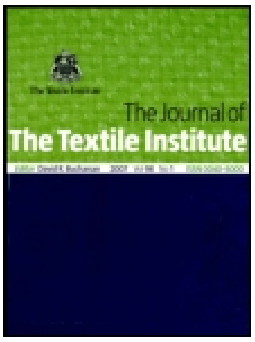

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A comparative study on yarn hairiness results from manual test and two commercial hairiness metres

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The true hairiness (actual hair number and length) of ring, compact and rotor spun yarns was measured by means of a tedious manual method. The hairiness results were then compared with yarn hairiness results obtained from two commercial instruments (Uster tester and Zweigle Hairiness Meter). The comparative analysis between the measurement methods has revealed very significant discrepancy between the true hairiness results and that from commercial instruments, not only just in terms of the number of hairs, but also in terms of the hair-length distribution. The hair numbers obtained from manual method are much greater than that obtained from the hairiness metres, and the true hair-length distribution does not follow the well-known exponential decay. This study shows that the two existing hairiness measuring systems, while essential for rapid assessment of yarn hairiness, are not accurately measuring the true hairiness of spun yarns.

Keywords: hairiness; yarns; test method; hair-length distribution

Introduction

Yarn hairiness refers to the protruding fibres from yarn surface in the form of either fibre ends or loops. It is one of the most critical quality parameters for staple spun yarns. A series of comprehensive reviews on yarn hairiness, including hairiness measuring systems, have been conducted (Barella, 1957, 1983; Barella & Manich, 1997, 2002). Surprisingly, little is known about the true hairiness of yarns, i.e. the actual number and true length of yarn hairs, even though hairiness testing by commercial instruments has become a common practice. Two important hairiness measuring systems, the Zweigle hairiness tester and the Uster tester with a hairiness module, have been widely used in both industry and research laboratories worldwide. The Zweigle hairiness tester utilizes a horizontal array of sensors spaced with specific distances and scans protruding fibres from vertically passing yarn sample (Zweigle GmbH, 1989). It classifies the number of hairs in different length groups and produces a quantitative parameter, i.e. S3 value, which shows the total number of protruding fibres equal to or longer than a set length (e.g. 3 mm). The Uster hairiness module works by shining light on a moving yarn sample and detecting the amount of scattered light due to protruding hairs, and then deriving a Uster hairiness index (H) to quantify the total length of protruding fibres within the measurement field of 1 cm length of the yarn (Uster Technologies Ltd., 2011). No data are currently available on how the hairiness results from these commercial instruments relate to the true hairiness of yarns.

There are certain limitations for commercially available hairiness testing instruments, some of which have been reported in the literature, such as the speed, friction and air drag effects on hairiness test results (Wang, 1997, 1998a, 1998b; Wang & Chang, 1999; Wang, Huang, & Huang, 1999). Ozkaya, Acar, and Jackson (2008) mentioned certain limitations of photo sensor array-based hairiness measurement systems in terms of sensor resolution and determination of yarn surface reference point. Sensor array with lower resolution cannot effectively distinguish closely placed yarn hairs and most probably consider them as a single hair leading to wrong counting of hairs. Similarly, hairiness results are sensitive to yarn surface reference point. Another important limitation of commercially established measurement systems is scanning for yarn hairiness within two-axis field of view. Two-dimensional scanning may overlook the hair fibres oriented along the third dimension.

A recently presented theory of intrinsic yarn hairiness emphasized on the determination of true

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length of protruding hairs as it directly relates to the performance of yarn during serviceability (Guha, Amarnath, Pateria, & Mittal, 2009). Another study on fabric pilling performance suggested that S3 values of various yarns measured by means of existing hairiness testers may not truly represent the yarn hairiness, as a particular yarn with less values of hairiness resulted in a more pilled fabric and vice versa (Beltran, Wang, & Wang, 2007). The protruded hairs are not always straight or perpendicular to yarn surface. They are often randomly oriented and entangled with each other. It would be rather difficult for a hairiness measuring system to accurately detect all hairs around a yarn circumference and to measure the true length of a hair that is not straight. Some solutions have been developed in the last decade based on image and signal processing techniques for more precise measurement of yarn hairiness (Carvalho, Cardoso, Belsley, Vasconcelos, & Oliveira, 2006; Carvalho, Cardoso, Belsley, Vasconcelos, & Soares, 2006, 2007; Fabijańska, Kuzański, Sankowski, & Jackowska-Strumiłło, 2008; Kuzanski, 2006, 2008; Kuzański, & Jackowska-Strumitto, 2007; Ozkaya, Acar, & Jackson, 2002, 2005, 2007) albeit with limited commercial success.

