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# Magnitude Estimation Approach for Assessing Stickiness Sensation Perceived in Wet Fabrics

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**Abstract:** Sweating will trigger stickiness sensation and affecting sensorial comfort of wearer. This study aims at assessing stickiness sensation perceived in wetted fabrics utilizing the Body Movement Simulator (BMS). BMS was built to drive the samples to and fro subject's volar forearms, providing repeatable fabric movement. Assessors were asked to compare the sample with the reference and assign numerical value to the sample using the magnitude estimation approach. 22 types of fabrics with different constructional parameters and fiber content were assessed by 23 assessors. Statistical analysis shows that within-judge reliability and between-judge consistency are satisfactory, and significant between-fabric differences are observed, demonstrating that both experimental method and assessor panel are reliable. The results reveal that thicker fabrics with higher absorption capacity and less contact area with skin contribute to weaker stickiness sensation. The perceived stickiness is highly related to water content and saturation level of samples, but poorly related to its surface friction and roughness in dry condition. This subjective assessment method is useful for assessing the stickiness sensation in textiles especially for sportswear, intimate apparel or hygiene products.

**Keywords:** Stickiness sensation, Sensory, Magnitude estimation, Textiles, Subjective assessment

## Introduction

Human skin exposes to textiles every day and the skin tribology in contact with textiles is important in connection with clothing comfort. People sweat when staying in hot environment or exercising. Clothing having direct contact with skin will absorb the sweat and the clothing becomes wet. Depending on fabric's water absorbency, the amount of water absorbed by fabrics and the amount of interfacial water vary. Fabric finishing may affect the water absorbency of fabric [1-4] and eventually affecting the wear comfort. If the wettability and wicking property of the fabric is poor, or if the evaporation rate of the fabric is low, sweat cannot be dissipated quickly and moisture is likely to accumulate at the interface [5]. Human skin becomes soften and swells due to water uptake [6,7] which leads to smoothing of skin surface, causes adhesion of the fabric to the skin surface, and increases real contact area [8,9] and the friction force between fabric and skin [10-12]. In other case, if the fabric-skin interfaces are saturated with water, a layer of water film will be formed acting as mixed lubrication or hydrodynamic lubrication [7,13]. Consistent results have been reported indicating that increasing hydration level of the skin tends to increase the coefficient of friction considerably [6,13-17]. The wetted fabric may stick to any surface it touches which seriously affect the sensorial comfort of the wearer [18-20] or cause skin injuries [21-23]. Persistent hydration of skin with the combination of pressure, friction and shear may even cause decubitus or pressure ulcers for bedridden people [22,24]. This is important for functional apparel, sock [17, 23], sportswear [18] or medical textiles [22,25-27] which are worn under stressful environment usually.

Against these research backgrounds, it is necessary to investigate the stickiness sensation perceived in wet fabrics. Stickiness, having the property of adhering to any surface that is touched, is related to the friction that occurs when one surface slides over another. When sliding a fabric over our skin, the force required to drag it is opposed by the friction force. The characteristics of the fabric will stimulate the sensory system of skin, leading to sensorial judgments of stickiness. In the two-term friction model, two major mechanisms contribute to friction: adhesion and deformation [28]. As shown in Figure 1, sticky stimulus causing deformation and adhesion of skin evokes the sensory receptors' responses and mechanoreceptors are responsible for these stimulations [29]. Chen *et al*. [29] mentioned that the Ruffini ending, located in deep epidermis, is capable of responding to tensile changes of skin due to friction on the contacting surfaces.

For the sake of assessing the stickiness sensation perceived in fabrics, numerous objective measurements have been developed [30-32]. Majority of the work focused on measuring friction force of dry fabric [33] whilst fabrics in

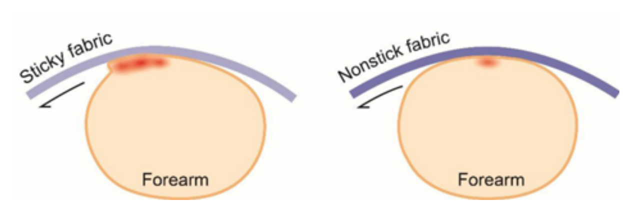


**Figure 1.** Fabric-skin interaction with different kinds of stimuli.

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wet condition were seldom investigated [34]. Also, the perceived stickiness cannot be described comprehensively by the objectively measured physical parameters [35] and hence in-vivo experiment or subjective assessment method is desired.

For the in vivo experiment, volar forearm or finger were moved against the textiles attached on a tri-axial force plate [22,36-39] and the force required to rub against it was measured. The intensity of normal load, sliding velocity, and skin hydration should be controlled properly in order to obtain meaningful data. In vivo test deals with the interaction between skin and the contacting material but does not take our perception into consideration. For a consumer product like textiles, the purchasing decision or judgement of product depend on consumer's haptic perception or user experience. Therefore, subjective assessment is also important. In the published literatures regarding subjective stickiness sensation assessment (summarized in Table 1) the psychological scaling approach, for example interval rating scale with five to twelve categories [10,20,40], was usually adopted. The use of psychological rating scale is simple even for naive assessors; however, the assessors might not get involved in the assessment and they tend to choose the middle categories, leading to a loss of sensitivity to discrimination. Besides, the interval between the points on a numbered category scale might not be equal [41]. Another problem is that the assessors tend to choose the neutral mark when the category scale is bidirectional with neutral choice and this reduces testing accuracy. In order to avoid these problems, our previous work provides an alternative to measure the clingy sensation perceived in fabrics by using the psychophysical approach and the absolute threshold amount of water required to trigger clingy sensation was investigated [42]. Examining the absolute threshold is a versatile and sensitive method which can produce accurate and reproducible result; however, the sensation magnitude (i.e. the intensity of discomfort) cannot be determined.

Apart from response assessment technique, the amount of water supplied to the testing sample should be considered with regard to the implication of the test. In Raccuglia *et al.*'s [20] study, fabric was wetted to 50 % of total absorption capacity. In Jeon *et al.*'s study [43], fabrics were wetted with 0.5 m*l* and 1.5 m*l* water to simulate light and heavy sweating. The amount of water applied in their studies might not be entirely correlated with the sweating magnitude and their corresponding implications are unclear.

**Table 1.** Literatures regarding subjective stickiness assessment

| Author | Experimental protocol | Response measurement |
|---|---|---|
| Gwosdow *et al.* [9] | Fabric was pulled across inner forearm and the pulling force of the fabric across the forearm was recorded. | Line scales (texture and pleasantness) |
| Jeon *et al.* [43] | Test specimen wetted with 0.5 m*l* and 1.5 m*l* water were put onto the inner forearm. | A 7-point rating scale (wet, damp, clammy, clingy and sticky) |
| Raccuglia *et al.* [20] | Wetted fabric (50 % of total absorption capacity) was moved against the ventral forearm automatically and the stickiness rating was assessed. | Unipolar ordinal scale, ranging from 0 to 12 (Not sticky - Extremely sticky) |
| Shao *et al.* [10] | The assessor was asked to stroke the stimuli (paper and board) with any hand that felt comfortable. | Seven-point bipolar scale (Sticky-slippery) |
| Ramalho *et al.* [44] | Samples were hung from a support and each assessor had to touch and grasp the textiles. | Five-point scale (Adhesive-slippery) |
| Jeguirim *et al.* [45] | The assessor was asked to manipulate the sample using their hand | 0-10 linear non-structured scale anchored by reference materials (Sticky) |
| Alimaa *et al.* [46] | The assessor should stroke the surface of the fabric gently and slowly (25 gf/cm$^2$) using the index finger and compare with the reference in terms of the sticky/slippery feeling. | Five-point sensory difference scale (2: significantly higher than standard, -2: significantly lower than standard) |
| Darden and Schwartz [47] | The assessor was asked to manipulate the sample using their hand but could not pick up the sample | Line scales (slipperiness) |
| Hollies [40] | Assessors were asked to wear shirts treated with different finishing and give responses after exercise and rest. | Four-point rating scale (sticky, clammy, damp, clingy) |
| Baker *et al.* [48] | Wear trial | 11-point Likert scale (Sticky, clammy, damp, clingy) |
| Tang *et al.* [42] | Fabric was moved to and fro the assessor's volar forearm while water was supplied to the fabric at a constant rate. As long as the water content of fabric increased, the assessor should tell when clingy sensation was sensed. | Absolute threshold amount of water required to trigger clingy sensation (minimum amount of water added to the fabric that can trigger the clingy sensation) |

The magnitude of stickiness sensation also varies with the speed of fabric movement against skin or the way to manipulate the sample. In Gwosdow *et al*. [9] study, fabric was moved against the volar forearm and the moving speed is controlled manually which might not be repeatable. In other studies, the assessor was asked to stroke the sample with their hands intentionally (i.e. active touch) [10,44-46]. In these cases, the way to manipulate the sample and the normal load applied might not be standardized. Also, touching the fabric intentionally does not correspond to actual wear condition (i.e. passive touch while wearing garment).

