testing on the Wool HandleMeter, thus showing the permanent nature of the decatising treatment. No effects could be attributed to the mercerising and total easy care treatments (Table 3).

There were a number of fibre (e.g. incidence of coarse fibres), yarn and fabric properties which did not influence the handle parameters predicted by the Wool HandleMeter. While in the present study fibre curvature and fibre curvature SD of fibres removed from the fabric did not influence the handle parameters, other studies on knitwear and woven fabrics suggested that a softer and silkier handle was associated with lower fibre curvature in the component raw wool fibres [3, 30,31]. In this study, 15 of the 19 fabrics were knitted from commercial yarns in which it is unlikely that fibre curvature was a specification in the original wool consignments, so the fabrics were unlikely to have sufficient differences in average fibre curvature of the raw wool to demonstrate an effect on finished fabric handle. Yarn ply, knitting structure and knitting machine gauge were standardised and were not tested in this analysis.

While many aspects of the change of ownership of knitted fabric along the supply chain involve specifications that are easily measured e.g. fabric mass per unit area, the Wool HandleMeter is able to quantify subjective aspects which will permit manufacturers and merchants to specify their requirements for these fabric attributes.

***Predicting wearer prickle sensation and liking of garments***

The Wool ComfortMeter measurement accurately predicted the average prickle responses by wearers and whether or not they “liked” single jersey lightweight wool garments after wearing them, without requiring any additional information about wool quality, fabric properties or fabric handle. These findings indicates that, for single jersey wool fabric of the type used in this study, the Wool ComfortMeter measurement provides a standalone prediction of wearer comfort that was only marginally improved by adding fabric thickness but not any other information about the wool and its processing or its handle attributes.

This finding differs from our earlier investigations using a larger range of fibre types and yarn and fabric structures, where inclusion of data on MFD did improve the accuracy of predicting wearer prickle responses based on Wool ComfortMeter data [7]. Another difference is the curvilinear nature of the prediction response compared with the linear association with the wearer prickle response when a larger range of fabrics were studied [7]. The accuracy of predicting wearer comfort was slightly greater (90.9% of variance accounted for) for the range of single jersey wool fabrics used in the current study, than that previously reported (87.7%) for the larger range of fabrics. While the difference was small it is probably explained by the exclusion of non-wool fabrics and knitting structures other than single jersey, as these affected the prediction model [7], and the coarser yarn count fabrics with fabrics with higher mass per unit area excluded from this study because they were outside the Wool HandleMeter testing range.

MFD was the most important wool characteristics, contributing to wearer prickle comfort and accounted for 73.0% of the variance in the logarithm of average prickle sensation scored by wearers. Other fibre measures provided no additional benefit in predicting the comfort properties of the wool knitwear tested. Wearer comfort continues to improve down to the lowest levels of MFD (13.8 μm) used in this study and this finding has important implications for the manufacture of elite quality next-to-skin knitwear. Fabrics made from ultrafine wool (13.8–15 μm) are close to the baseline level of the Wool ComfortMeter (Figure 2) and also to the limits of even the most sensitive wearers' ability to detect any prickle sensation. The lowest average wearer prickle score of 1.5 indicates that on average over the wearer protocol half the people in the test could detect no prickle and the other half detected little discernible prickle. This prickle score is equivalent to or better than the prickle scores achieved by some commercial cotton and polyester garments in the same wearer trial [7]. It is interesting that the "prickle factor" measurement (% fibres greater than 30 μm in diameter) was not significant in prediction models of wearer assessment of prickle once either the Wool ComfortMeter measurement or the MFD were included.

For both the wearer prickle response and the Wool ComfortMeter measurement, there was greater variation (scatter) as MFD increased, as shown by the requirement to transform the data to stop the variance increasing as MFD increased. This result is quite different to that observed when the prickle response was related to the Wool ComfortMeter, where the responses did not show increased scatter in relation to the predicted response as Wool ComfortMeter measurement values increased (Figure 2).