An early manual hairiness determination method proposed by Jedriyka (1963) utilizes images taken under a microscope (50×). Boundaries of yarn were determined in this method and hair length was examined at particular distance from yarn boundary. Though this method provides quite accurate assessment of hair numbers, the same cannot be said about the determination of true hair length (TL) due to the random orientation and entanglement of many hairs. No results were provided on hair-length distributions or on how the results differed from those obtained from a hairiness instrument.

The aim of this study is to determine the true number as well as actual length of hairs (i.e. true yarn hairiness) in different length groups, for ring, compact and rotor spun yarns, and then compare the results with those from two commercial hairiness metres: Zweigle Hairiness Meter and Uster hairiness module. Results from this comparative study should assist further development of accurate yarn hairiness test systems.

Experimental

Materials

Three different yarns were prepared for this study, a 15 tex Com4 compact spun yarn (100% cotton), a 50 tex rotor spun yarn (100% cotton) and a 34 tex ring spun yarn (100% wool). The cotton yarns were tested in their natural white colour, but the wool yarn was dyed black. The 15 tex cotton compact yarn, 50 tex cotton rotor yarn and 34 tex wool ring yarn are further denoted as Yarn A, Yarn B and Yarn C.

Methods

Yarn hairiness was measured both manually and with two commercial instruments: Uster Tester 4 hairiness measurement module and Zweigle G565 hairiness tester. Both manual and conventional testing methods are described as follows.

Manual method of yarn hairiness measurement

To manually evaluate the hairiness of the selected yarns, 40 specimens of 25 cm each in length were prepared from the three yarn samples. Each specimen was placed on an A4 sized graph paper and fixed by means of a permanent tape at both ends. A set of multiple tools consisting of customized modified applicators, fine brushes, mini combs and tweezers, as shown in Figure 1, was used to precisely 'pick and fix' the protruding yarn hairs on the paper base. Each protruded hair was selected and straightened to reveal their true length and then fixed on paper base with the help of a specially designed sharp tip applicator. The applicator was dipped in an adhesive first to pick the protruding hair, straighten it and then fix it in position to avoid any entanglements or random orientations (Figure 2). Care was taken to avoid pulling the hairs out of the yarn surface. This process was assisted with the use of a magnifying glass and appropriate illumination source. A major benefit of this method is the inclusion of virtually all hair fibres irrespective of their orientation and type. For looped hairs, the centre portion was picked up and fixed on the graph paper, so each hair loop resembling a triangle on the paper. Each loop is counted as one hair, and the entire loop length is used as the hair length.

Graph sheets containing yarn specimens were then scanned at 600 dpi (dots per inch) resolution by Canon iR3235 scanner, using the best possible digital image quality. The scanned images of yarns were imported into image analysis software (Digimizer version 4.0) for hair counting and length measurement. True length of the hair fibres was measured with great care with the help of the software utilizing the digital image. Curves and lines were drawn on the digital image upon boundaries of protruded hairs along their length. The length of each single hair was recorded by image analysis software in units of pixels. By carrying out a simple calibration, pixel length was converted to millimetres using a reference line of predetermined length on the paper base.

Figure 1. Toolset used for manual picking and fixation of yarn hairs on paper base.