In this study, a novel subjective assessment method is developed for assessing the stickiness sensation perceived in apparel fabrics. 22 types of fabrics with different constructional parameters and fiber content were assessed. Magnitude estimation approach which can solve the problems caused by psychological rating scale and measure the sensation magnitude is adopted. In order to standardize the sweating level and the way that the sample was manipulated, fabrics were applied with fixed amount of water and were moved against our skin consecutively with the help of BMS. The experimental setup and protocol is provided whereas the teaching instruction, screening criteria and training procedures are thoroughly described. Statistical analysis is performed to examine the accuracy, repeatability and sensitivity of the assessment method. Besides, we try to figure out the determinants for the magnitude of stickiness sensation perceived. Correlation analysis is conducted (i) to verify if any instrumentally measured fabric parameters correlate well with the magnitude estimates of stickiness, and (ii) to examine whether water content and saturation level of the fabric is related to the magnitude estimates of stickiness.

## Methods

### Participants

At the beginning of the experiment, twenty five healthy assessors were invited for the subjective evaluation and informed consent was obtained from all subjects. After the training session and screening exercise, fifteen healthy women (aged between 22 to 38 with the average age of 27) and eight healthy men (aged between 23 to 38 with the average age of 29), without background knowledge on the testing samples, peripheral neuropathy or other skin abnormality, were confirmed as reliable assessors and have

**Table 2.** Sample specifications

| Fabric code | Fabric structure | Fabric type | Fiber content | Yarn count♦ | Yarn density | | Weight (g/m$^2$) | Thickness (mm) | Porosity | Water absorption time (s)◊ | Water absorption capacity (mg/cm$^2$)▲ | Surface friction (MIU)¶ | Surface roughness (SMD, µm)¶ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Ends per cm | Picks per cm | | | | | | | |
| KN1 | Single jersey | Knitted | 40 % cotton, 60 % polyester | 32s | - | - | 145 | 0.56 | 0.822 | 15.5 | 37.17 | 0.191 | 1.68 |
| KN2 | Single jersey | Knitted | 95 % rayon, 5 % spandex | 32s | - | - | 259 | 0.86 | 0.802 | 0.7 | 61.54 | 0.211 | 2.26 |
| KN3 | 1×1 rib | Knitted | Cotton | 32s | - | - | 231 | 1.08 | 0.862 | 0.6 | 70.99 | 0.191 | 3.81 |
| KN4 | Single jersey | Knitted | Cotton | 32s | - | - | 127 | 0.64 | 0.871 | 6.2 | 41.19 | 0.190 | 1.81 |
| KN6 | Pique | Knitted | 95 % polyester, 5 % spandex | - | - | - | 182 | 0.89 | 0.851 | 13.1 | 24.56 | 0.246 | 7.39 |
| KN7 | Pique | Knitted | Coolmax | - | - | - | 141 | 0.67 | 0.848 | 4.6 | 45.60 | 0.175 | 1.15 |
| KN8 | Pique | Knitted | Polyester, Bamboo | - | - | - | 152 | 0.56 | 0.802 | 58.2 | 41.45 | 0.224 | 5.72 |
| PIN | Double jersey mesh | Knitted | Polyester | - | 13 | 22 | 228 | 0.97 | 0.831 | 0.5 | 55.85 | 0.262 | 4.35 |
| ORA | Single jersey mesh | Knitted | Polyester, Lycra | - | 16 | 52 | 203 | 0.60 | 0.755 | 6.3 | 36.52 | 0.282 | 4.66 |
| BME | Double jersey mesh | Knitted | Polyester | - | 18 | 23 | 174 | 0.80 | 0.844 | 1.7 | 56.44 | 0.267 | 4.19 |
| PUR | Double jersey interlock | Knitted | Polyester | - | 10 | 17 | 245 | 0.94 | 0.812 | 3.5 | 57.75 | 0.264 | 8.40 |
| WO8 | Plain | Woven | Cotton | 21s×21s | 24 | 24 | 157 | 0.66 | 0.846 | 1.5 | 30.79 | 0.196 | 5.68 |
| WO1 | Plain | Woven | Cotton | 80s×80s | 35 | 35 | 57 | 0.37 | 0.900 | 31.8 | 14.62 | 0.177 | 3.44 |
| WO2 | Plain | Woven | Cotton | 60s×60s | 35 | 35 | 79 | 0.40 | 0.874 | 9.2 | 17.13 | 0.162 | 2.98 |
| WO3 | Plain | Woven | Cotton | 40s×40s | 52 | 39 | 157 | 0.42 | 0.760 | 13.0 | 18.26 | 0.181 | 2.89 |
| WO5 | Plain | Woven | Cotton | 40s×40s | 52 | 28 | 136 | 0.48 | 0.815 | 3.6 | 22.59 | 0.187 | 4.11 |
| WO6 | Twill | Woven | Cotton | 40s×40s | 52 | 28 | 132 | 0.56 | 0.847 | 2.2 | 25.99 | 0.183 | 2.54 |
| WO7 | Plain | Woven | Cotton | 40s×40s | 47 | 24 | 115 | 0.48 | 0.846 | 2.9 | 22.16 | 0.179 | 3.62 |
| WMJ | Micro jacquard | Woven | Polyester | - | - | - | 98 | 0.31 | 0.774 | 180.0 | 13.43 | 0.174 | 12.13 |
| W3M | Plain | Woven | 96 % polyester, 4 % spandex | - | - | - | 89 | 0.28 | 0.769 | 87.5 | 16.46 | 0.210 | 2.36 |
| SLK | Plain | Woven | Silk | - | 64 | 43 | 68 | 0.20 | 0.746 | 180.0 | 12.38 | 0.193 | 3.20 |
| PET2 | 5/1 twill | Woven | Polyester | - | 67 | 30 | 156 | 0.38 | 0.704 | 40.9 | 9.21 | 0.154 | 2.74 |

♦Coarseness of yarn (the higher the number, the finer the yarn is), ◊water absorption time was assessed by wettability test (AATCC 79) [49], ▲measured according to Tang *et al*. [50], ¶measured by Kawabata Evaluation System for Fabrics (KES-F4), - undefined.