The results show that there was little relationship between the handle of fabrics, the objective determination of the sense of touch as quantified by the Wool HandleMeter, and the comfort of fabrics determined either by wearers or the Wool ComfortMeter (Table 5, Figure 1). While the Wool ComfortMeter explained over 90% of the variance in wearer prickle discomfort (Equation 1), the Wool HandleMeter could explain little of wearer prickle discomfort (Table 5). The subjective assessment of fabric softness has been considered by some of the next to skin knitwear industry as a good indicator of wearer comfort. This work has shown that the fundamental driver of the wearer prickle rating, MFD, which explained 73% of the variance in the wearer prickle rating prediction model, explains less than 10% of the variance in the softness rating (Equation 2, Table 4). Clearly there is no connection between the handle of these fabrics and wearer perceptions of fabric comfort as quantified in the wearer trial prickle sensations or wearers' "liking" of garments.

## Conclusions

The key findings of this investigation were:

1. The Wool HandleMeter, which was developed using handle evaluations provided by a panel of experts, is a good predictor of 8 key wool fabric handle parameters (*r* value average 0.90, range 0.80 to 0.96, Table 3) for lightweight single jersey wool knitwear. Thus the Wool HandleMeter is a valuable tool to objectively describe the handle characteristics of lightweight single jersey wool fabrics between the knitter and the consumer.

2. The Wool HandleMeter is a poor predictor of wearer assessments of fabric prickle discomfort and whether or not wearers will like a garment once they have worn it (Table 5, Figure 1). These results demonstrate that there is no connection between the handle characteristics of wool single jersey fabric and whether or not the fabric may cause prickle discomfort. In other words, good fabric handle does not guarantee prickle free wool garments. Importantly, it does not predict if the consumer will like wearing the fabric.

3. The Wool ComfortMeter measurement is a good predictor of wearer assessment of fabric comfort (prickle and itch) and whether or not consumers like wearing a garment (Table 6, Figures 2, 4). The Wool ComfortMeter accounted for more of the variance in the wearer prickle response prediction model than did any combination of wool fibre diameter measurements. The Wool ComfortMeter therefore provides a very useful objective measure of lightweight wool knitwear for quality specifications, quality assurance and marketing.

4. Together the Wool ComfortMeter and Wool HandleMeter provide objective measurement of two important aspects of concern to consumers purchasing lightweight single jersey wool knitwear. The clear message to the wool supply chain is that there is no predictive relationship between handle and comfort (prickle and itch) and that it is prickle discomfort rather than handle that determines whether consumers will like wearing a garment.

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**Appendix 1** The characteristics of fibres, yarns and fabrics used to evaluate Wool ComfortMeter assessment of wearer prickle response and Wool HandleMeter parameters: average weighted prickle responses (Prickle); mean Wool ComfortMeter (WCM) measurements of washed garments; mean fibre diameter (MFD) of constituent fibres, CVD and percentage of fibres coarser than 27 µm (%F> 27 µm) of constituent fibres; yarn properties; knitting machine gauge; fabric mass per unit area (GSM), fabric thickness and fabric density (g/m$^2$/mm thickness). The fabric code is comparable with previous tabulations of wearer trial fabric data, the fabrics omitted from this table being outside the specified GSM for the Wool HandleMeter