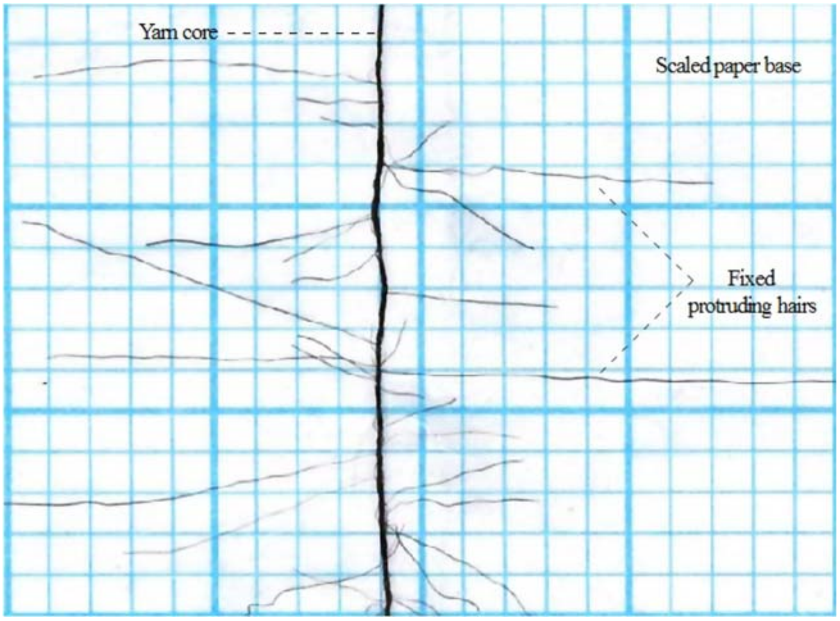

Figure 2. Manual method of true hairiness measurement.

The individual hair results were used to derive important hairiness parameters such as the total number of hairs, their classification in subsequent length classes and total length of protruding hairs in a yarn sample of unit length. These calculated parameters were then compared with those results gathered from commercial hairiness metres, i.e. hairiness index (*H*), S3 value and hairiness histogram.

Conventional method of measurement

Hairiness testing of yarn samples was carried out on a Zweigle G565 hairiness tester and an Uster tester 4 with a hairiness module separately. Yarn specimens of 10 m length were tested on a Zweigle Hairiness Meter at a speed of 50 m/min, while specimens of 100 m length were tested on Uster tester 4 at speed of 50 m/min. A total of 10 specimens of each yarn type were tested on both instruments and the results were averaged out for 1 m yarn length for hairiness comparison.

Results and discussion

The hairiness comparisons for averaged sample length of 1 m each for all three yarn specimens are shown in Tables 1 and 2. Table 1 represents the values measured by Zweigle hairiness tester, while Table 2 shows the results of hairiness testing by Uster tester 4 with integrated hairiness module. To compare the performance of different hairiness testing instruments, the hairiness index was calculated from results obtained from the Zweigle Hairiness Meter and the manual method, using a previously established formula as follows (Basu, 1999):

$$K = \sum_{i=1}^{m} N_i L_i + N_{\max} L_{\max}, \quad (1)$$

where m = the class before the longest hair length class.

$$L_i = \frac{l_i + (l_{i+1})}{2},$$

where l_i = length of hairs of class i; l_{i+1} = number of hairs of class $(i+1)$; N_i = number of hairs of class i per 100 m; $L_{\max}$ = length of hairs of longest class; and $N_{\max}$ = number of hairs of longest class per 100 m.

Normally, the length groups in Zweigle hairiness histogram start with N1 which denotes the number of protruding hairs having length between 1 and 2 mm, but a new length group N0 is defined on the basis of manual technique that includes all protruding hairs from yarn body that have a length less than 1 mm.

On the basis of above-mentioned data from Zweigle hairiness tester and manual method of hairiness determination, hairiness distribution histograms were produced for all three types of yarns as shown in Figures 3–5. Hair-length distribution histogram is provided by the Zweigle Hairiness Meter, not by the Uster tester, to provide a visual estimation of yarn hairiness in different length groups.

From Tables 1–4 and Figures 3–5, it is clear that the hairiness results obtained by different test methods are significantly different. Apparently, the TL distribution and the hair-length distribution from the Zweigle Hairiness Meter are also very different. To statistically determine the significance of the results measured by both techniques, 'Paired t-analysis' has been applied on given data at 95% confidence interval (CI). The P-values less than 0.05 lead to rejection of hypothesis that there is no significant difference between results determined by both measurement techniques. In Tables 3 and 4, the comparison of results obtained

Table 1. Hairiness results from Zweigle hairiness tester and manual technique, averaged out of 1 m yarn length.

	Yarn A		Yarn B		Yarn C	
Length group	Zweigle tester	Manual technique	Zweigle tester	Manual technique	Zweigle tester	Manual technique
N0	0	24	0	36	0	27
N1	125	55	176	94	159	81
N2	45	62	34	97	62	78
N3	10	42	13	81	37	63
N4	6	81	10	103	34	93
N6	2	39	2	72	19	71
N8	0	29	1	49	14	51
N10	0	23	0	38	10	42
N12	0	18	0	35	9	46
N15	0	15	0	24	4	33
N18	0	7	0	11	2	24
N21	0	5	0	4	1	20
N25	0	0	0	1	0	35
S3	18	259	26	417	129	478

Table 2. Hairiness index results.