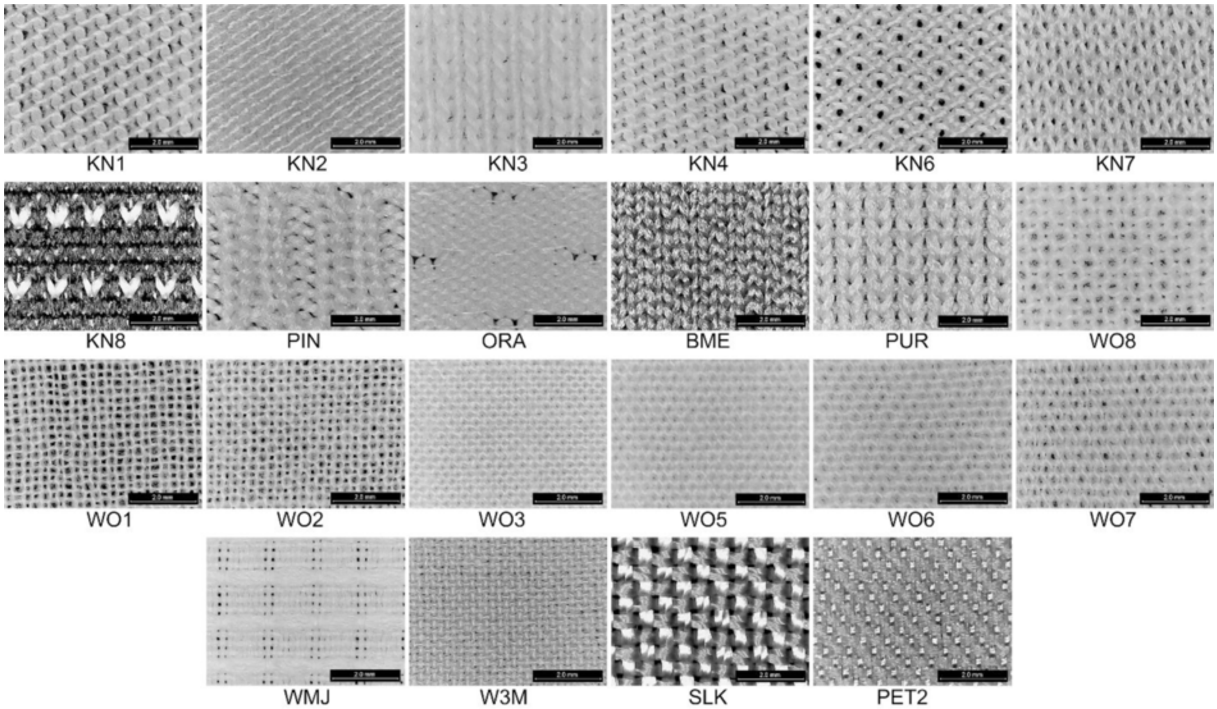


**Figure 2.** Magnified images of the test fabrics.

completed the designated assessment. The testing procedures were in accordance with the tenets of the Declaration of Helsinki.

### Experimental Condition

All experiment was conducted in a climatic chamber. The temperature was 20±2 $^{o}$C, the relative humidity was 65± 5 % and air velocity was less than 0.15 m/s.

### Stimuli

Twenty two types of apparel fabrics, comprising different fiber composition (e.g. cotton, polyester, silk and rayon) and fabric construction (e.g. knitted and woven), were investigated. Special fabrics like moisture management fabrics, knitted fabrics with mesh pattern or pique pattern (i.e. extra yarns are incorporated to the back side of the fabric to add depth to the fabric design), varying in contact area with skin surface, were also included.

The specifications of each fabric are summarized in Table 2 whereas their magnified images are shown in Figure 2. The samples (12×12 cm) were conditioned for at least 24 hours before actual testing. They were not reused so that contaminant such as body grease will not affect testing accuracy.

### Experimental Protocol

Assessors were asked to make comparison between the test sample and the reference stimulus, and assign numerical values to the sample using magnitude estimation approach. The principle of magnitude estimation is provided in Section ‘Teaching session’. Fabric ‘WO3’, which the panel leader considered its magnitude of stickiness to be at the middle of the samples, was chosen as the reference stimulus. The body site to be tested is at the middle of volar forearm. This allows easy application of fabrics while maintaining the comfort status of the assessor during test [20]. Additionally, volar forearm is hairless and the hairless portion is likely to be less sensitive to prickle as suggested by Garnsworthy [51]. Therefore, assessing the stickiness sensation in this body site is more accurate since it will be minimally interfered by other sensory attributes, for example the prickliness of the material.

Before entering the climatic chamber, the assessors should rinse their forearms and dry with tissue paper gently. They were then acclimatized in the conditioned testing environment for 30 minutes. During the 30-minute adapting period, the objectives and testing procedures were described. However, in order to prevent expectation error, sample details were not disclosed. They were then asked to sign the consent form and complete a brief questionnaire regarding their demographic data. Researchers [52] have found that the perceived clamminess may be dominated by visual considerations. To prevent the haptic perception from being influenced by visual perception, a curtain was placed between the testing setup and the assessor.

In order to simulate body movement during wear, a Body Movement Simulator (BMS) was built to drive fabrics to and fro subject’s forearms consecutively. This provides

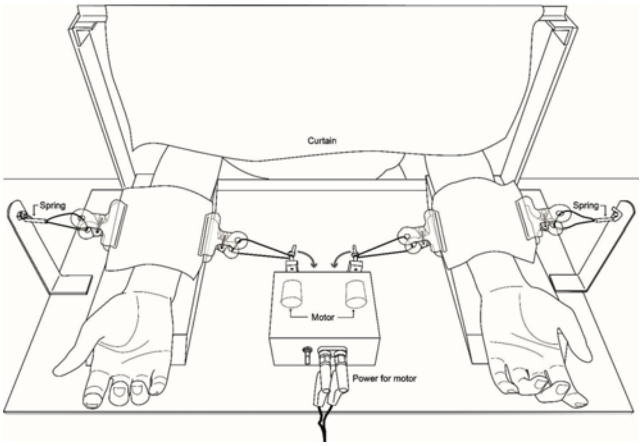


**Figure 3.** Illustration of Body Movement Simulator (BMS).

repeatable fabric movement and allows pairwise comparison of stickiness sensation between test sample and reference stimulus. The design of the BMS is with reference to the experimental setup of [42] and illustration of the setup for the subjective test is shown in Figure 3. Left-right arrangement of the reference stimulus was randomly decided for each assessor. This was not changed throughout the whole assessment to prevent confusion. As shown in Figure 3, each sample was held by two plastic clips. One clip was attached to the spring whilst another clip was secured to the motor via inelastic string to ensure automatic and repeatable fabric movement. The cycle time was 1.4 seconds and the movement magnitude was 3 cm approximately.

In order to imitate and standardize the sweat-induced fabric surface, all samples were wetted beforehand by spraying fixed amount of water (1.4 g, i.e. 9.7 mg/cm$^2$) on it. The added amount are typical for abundant sweating [36] but does not saturate most of the fabrics except fabric 'PET2'. The added amount is approximate to the setting in Rotaru *et al*. study [22]. Assuming the local sweat rate is the same in different body part, the whole body sweat amount is calculated according to equation (1). When body area is assumed to be 1.8 m$^2$ [53], water supplied to the testing sample is 1.4 g and area of the testing sample is 0.144 m$^2$, the whole body sweat amount is 175 g. This corresponds to light activity for long period or short-term strenuous activity. For example, 9.5 minutes running (sweat rate is 1100 m*l*/h) [54], 9.2 minutes badminton playing (sweat rate is 1140 m*l*/h) [55], 5.3 minutes beach volleyball tournament (sweat rate is 1996 m*l*/h) [56], 3 minutes hill climbing (sweat rate is 3530 m*l*/h) [57] or 14.6 hour resting (sweat rate is 350 m*l*/24 h) [58]. This experiment assumes that the sweating amount is fixed no matter what clothes is worn which allows fair comparison between fabrics. The way to apply water to the sample is illustrated in Figure 4. It shows that water is sprayed onto the tilted fabric. The tilt angle is 60 degree from the horizontal plane. This allows rolling off of excess

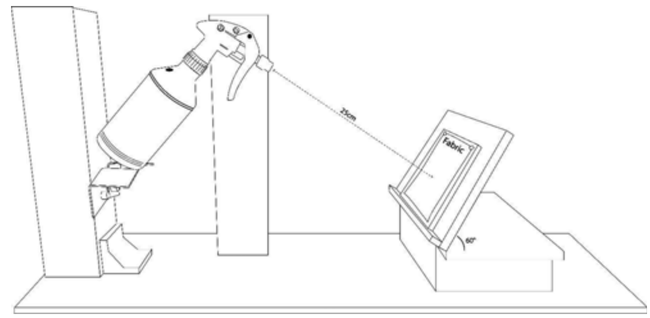


**Figure 4.** Setup for applying fixed amount of water to the sample.

water. Same situation occurs when excess sweat rolls off from garment.

$$\frac{\text{Whole body sweating amount (g)}}{\text{Body area (m}^2\text{)}} = \frac{\text{Water applied to the testing sample (g)}}{\text{Area of the testing sample (m}^2\text{)}} \quad (1)$$

***Teaching Session***

The assessors were instructed to concentrate on a particular attribute being evaluated. During the teaching session, the principle of magnitude estimation was explained. The assessors were asked to assign numeric values to the magnitude of an attribute using a ratio principle. The stickiness estimates for the external reference (i.e. fabric 'WO3') were pre-assigned as 100. Assessors should rate the test stimulus in relation to the external reference and the modulus (i.e. 100). If the stickiness sensation seems twice as strong in test sample when compared to reference stimulus, test sample should receive a value which is twice the value assigned to reference sample (i.e. 2×100=200). If the test sample is half as strong, it should be rated as 50 [59,60]. Assessors can use whatever number that is deemed appropriate to them. There is no upper limit to the scale, however, it should be any positive and non-zero number. In addition, the assessor should verbally report the estimates of stickiness within 15 seconds, otherwise assessment of that fabric should be repeated. Since continuous exposure to stimulus tends to reduce one's sensitivity, at least 45-second resting period was provided between each sample to prevent sensory fatigue. During the recovery period, the assessor should dry the skin surface with soft tissue paper gently. Rubbing was not allowed to prevent skin irritation.