| | | | Fibre | | | | | Fabric | | | Wool HandleMeter parameters | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fabric code | Prickle | WCM | MFD (µm) | CVD (%) | %F> 27 µm | Yarn detail [a] | Machine gauge | GSM (g/m$^2$) | Thickness (mm) | Density | Clean/ Hairy | Cool/ Warm | Greasy/ Dry | Hard/ Soft | Light/ Heavy | Loose/ Tight | Rough/ Smooth | Overall |
| 1 | 1.61 | 263 | 15.5 | 19.6 | 0.48 | R25/1/1 | 24 | 183.5 | 0.713 | 257 | 5.8 | 6.2 | 6.2 | 6.3 | 5.4 | 5.1 | 5.4 | 5.5 |
| 2 | 1.90 | 347 | 18.5 | 19.1 | 1.64 | R25/1/1 | 24 | 173.1 | 0.690 | 251 | 6.7 | 6.1 | 6.3 | 6.2 | 5.3 | 4.7 | 4.9 | 4.8 |
| 3 | 2.61 | 529 | 20.9 | 20.6 | 6.84 | R25/1/1 | 24 | 176.5 | 0.696 | 254 | 7.0 | 6.2 | 6.6 | 5.7 | 5.4 | 4.8 | 4.5 | 4.5 |
| 16 | 2.35 | 391 | 19.1 | 24.7 | 3.62 | R25/1/1 | 24 | 155.8 | 0.548 | 284 | 4.9 | 5.1 | 5.6 | 6.9 | 4.4 | 5.4 | 6.4 | 6.2 |
| 20 | 2.00 | 431 | 17.4 | 22.7 | 1.86 | R25/1/1 | 24 | 170.5 | 0.659 | 259 | 6.5 | 5.9 | 6.3 | 5.9 | 5.3 | 5.0 | 4.9 | 4.7 |
| 21 | 2.19 | 469 | 17.9 | 21.6 | 1.9 | R25/1/1 | 24 | 158.9 | 0.663 | 239 | 6.2 | 6.0 | 6.3 | 6.2 | 4.9 | 4.9 | 5.1 | 5.2 |
| 22 | 2.36 | 491 | 18.1 | 23.2 | 3.12 | R25/1/1 | 24 | 176.5 | 0.709 | 249 | 6.1 | 6.2 | 6.6 | 5.9 | 5.3 | 5.2 | 4.8 | 4.9 |
| 23 | 3.76 | 817 | 21.2 | 26 | 12.4 | R25/1/1 | 24 | 170.9 | 0.691 | 247 | 6.0 | 6.1 | 6.6 | 5.8 | 5.2 | 5.3 | 4.8 | 5.0 |
| 25 | 1.89 | 204 | 16.2 | 19.2 | 0.54 | R25/1/1 | 24 | 183.8 | 0.581 | 316 | 4.6 | 5.1 | 5.4 | 7.1 | 4.3 | 4.8 | 7.1 | 7.0 |
| 27 | 2.67 | 459 | 17.2 | 19.5 | 0.89 | R25/1/1 | 24 | 184.9 | 0.644 | 287 | 5.2 | 5.6 | 6.6 | 6.1 | 4.8 | 5.5 | 5.7 | 5.8 |
| 32 | 2.20 | 433 | 19.1 | 22 | 3.22 | R25/1/1 | 24 | 218.0 | 0.735 | 297 | 5.6 | 6.2 | 7.0 | 5.8 | 5.7 | 5.4 | 5.1 | 5.2 |
| 33 | 2.23 | 482 | 20.0 | 25.6 | 5.75 | R25/1/1 | 24 | 178.0 | 0.583 | 305 | 5.3 | 5.5 | 6.7 | 6.2 | 4.2 | 5.5 | 5.4 | 5.8 |
| 34 | 3.56 | 685 | 20.1 | 22.6 | 5.58 | R17/1/1 | 24 | 160.0 | 0.580 | 276 | 5.5 | 5.6 | 6.5 | 6.6 | 3.8 | 5.1 | 5.5 | 6.0 |
| 35 | 2.66 | 538 | 19.7 | 21.8 | 4.35 | R17/1/1 | 24 | 156.0 | 0.555 | 281 | 5.5 | 5.5 | 6.3 | 6.9 | 3.7 | 4.9 | 5.7 | 6.0 |
| 41 | 2.09 | 439 | 18.1 | 22.5 | 2.26 | R20/1/1 | 24 | 218.6 | 0.694 | 315 | 4.1 | 5.2 | 5.9 | 6.2 | 5.5 | 5.4 | 6.3 | 5.9 |
| 45 | 1.51 | 35 | 13.8 | 23.3 | 0.77 | R25/1/1 | 24 | 181.2 | 0.566 | 320 | 5.8 | 6.7 | 7.9 | 5.3 | 5.9 | 5.3 | 4.0 | 4.6 |
| 46 | 1.50 | 49 | 14.2 | 23.2 | 0.86 | R25/1/1 | 24 | 171.8 | 0.559 | 307 | 5.9 | 6.6 | 7.5 | 5.6 | 5.6 | 5.2 | 4.3 | 4.9 |
| 47 | 1.58 | 82 | 14.6 | 21.1 | 0.64 | R25/1/1 | 24 | 194.2 | 0.525 | 370 | 5.5 | 6.5 | 7.4 | 5.6 | 5.7 | 5.2 | 4.6 | 5.2 |
| 48 | 1.74 | 87 | 15.0 | 23.3 | 0.86 | R25/1/1 | 24 | 190.8 | 0.550 | 347 | 5.9 | 6.6 | 7.7 | 5.5 | 5.5 | 5.2 | 4.2 | 4.8 |

[a] Includes: resultant count in tex/number of plys/number of ends.