Hairiness index	Uster tester	Zweigle tester	Manual technique
Yarn A	3.95	0.37	2.33
Yarn B	8.23	0.46	3.74
Yarn C	2.49	1.31	5.4

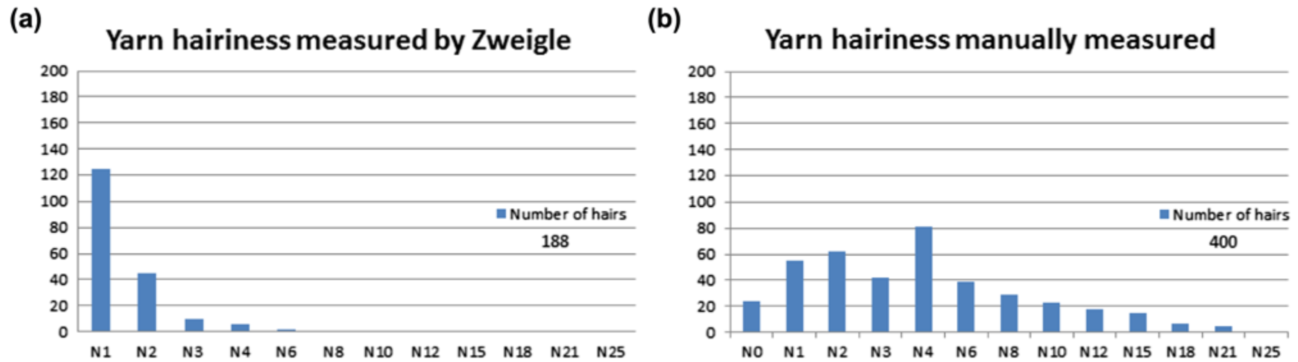

Figure 3. Histogram of Yarn A (15 tex cotton compact yarn) hairiness (within 1 m of yarn) measured by (a) Zweigle hairiness metre and (b) manual method.

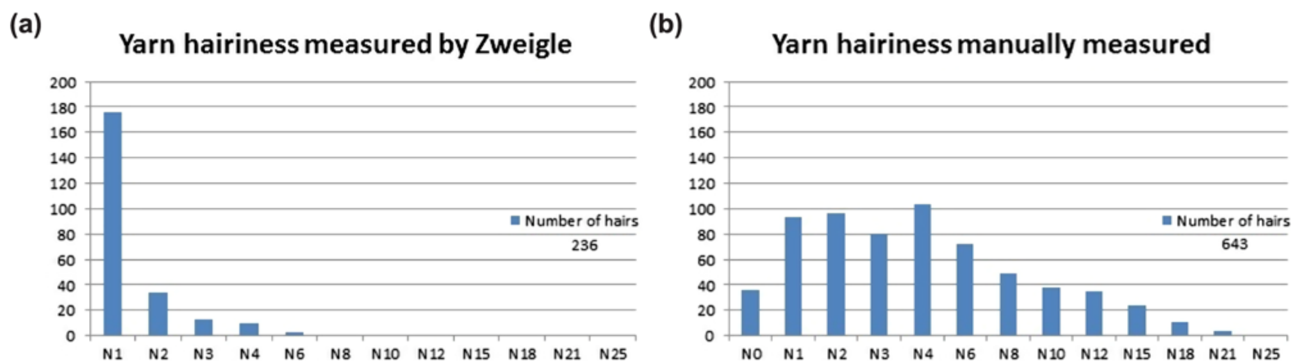

Figure 4. Histogram of Yarn B (50 tex cotton rotor yarn) hairiness (within 1 m of yarn) measured by (a) Zweigle hairiness metre and (b) manual method.