ASTM E1697 mentioned that estimating the area of geometric shapes has proven very useful for introducing the basic concept of magnitude estimation [60]. Thus, assessors were trained to rate a set of 18 figures (composed of six circles, six equilateral triangles and six squares ranging in size from approximately 2 cm$^2$ to 200 cm$^2$) based on its area using magnitude estimation approach. The square in 8.5 cm long was chosen as the reference and its modulus was defined as 100. The test sample and the reference were presented on a sheet of white paper. After completing the area estimation, assessors were provided with feedback to reassure that they understand the exercise.

Once the panel has successfully completed the area estimation exercise, further training was carried out on stickiness estimates of a series of fabrics. Same as the abovementioned testing protocol, the test sample as well as the reference stimulus were dragged against the volar forearms simultaneously and the assessors were asked to assign number to the test stimulus based on the reference. Two fabrics with extreme stickiness performance (extremely sticky and not sticky) were included in this session so that the assessor can familiar with various testing situations. After that, they were provided with feedback to ensure that they understand the exercise. Details about the teaching session is shown in Appendix A.

***Screening Session***

Details about the screening session is shown in Appendix B.

***Training Session***

Details about the training session is shown in Appendix C.

***Actual Testing***

22 types of samples were presented once, plus two additional replicates for fabric 'KN1', 'WO3', 'W3M', and 'SIK'. Therefore, 30 pairs of specimens were assessed by each subject in total. The replicates were used for confirming within-subject reliability. The actual testing lasted for around 45 to 60 minutes. The assessor could request for a break or even quit the assessment whenever they feel discomfort.

**Data Rescaling**

Before performing statistical analysis, the data collected from the assessor panel were rescaled according to ISO-11056 [61] and ASTM E1697 [60]. This is because different numerical scale were used by the assessors which may produce significant assessor effect. First, natural logarithms (ln) of the raw data were calculated. Second, the rescaling factors were determined by calculating the mean logarithms of each assessor. Third, the mean logarithm for the whole panel was calculated. Fourth, the correction value for each assessor was calculated by subtracting the mean logarithm of the assessor from the mean logarithm of the group. The last step is to add its correction value to all estimations of each assessor. The rationale for this rescaling method is that the total magnitude of assessors' responses should be identical since each assessor has experienced the same set of stimuli.

**Statistical Analysis**

After data rescaling, geometric means were calculated, because of the ratio nature of the measurement. These data were then undergone further statistical analysis using SPSS 22. The significance level was set at 0.05. Within-judge reliability, between-judge consistency and between-sample difference was examined by repeated measures analysis of variance (ANOVA). In order to investigate the significance in the ranking of the data, non-parametric test was used. Friedman test, a nonparametric equivalent of a one-sample repeated measures design, was chosen to test the null hypothesis that k related variables are from the same population. It was adopted to test the between-fabric difference. Meanwhile, Kendall's Coefficient of Concordance (W), a measures of agreement among judges, ranging from 0 to 1 (no agreement to complete agreement), was utilized to investigate the between-judge consistency.

## Results and Discussion

Box-and-whisker plot illustrating the normalized magnitude estimates of stickiness for the 22 fabrics is shown in Figure 5. The central tendency and dispersion of the data is clearly shown in the plot. The mean of the data is represented by a square. The band inside the box is the median and the bottom and top of the box represents 25 percentile and 75 percentile of data. The ends of the whiskers represent one standard deviation from the mean while the maximum and minimum value are marked with asterisks.

Among the 22 fabrics, the estimates of stickiness for fabric 'BME', 'PUR', 'KN7' and 'KN8' are particularly low. These are all knitted fabric made of polyester fiber. On the other hand, the estimates of stickiness for fabric 'SIK', 'WO1', and 'PET2' are high. In general, the estimates of stickiness for the knitted fabrics are lower than for the woven fabrics. This can attribute to higher water absorption capacity, higher thickness and shorter water absorption time. The correlation between estimates of stickiness and various

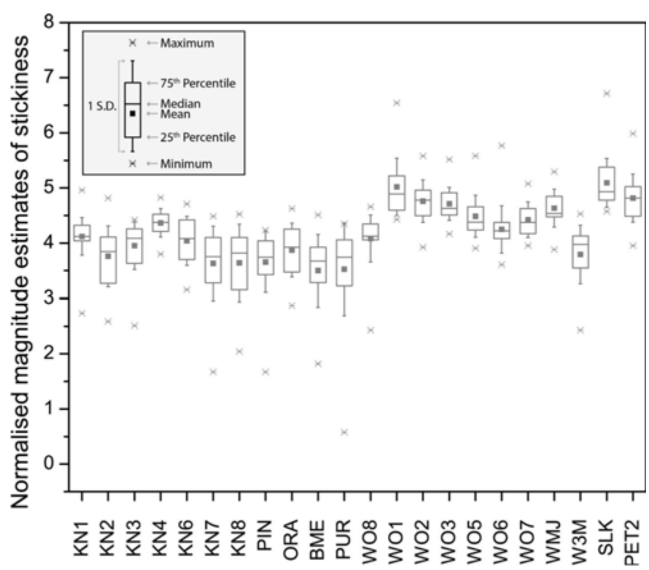


**Figure 5.** Normalized magnitude estimates of stickiness for 22 types of fabrics from 23 assessors.

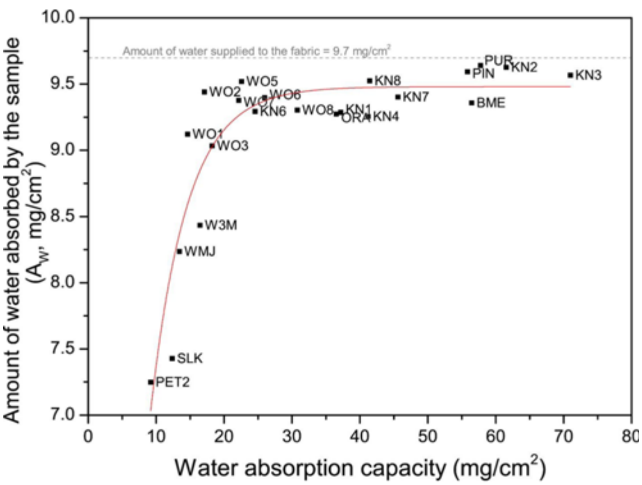


**Figure 6.** Amount of water absorbed by the sample ($A_W$) against water absorption capacity.

fabric properties is provided in Figure 7.

Before putting the sample onto the volar forearm, it was wetted by spraying predetermined amount of water on it and the amount of water absorbed by the sample ($A_W$) varies. Figure 6 shows the correlation between $A_W$ and water absorption capacity. The amount of water sprayed to the sample (9.7 mg/cm$^2$) is marked with a dotted line in the figure. It shows that there is discrepancy between the amount of water sprayed and the $A_W$. This is because water is sprayed at tilted position and water may roll off the fabric if it cannot absorb water quickly. The discrepancy is particularly high for fabric 'PET2' and 'SIK'. The trend line shows that fabrics with lower water absorption capacity result in lower $A_W$.

**Within-judge Reliability**

Four types of fabrics, including 'KN1', 'WO3', 'W3M', and 'SIK', were tested repeatedly. The reliability of the assessor panel is examined by two-way repeated measures ANOVA test while the normalized magnitude estimate of stickiness is the dependent variable with 'Fabric' and 'Repeat' being the independent variables. The results show that the overall stickiness estimates for the three replicates do not have statistically significant difference throughout the 4 fabrics [Sphericity Assumed $F=1.607$, $p=0.212>0.05$].