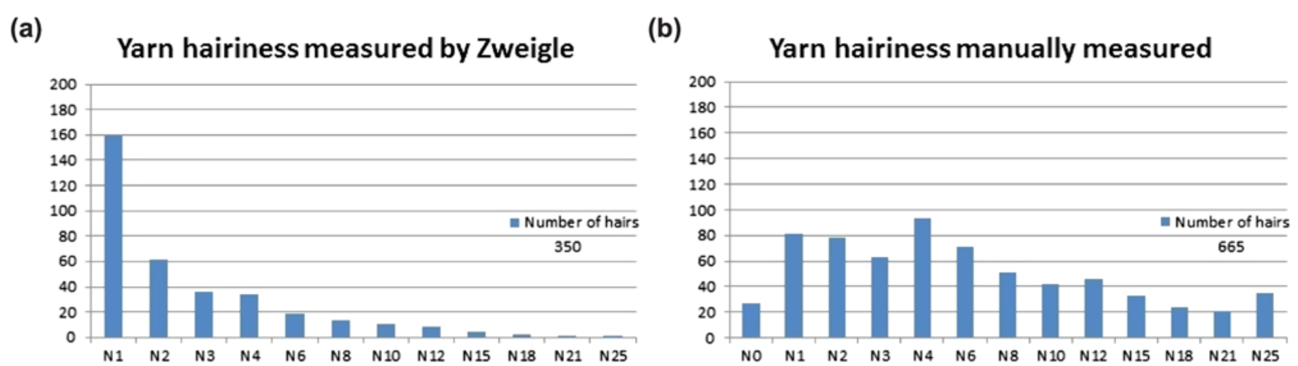

Figure 5. Histogram of Yarn C (34 tex wool ring yarn) hairiness (within 1 m of yarn) measured by (a) Zweigle hairiness metre and (b) manual method.

from manual method is made with Zweigle hairiness tester and Uster tester, respectively. The *P*-value is zero for all three types of yarns referring to rejection of null hypothesis and existence of statistically significant difference between testing methods.

In the manual technique, all hair fibres were counted and measured for their true length. With the Zweigle Hairiness Meter, it is the projected horizontal length, denoted as effective length (EL) here, of hairs on one side of the yarn that is measured. The projected length is always shorter than the TL unless the hair fibre is perfectly straight and perpendicular to the yarn axis. The difference is illustrated in Figure 6 with the help of SEM images taken from the rotor spun yarn (Yarn B). In addition, the projected length is affected by friction contact, intrinsic orientation of

Table 3. Paired *t*-analysis for S3 value from Zweigle hairiness tester and manual method.

	N	Mean	Standard deviation	Standard error mean
S3 values for Yarn A				
Manual method	10	253.2	23.03	7.28
Zweigle hairiness tester	10	17.1	3.7	1.17
Difference	10	236.1	21.29	6.73
95% CI for mean difference: (220.87, 251.33)				
T-test of mean difference = 0 (vs. not = 0): *T*-value = 35.06, *P*-value = 0				
S3 values for yarn B				
Manual method	10	416.7	26.86	8.49
Zweigle hairiness tester	10	25.91	2.44	0.77
Difference	10	390.79	25.96	8.21
95% CI for mean difference: (372.22, 409.36)				
T-test of mean difference = 0 (vs. not = 0): *T*-value = 47.61, *P*-value = 0				
S3 values for yarn C				
Manual method	10	477.8	35.5	11.2
Zweigle hairiness tester	10	129.2	6.5	2
Difference	10	348.6	36	11.4
95% CI for mean difference: (322.9, 374.4)				
T-test of mean difference = 0 (vs. not = 0): *T*-value = 30.64, *P*-value = 0				

Table 4. Paired *t*-analysis for hairiness index value from Uster tester and manual method.

	N	Mean	Standard deviation	Standard error mean
Hairiness index values for Yarn A				
Manual method	10	2.34	0.05	0.02
Uster tester	10	3.97	0.06	0.02
Difference	10	−1.63	0.06	0.02
95% CI for mean difference: (−1.67, −1.58)				
T-test of mean difference = 0 (vs. not = 0): *T*-value = −80.68, *P*-value = 0				
Hairiness index values for Yarn B				
Manual method	10	3.75	0.26	0.08
Uster tester	10	8.23	0.13	0.04
Difference	10	−4.49	0.25	0.08
95% CI for mean difference: (−4.67, −4.3)				
T-test of mean difference = 0 (vs. not = 0): *T*-value = −55.78, *P*-value = 0				
Hairiness index values for Yarn C				
Manual method	10	5.4	0.46	0.15
Uster tester	10	2.49	0.05	0.02
Difference	10	2.91	0.47	0.15
95% CI for mean difference: (2.57, 3.25)				
T-test of mean difference = 0 (vs. not = 0): *T*-value = 19.45, *P*-value = 0				

hairs and air drag during hairiness testing (Wang, 1998a, 1998b). These factors explain the considerably greater values of total hairs and long hairs in particular (e.g. S3 value) from the manual measurements.