The reliability of each assessor is further examined by one-way repeated measures ANOVA test. The null hypothesis is that the stickiness estimates from the three replicates do not have significant difference. Table 3 indicates that the p-

**Table 3.** Tests of within-subjects effects table from SPSS

| | | Type III sum of squares | df | Mean square | F | Sig. |
|---|---|---|---|---|---|---|
| Assessor 1 | Sphericity assumed | 0.121 | 2 | 0.060 | 2.085 | 0.205 |
| Assessor 2 | Sphericity assumed | 0.147 | 2 | 0.074 | 1.752 | 0.252 |
| Assessor 3 | Sphericity assumed | 0.198 | 2 | 0.099 | 4.722 | 0.059 |
| Assessor 4 | Sphericity assumed | 0.219 | 2 | 0.109 | 1.747 | 0.252 |
| Assessor 5 | Sphericity assumed | 0.081 | 2 | 0.040 | 0.918 | 0.449 |
| Assessor 6 | Sphericity assumed | 0.038 | 2 | 0.019 | 3.758 | 0.087 |
| Assessor 7 | Sphericity assumed | 0.447 | 2 | 0.224 | 2.705 | 0.145 |
| Assessor 8 | Sphericity assumed | 0.015 | 2 | 0.008 | 1.865 | 0.235 |
| Assessor 9 | Sphericity assumed | 0.155 | 2 | 0.077 | 0.301 | 0.750 |
| Assessor 10 | Sphericity assumed | 1.115 | 2 | 0.558 | 3.211 | 0.113 |
| Assessor 11 | Sphericity assumed | 0.405 | 2 | 0.203 | 1.286 | 0.343 |
| Assessor 12 | Sphericity assumed | 0.679 | 2 | 0.340 | 1.868 | 0.234 |
| Assessor 13 | Sphericity assumed | 0.025 | 2 | 0.013 | 0.487 | 0.637 |
| Assessor 14 | Sphericity assumed | 0.697 | 2 | 0.349 | 1.286 | 0.343 |
| Assessor 15 | Sphericity assumed | 0.308 | 2 | 0.154 | 4.456 | 0.065 |
| Assessor 16 | Sphericity assumed | 0.669 | 2 | 0.334 | 1.263 | 0.348 |
| Assessor 17 | Sphericity assumed | 0.169 | 2 | 0.084 | 1.649 | 0.269 |
| Assessor 18 | Sphericity assumed | 0.059 | 2 | 0.029 | 1.290 | 0.342 |
| Assessor 19 | Sphericity assumed | 0.093 | 2 | 0.046 | 1.258 | 0.350 |
| Assessor 20 | Sphericity assumed | 0.012 | 2 | 0.006 | 0.109 | 0.898 |
| Assessor 21 | Sphericity assumed | 0.017 | 2 | 0.008 | 0.792 | 0.495 |
| Assessor 22 | Sphericity assumed | 0.010 | 2 | 0.005 | 0.259 | 0.780 |
| Assessor 23 | Sphericity assumed | 0.025 | 2 | 0.013 | 1.045 | 0.408 |

value of each assessor is larger than 0.05, and so the null hypothesis has to be retained. It implies that these 23 assessors can give repeatable result within the three replicates and they can be regarded as reliable.

**Between-judge Consistency**

After checking the within-judge reliability, the next step is to investigate the consistency between different assessors. Repeated measures ANOVA test results reveal that stickiness estimates from the 23 assessors do not have significant overall difference [Greenhouse-Geisser adjusted $F=0.155$, $p=0.970>0.05$], implying consistent result obtained from the assessors.

The non-parametric Kendall's Coefficient of Concordance is also adopted to examine the between-judge consistency in terms of the ranking of the 22 fabrics. Kendall's Coefficient of Concordance is 0.646 ($p=0.000<0.05$), implying that assessors agree with each other at a reasonably high extent.

**Between-fabric Difference**

One-way repeated measures ANOVA test was performed in order to check if there is any significant difference among the 22 types of fabrics. The results show that there are significant overall differences on the stickiness estimates for the 22 fabrics [Greenhouse-Geisser $F=23.424$, $p=0.000<0.05$].

The non-parametric Friedman test tests the null hypothesis that the estimates of stickiness are the same for 22 types of fabrics in terms of its ranking. The results indicate that the Friedman $\chi^2$ statistics is significant, $\chi^2$ (df=21)=311.856, $p=0.000<0.05$. Thus, it can be concluded that there are significant between-fabric differences.

Friedman test, like its parametric alternative, states whether overall differences exist, but does not pinpoint which pairs do have significant difference. Therefore, paired t-test was performed and the results are shown in Table 4. It shows that 75 % of all possible pairs have significant difference in stickiness estimates. High percentage of pairs with significant differences suggest that the subjective assessment method proposed has good sensitivity.

**Influential Factors for Stickiness Sensation Perceived in Fabrics**

The relationship between stickiness estimates and

**Table 4.** Pairwise comparison matrix indicating p-value and pairs with significant difference in normalized magnitude estimates of stickiness

| P-value | KN1 | KN2 | KN3 | KN4 | KN6 | KN7 | KN8 | PIN | ORA | BME | PUR | WO8 | WO1 | WO2 | WO3 | WO5 | WO6 | WO7 | WMJ | W3M | SLK | PET2 | Percentage of pairs that have significant difference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KN1 | | 1 | | 1 | | 1 | 1 | 1 | | 1 | 1 | | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 76 |
| KN2 | 0.006 | | | 1 | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 57 |
| KN3 | 0.187 | 0.218 | | 1 | | 1 | | 1 | | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 67 |
| KN4 | 0.002 | 0.000 | 0.002 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | 1 | 1 | 1 | 1 | 86 |
| KN6 | 0.295 | 0.062 | 0.558 | 0.006 | | 1 | 1 | 1 | | 1 | 1 | | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 71 |
| KN7 | 0.002 | 0.468 | 0.043 | 0.001 | 0.026 | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 67 |
| KN8 | 0.001 | 0.435 | 0.079 | 0.000 | 0.011 | 0.920 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 62 |
| PIN | 0.002 | 0.496 | 0.037 | 0.000 | 0.023 | 0.807 | 0.920 | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 62 |
| ORA | 0.066 | 0.439 | 0.505 | 0.001 | 0.195 | 0.210 | 0.226 | 0.154 | | | 1 | | | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 48 |
| BME | 0.001 | 0.176 | 0.000 | 0.000 | 0.007 | 0.436 | 0.460 | 0.308 | 0.012 | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 67 |
| PUR | 0.003 | 0.212 | 0.036 | 0.001 | 0.018 | 0.377 | 0.420 | 0.341 | 0.111 | 0.908 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 71 |
| WO8 | 0.725 | 0.019 | 0.293 | 0.014 | 0.782 | 0.009 | 0.012 | 0.009 | 0.173 | 0.003 | 0.008 | | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 71 |
| WO1 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | 86 |
| WO2 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.024 | | | 1 | 1 | 1 | | 1 | 1 | | 86 |
| WO3 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.002 | 0.409 | | 1 | 1 | 1 | | 1 | 1 | | 86 |
| WO5 | 0.003 | 0.000 | 0.000 | 0.141 | 0.005 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.005 | 0.000 | 0.001 | 0.000 | | 1 | | 1 | 1 | 1 | 1 | 90 |
| WO6 | 0.277 | 0.005 | 0.015 | 0.204 | 0.149 | 0.006 | 0.007 | 0.004 | 0.003 | 0.000 | 0.008 | 0.149 | 0.000 | 0.000 | 0.000 | 0.031 | | 1 | 1 | 1 | 1 | 1 | 81 |
| WO7 | 0.002 | 0.000 | 0.000 | 0.395 | 0.003 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.001 | 0.005 | 0.000 | 0.000 | 0.000 | 0.448 | 0.043 | | 1 | 1 | 1 | 1 | 90 |
| WMJ | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.003 | 0.097 | 0.120 | 0.011 | 0.001 | 0.005 | | 1 | 1 | 1 | 90 |
| W3M | 0.002 | 0.779 | 0.206 | 0.000 | 0.043 | 0.291 | 0.275 | 0.320 | 0.538 | 0.060 | 0.175 | 0.002 | 0.000 | 0.000 | 0.000 | 0.000 | 0.001 | 0.000 | 0.000 | | 1 | 1 | 62 |
| SLK | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.330 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | | 1 | 95 |
| PET2 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.116 | 0.440 | 0.152 | 0.000 | 0.000 | 0.001 | 0.013 | 0.000 | 0.005 | | 86 |
| | | | | | | | | | | | | | | | | | | | | | Average | | 75 |

1 Pairs with significant difference.

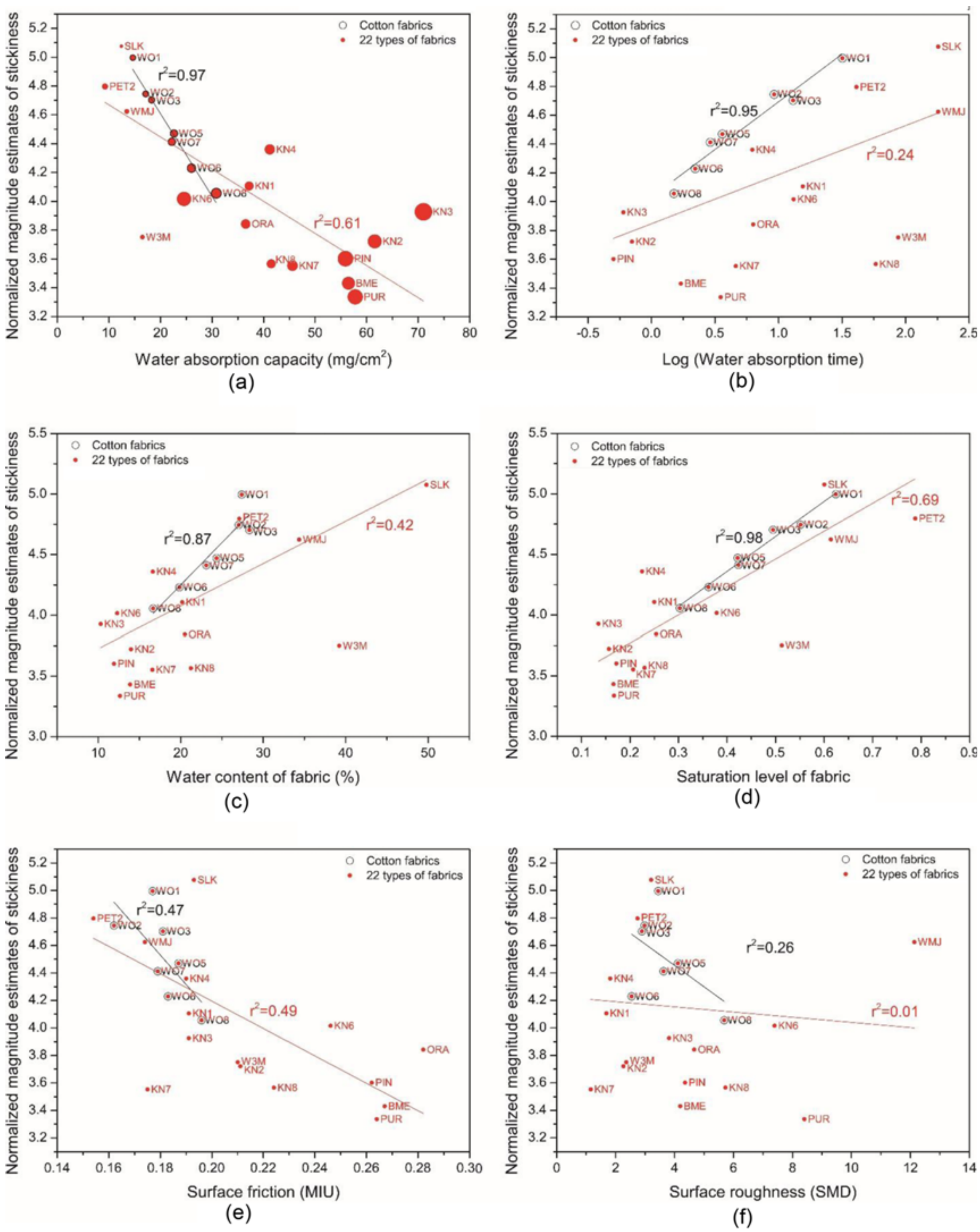


**Figure 7.** Correlation between normalized magnitude estimates of stickiness and various fabric properties; (a) Water absorption capacity whereas the size of the circle is proportional to fabric thickness, (b) water absorption time by wettability test, AATCC 79, (c) water content of fabric, (d) saturation level of fabric, (e) surface friction (MIU) by KES-F, and (f) surface roughness (SMD) by KES-F.

objectively measured fabric parameters is discussed in this section and the result is provided in Figure 7. The solid red points show the result for 22 types of fabrics while the hollow circles represent eight pieces of woven cotton fabrics.

***Water Absorption Capacity of Fabric***

Among the 22 types of fabrics, Figure 7(a) shows that estimates of stickiness are negatively related to water absorption capacity ($r^2$=0.61). Additional information can be obtained from Figure 7(a). That is fabric thickness. The size of each circle is proportional to fabric thickness. Water absorption capacity as well as fabric thickness determine the amount of interfacial water between fabric and skin surface. For fabrics with higher thickness, their water absorption capacity is also high, so they can withstand more water and the interfacial water is less, consequently the perceived stickiness is milder. When eliminating the effect of material and finishing, and focusing only on the woven cotton fabrics (i.e. WO1, WO2, WO3, WO5, WO6, WO7, WO8), the coefficient of determination ($r^2$) is much higher ($r^2$=0.97). This implies that thicker fabrics with higher water absorption capacity give weaker stickiness feel.

For example, in case of fabric ‘KN3’ and ‘KN4’, they are both knitted by hygroscopic 32s cotton yarn. Fabric ‘KN3’ (1×1 rib structure) is thicker than fabric ‘KN4’ (single jersey structure) and its water absorption capacity is higher (KN3:70.99 g/cm$^2$; KN4: 41.19 g/cm$^2$). Therefore, the water added can completely penetrate into ‘KN3’, much water is required to saturate the fabric and negligible amount of water will redistribute to the skin surface, leading to significantly lower stickiness estimates ($p=0.002<0.05$).

In another case, fabric ‘WO1’ and ‘WO2’ are plain woven fabrics made by cotton yarns with different coarseness levels. As mentioned in Table 2 and Figure 2, thinner fabric ‘WO1’ (WO1: 0.37 mm; WO2: 0.40 mm) are woven with finer yarn (WO1: 80s cotton; WO2: 60s cotton) and its pore size is larger. This contributes to lower water absorption capacity (WO1: 14.62 mg/cm$^2$; WO2: 17.13 mg/cm$^2$). When wearing thinner fabric, like ‘WO1’, during profuse sweating condition, the water within the interfaces tends to increase the adhesion between the two surfaces and the moisture might redistribute to the assessor’s skin. Liquid bridges will be easily formed by superficial water droplets, leading to significantly higher stickiness estimates ($p=0.024<0.05$).

***Water Absorption Time of Fabric***

Among the 22 types of fabrics, Figure 7(b) shows that estimates of stickiness are positively but weakly related to log(water absorption time) ($r^2$=0.24). When focusing on only the cotton woven fabrics (i.e. WO1, WO2, WO3, WO5, WO6, WO7, WO8), stickiness estimates are highly proportion to log(water absorption time) ($r^2$=0.95). Water absorption time determines the speed of water transport. For fabrics with longer water absorption time, the sweat cannot be absorbed quickly and liquid bridge might be formed within the interfaces, increasing the adhesion between the two surfaces and leading to stronger stickiness feel.

For example, in case of fabric ‘WO3’, ‘WO5’ and ‘WO7’, they are woven with same pieces of yarn (40s cotton) but varying in fabric density. As mentioned in Table 2, fabric ‘WO3’ is the densest. The dense fabric provides less room for the fiber to swell and for water to penetrate and bond, so the adhesion of water to fabric is less and its water absorption time is significantly longer (WO3: 13s, WO5: 3.6s, WO7: 2.9s). These features contribute to stronger stickiness sensation.