The hair-length distribution histograms constructed from manual method and by the Zweigle hairiness metre are also very different (Figures 3–5). The rapid drop in hair number after N1 is not reflected in the manually obtained results. Interestingly, for all types of yarns, the manual method-based results show that the hair number peaks at around 4 mm in length. This is a key finding from this study. This finding is also a surprising one considering the large length difference between cotton and wool fibres used in the two

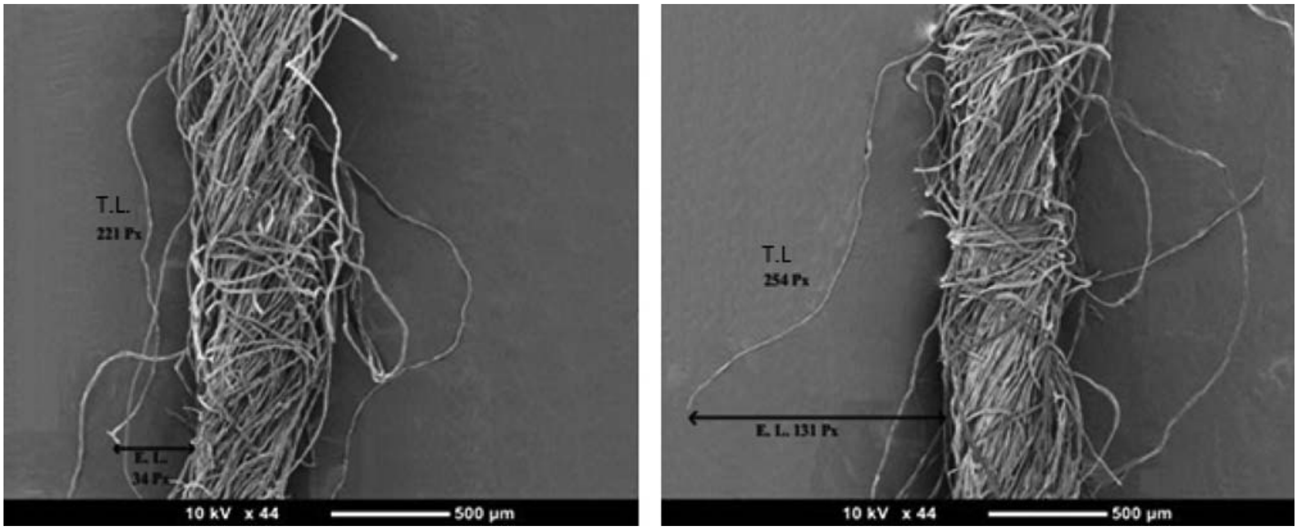

Figure 6. SEM images illustrating true and EL of protruded hairs.

different yarns and hardly any hairs longer than 4 mm were detected by the Zweigle Hairiness Meter.

Conclusion

We have manually measured the actual number as well as true length of hair fibres on three types of yarns (ring spun cotton compact yarn, rotor spun cotton yarn and ring spun wool yarn), and compared these results with the hairiness results obtained from two commercial hairiness metres. Statistically significant differences exist in both the total hair count and the hair-length distribution. Manual counting resulted in a much higher number of hairs than the Zweigle Hairiness Meter and the Uster tester. With the Zweigle Hairiness Meter, the hair number drops rapidly beyond hairs of 1–2 mm in length, yet this is not reflected in the manual hair measurement. The hair number peaked at around the 4 mm hair length for all three yarn specimens, i.e. the cotton compact yarn, rotor spun cotton yarns and ring spun wool yarns, based on results from the manual hair measurements. This finding challenges the well established exponential delay in hair count as hair length increases, at least for the yarns examined in this study.

The manual method of hair measurement is an accurate way of counting the true number of hairs and measuring their true length at the same time. It is also a tedious process which cannot replace commercial hairiness metres. Nevertheless, it should be used as a reference method to benchmark the performance of hairiness test instruments. Such benchmarking is essential to further improve the accuracy of hairiness testing instruments.

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