***Water Content of Fabric***

Normalized magnitude estimates of stickiness against water content of fabric is shown in Figure 7(c). The calculation of water content of the fabric is shown in equation (2). This indicates the degree of wetness in terms of geometrical volume of the sample after spraying. Figure 7(c) shows that water content of fabric is positively related to stickiness estimates ($r^2$=0.42). Fabrics with higher water content imply that majority of the space within the sample is occupied with water, so the contact area between fabric and skin tends to increase and its stickiness estimates are higher. This parameter, however, does not reflect the location of water distribution within the fabric and so its correlation with stickiness estimates is not very strong.

$$\text{Water content of fabric} = \frac{\text{Amount of water absorbed by the sample (mg/cm}^2\text{)}}{\text{Thickness (cm)} \times \text{Porosity } (\varepsilon)} \times 100\ \% \quad (2)$$

***Saturation Level of Fabric***

The correlation between stickiness estimates and saturation level of fabric is shown in Figure 7(d). The calculation of saturation level of fabric is shown in equation (3). This indicates the degree of saturation in terms of water absorption capacity of the sample. Higher saturation level implies that the amount of water absorbed by the sample approaches its water absorption capacity. Figure 7(d) shows that saturation level of fabric is positively and strongly related to stickiness estimates ($r^2$=0.69). When focusing on the woven cotton fabrics (i.e. WO1, WO2, WO3, WO5, WO6, WO7, WO8), the correlation is even stronger ($r^2$=0.98).

$$\text{Saturation level of fabric} = \frac{\text{Amount of water absorbed by the sample (mg/cm}^2\text{)}}{\text{Water absorption capacity of sample (mg/cm}^2\text{)}} \quad (3)$$

***Surface Friction of Fabric in Dry Condition***

Normalized magnitude estimates of stickiness against surface friction of fabric is shown in Figure 7(e). Surface friction is measured by Kawabata Evaluation System for Fabrics (KES-F) under dry condition [32]. Negative correlation is found between surface friction and stickiness estimates ($r^2$=0.49); however, the direction of correlation is irrational and it suggests that the frictional property measured in dry condition cannot be used to predict the stickiness sensation perceived in wet fabric. It suggests that a new measurement system is needed to measure the frictional property of textiles in wet condition.

***Surface Roughness of Fabric in Dry Condition***

Normalized magnitude estimates of stickiness against surface roughness of fabric is shown in Figure 7(f). Surface roughness is also measured by KES-F under dry condition.

The result shows that surface roughness and stickiness estimates are uncorrelated ($R^2$=0.01). This is possibly due to the fact that many other fabric properties are likely involved in stickiness assessment.

***Effect of Fiber Type on Perceived Stickiness***

As shown in Table 2, the surface friction (MIU) of fabric 'PET2' and 'SIK' in dry condition is similar to other woven cotton fabrics; however, the stickiness estimates assessed in wet condition are significantly higher than the others. This suggests that the effect of fiber type is much more pronounced on wet fabrics [34]. This is because chemical composition of the fibers affects the amount and speed of water absorption [62]. With increasing wetness, water molecules will first accumulate on the cracks and pores of the fiber surface and then penetrate into the fiber. Some fibers like cotton may swell. There is also capillary wicking within- and between-fibers. Water may be released easily when pressure applied onto fabrics filled with free water (i.e. unabsorbed water). On the other hand, the stickiness sensation is weak when water is bound inside the fiber. These suggest that the effect of fiber type may affect the nature of absorbency which leads to the difference in skin wetness and stickiness.

For example, after spraying water to fabric 'PET2' and 'SIK', water does not penetrate into the fabric completely. Instead, it can be observed that water drops are 'standing' on it. The unabsorbed water will transfer to skin surface directly during contact. Liquid bridges were formed between fabric-skin interfaces. The increased skin moisture may cause adhesion of the fabric to the skin surface, resulting in greater fabric-skin contact area and thus higher friction coefficient. This coincides with the finding from Shao *et al*. [10] that stickiness is associated not only with more friction but also with more contact between finger and surface.

## Conclusion

In this study, a subjective assessment method with the incorporation of Body Movement Simulator (BMS) was developed for assessing the stickiness sensation perceived in wet apparel fabrics. The proposed volar forearm test can better simulate the real sweating and wearing condition – wet fabrics were assessed with the incorporation of fabric movement. The magnitude of body movement and the sweating level (i.e. the amount of water applied to the fabric) can be adjusted, with reference to various activity levels, indicating the versatility of the setup. During test, the test sample and the reference stimulus were dragged against the volar forearms simultaneously and the assessor was asked to compare its level of stickiness in ratio based on magnitude estimation approach. With the use of magnitude estimation approach, the problems caused by conventional interval rating scale can be avoided. Additionally, the assessor do not need to memorize the perception of the reference stimulus, the possibility of panel drift can be avoided. In general, the proposed volar forearm test is simple, user-friendly and systematic, ensuring reproducibility and repeatability of the test. Also, it can be used to assess various types of textiles which should expose to wet skin surface, for example sportswear, intimate apparel, and incontinence products.

In summary, stickiness estimates increase with water content of fabrics, saturation level of fabrics and water absorption time, and decreases with water absorption capacity. When wearing clothing with poor water absorbency during sweating, the interfacial water and skin moisture level increases. It will soften the skin layer and cause adhesion of the fabric to the skin surface, leading to greater fabric-skin contact area and higher friction coefficient. This will increase the stickiness of fabric and seriously affect the sensorial comfort of the wearer. Thus, clothing should minimize skin stickiness with designs that minimizing the contact area and having excellent water absorption capacity. Clearly, fabrics with lower water absorption capacity (e.g. thinner fabrics) and poor water transport property should be avoided for applications where wearer might sweat heavily.

Besides, correlation study found that stickiness estimates do not have rational relationship with dry friction of fabrics and is unrelated to fabric roughness. It suggests that either surface friction or surface roughness measured by KES-F is not good predictor for stickiness sensation and so more advanced equipment is desired. In our subsequent study, we will introduce a measurement system which can measure stickiness property of textiles under different wetness levels.

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## Appendix A. Details for teaching session.

1. Reference stimulus: fabric 'WO3' sprayed with 1.4 g water
Test stimulus: fabric 'SIK' sprayed with 1.4 g water
Feedback: This test stimulus is almost the stickiest in subsequent testing. The expected estimates of stickiness should be much higher than 100.

2. Reference stimulus: fabric 'WO3' sprayed with 1.4 g water
Test stimulus: fabric 'BME' sprayed with 1 g water
Feedback: This test stimulus provides the lowest degree of stickiness among the following samples. The expected estimates of stickiness should be much lower than 100.

3. Reference stimulus and test stimulus: fabric 'WO3' sprayed with 1.4 g water
Feedback: The expected stickiness estimates should be more or less equal to 100.

## Appendix B. Details for screening session

After the teaching session is the screening session. The assessors should apply what they have learnt and manipulate eight sets of samples (as shown in Table A1) in order to test their reliability and sensory acuity. These eight pairs were randomly presented to the assessors. Here are the guidelines for screening out the assessors.

· The estimate of stickiness for pair 1 is equal to 100

· The estimate of stickiness for pair 2 is equal to 100

· The coefficient of variation (CV%) for the stickiness estimates in pair 3,4,5 or 6,7,8 is larger than 30 %.

**Table A1.** Sample arrangement for the screening session

| Pair | Reference plate | Test plate | Purpose |
|---|---|---|---|
| 1 | Fabric 'WO3' with 1.4 g water | Fabric 'WO3' with 0.7 g water | Ability to differentiate fabrics with different moisture content |
| 2 | Fabric 'WO3' with 1.4 g water | Fabric 'WO3' with 2 g water | Ability to differentiate fabrics with different moisture content |
| 3,4,5 | Fabric 'WO3' with 1.4 g water | Fabric 'WO1' with 1.8 g water | Ability to give repeatable result |
| 6,7,8 | Fabric 'WO3' with 1.4 g water | Fabric 'W3M' with 1.4 g water | Ability to give repeatable result |

## Appendix C. Details for training session

Seven types of fabrics with extreme difference in surface feature and water absorbency were assessed following the abovementioned testing protocol. Fabric 'KN1', 'KN2', 'WO1', 'WO3', 'W3M', 'SIK' and 'PET2' were included and were assigned in random order. This ensures that the assessors are familiar with the experimental process and the use of magnitude estimation for stickiness sensation assessment.

## References

1. M. P. Gashti, *Fiber. Polym.*, **17**, 130 (2016).
2. I. Ebrahimi, M. Parvinzadeh Gashti, and M. Sarafpour, *J. Photochem. Photobiol. A*, **360**, 278 (2018).
3. M. Parvinzadeh Gashti, M. Yousefpour Navid, and M. Hossein Rahimi, *Pigm. Resin. Technol.*, **42**, 34 (2013).
4. M. P. Gashti and H. Adibzadeh, *Fiber. Polym.*, **15**, 65 (2014).
5. S. M. Pasumarty, S. A. Johnson, S. A. Watson, and M. J. Adams, *Tribol. Lett.*, **44**, 117 (2011).
6. R. K. Sivamani, J. Goodman, N. V. Gitis, and H. I. Maibach, *Skin Res. Technol.*, **9**, 227 (2003).
7. S. Derler, L. C. Gerhardt, A. Lenz, E. Bertaux, and M. Hadad, *Tribol. Int.*, **42**, 1565 (2009).
8. J. van Kuilenburg, M. A. Masen, and E. van der Heide, *Proc. Inst. Mech. Eng. J.*, **229**, 243 (2015).
9. A. Gwosdow, J. Stevens, L. Berglund, and J. Stolwijk, *Text. Res. J.*, **56**, 574 (1986).
10. F. Shao, X. Chen, C. Barnes, and B. Henson, *Proc. Inst. Mech. Eng. H*, **224**, 97 (2010).
11. J. F. Ramírez, J. J. Pavón, and A. Toro, *Proc. Inst. Mech. Eng. J.*, 259 (2014).
12. D. N. Tasron, T. J. Thurston, and M. J. Carré, *Procedia Eng.*, **112**, 110 (2015).
13. S. Tomlinson, R. Lewis, X. Liu, C. Texier, and M. Carré, *Tribol. Lett.*, **41**, 283 (2011).
14. M. A. Masen, *J. Mech. Behav. Biomed. Mater.*, **4**, 1620 (2011).
15. O. Dinç, C. Ettles, S. Calabrese, and H. Scarton, *J. Tribol.*, **113**, 512 (1991).
16. S. Derler and L. C. Gerhardt, *Tribol. Lett.*, **45**, 1 (2012).
17. D. Tasron, R. Maiti, M. Hemming, R. Lewis, and M. Carré, *Procedia Eng.*, **147**, 753 (2016).
18. Y. Dong, J. Kong, C. Mu, C. Zhao, N. L. Thomas, and X. Lu, *Mater. Des.*, **88**, 82 (2015).
19. E. Bertaux, S. Derler, R. M. Rossi, X. Zeng, L. Koehl, and V. Ventenat, *Text. Res. J.*, **80**, 1803 (2010).
20. M. Raccuglia, K. Pistak, C. Heyde, J. Qu, N. Mao, S. Hodder, and G. Havenith, *Text. Res. J.*, doi:10.1177/0040517517716905 (2017).
21. L. Meredith, J. Brown, and E. Clarke, *Biotribology*, **3**, 20 (2015).
22. G.-M. Rotaru, D. Pille, F. Lehmeier, R. Stämpfli, A. Scheel-Sailer, R. Rossi, and S. Derler, *Tribol. Int.*, **65**, 91 (2013).
23. E. Baussan, M.-A. Bueno, R. Rossi, and S. Derler, *Wear*, **268**, 1103 (2010).
24. S. Derler, G.-M. Rotaru, W. Ke, L. El Issawi-Frischknecht, P. Kellenberger, A. Scheel-Sailer, and R. Rossi, *J. Mech. Behav. Biomed. Mater.*, **38**, 114 (2014).
25. W. Ke, G. M. Rotaru, J. Y. Hu, X. Ding, R. M. Rossi, and S. Derler, *Tribol. Lett.*, **56**, 457 (2014).
26. U. Wollina in "Handbook of Medical Textiles" (V. Bartels Ed.), p.248, Elsevier, 2011.
27. S. Derler, A. Rao, P. Ballistreri, R. Huber, A. Scheel-Sailer, and R. M. Rossi, *Tribol. Int.*, **46**, 208 (2012).
28. D. F. Moore, "The Friction and Lubrication of Elastomers", Pergamon Press Oxford, 1972.
29. S. Chen, S. Ge, W. Tang, J. Zhang, and N. Chen, *Text. Res. J.*, **85**, 2177 (2015).
30. W. W. Carr, J. E. Posey, and W. C. Tincher, *Text. Res. J.*, **58**, 129 (1988).
31. M. G. Gee, P. Tomlins, A. Calver, R. H. Darling, and M. Rides, *Wear*, 1437 (2005).
32. S. Kawabata, *Sen'i Kikai Gakkaishi*, **26**, P721 (1973).
33. V. Chaudhary, P. K. Bajpai, and S. Maheshwari, *Fiber. Polym.*, **19**, 403 (2018).
34. R. R. Van Amber, B. J. Lowe, B. E. Niven, R. M. Laing, C. A. Wilson, and S. Collie, *Text. Res. J.*, **85**, 115 (2015).

35. E. Kamalha, Y. Zeng, J. I. Mwasiagi, and S. Kyatuheire, *J. Sens. Stud.*, **28**, 423 (2013).
36. L.-C. Gerhardt, V. Strässle, A. Lenz, N. D. Spencer, and S. Derler, *J. Royal Soc. Interface*, **5**, 1317 (2008).
37. S. Derler, U. Schrade, and L. Gerhardt, *Wear*, **263**, 1112 (2007).
38. L. Skedung, K. Danerlöv, U. Olofsson, C. Michael Johannesson, M. Aikala, J. Kettle, M. Arvidsson, B. Berglund, and M. W. Rutland, *Tribol. Int.*, **44**, 505 (2011).
39. R. Jiang, J. Hu, X. Yang, and X. Ding, *Fiber. Polym.*, **17**, 630 (2016).
40. N. Hollies, *J. Text. Inst.*, **80**, 1 (1989).
41. S. S. Stevens and E. H. Galanter, *J. Exp. Psychol.*, **54**, 377 (1957).
42. K. P. M. Tang, C. W. Kan, and J. T. Fan, *J. Sens. Stud.*, **30**, 329 (2015).
43. E. Jeon, S. Yoo, and E. Kim, *Ergonomics*, **54**, 576 (2011).
44. A. Ramalho, P. Szekeres, and E. Fernandes, *Tribol. Int.*, **63**, 29 (2013).
45. S. E.-G. Jeguirim, A. B. Dhouib, M. Sahnoun, M. Cheikhrouhou, N. Njeugna, L. Schacher, and D. Adolphe, *J. Sens. Stud.*, **25**, 201 (2010).
46. D. Alimaa, T. Matsuo, M. Nakajima, and M. Takahashi, *Text. Res. J.*, **70**, 985 (2000).
47. M. A. Darden and C. J. Schwartz, *Wear*, **267**, 1289 (2009).
48. L. Baker, H. Chen, and B. Cluver, *J. Text. Eng. Fash. Tech.*, **2**, 00044 (2017).
49. "AATCC 79 Absorbency of Textiles", American Association of Textile Chemists and Colorists, North Carolina, United States, 2007.
50. K. P. M. Tang, C. W. Kan, and J. T. Fan, *Text. Res. J.*, **85**, 838 (2014).
51. R. K. Garnsworthy, "Understanding the Causes of Prickle and Itch from the Skin Contact of Fabrics", 1988.
52. M. Yamakawa and S. Isaji, *J. Text. Mach. Soc. Jpn.*, **33**, 9 (1987).
53. H. J. Sauer in "Principles of Heating, Ventilating, and Air Conditioning : A Textbook with Design Data Based on the 2001 ASHRAE Handbook--Fundamentals" (J. Harry J. Sauer, R. H. Howell, and W. J. Coad Eds.), p.8.1, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Ga., 2001.
54. R. Mora-Rodriguez, J. Ortega, and N. Hamouti, *Eur. J. Appl. Physiol.*, **111**, 1073 (2011).
55. J. Abián-Vicén, J. Del Coso, C. González-Millán, J. J. Salinero, and P. Abián, *PLoS One*, **7**, e37821 (2012).
56. E. Zetou, G. Giatsis, F. Mountaki, and A. Komninakidou, *J. Sci. Med. Sport*, **11**, 139 (2008).
57. C. N. Bardis, S. A. Kavouras, G. Arnaoutis, D. B. Panagiotakos, and L. S. Sidossis, *J. Athl. Train.*, **48**, 741 (2013).
58. H. Daanen in "Textiles for Sportswear", p.153, Woodhead Publishing, 2015.
59. H. R. Moskowitz, *J. Food Qual.*, **1**, 195 (1977).
60. R. Shishoo, "Textiles in Sport", Woodhead Pub. in Association with the Textile Institute, CRC, Cambridge : Boca Raton, 2005.
61. "ISO 11056 Sensory Analysis - Methodology - Magnitude Estimation Method", International Organization for Standardization, Switzerland, 1999.
62. P. Kenins, *Text. Res. J.*, **64**, 722 (1994).