https://doi.org/10.2352/issn.2169-2629.2019.27.9

Appearance perception of textiles: a tactile and visual texture study

Fereshteh Mirjalili, Jon Yngve Hardeberg; Norwegian University of Science and Technology, Gjøvik, Norway.

Abstract

Texture analysis and characterization based on human perception has been continuously sought after by psychology and computer vision researchers. However, the fundamental question of how humans truly perceive texture still remains. In the present study, using a series of textile samples, the most important perceptual attributes people use to interpret and evaluate the texture properties of textiles were accumulated through the verbal description of texture by a group of participants. Smooth, soft, homogeneous, geometric variation, random, repeating, regular, color variation, strong, and complicated were ten of the most frequently used words by participants to describe texture. Since the participants were allowed to freely interact with the textiles, the accumulated texture properties are most likely a combination of visual and tactile information. Each individual texture attribute was rated by another group of participants via rank ordering. Analyzing the correlations between various texture attributes showed strong positive and negative correlations between some of the attributes. Principal component analysis on the rank ordering data indicated that there is a clear separation of perceptual texture attributes in terms of homogeneity and regularity on one hand, and non-homogeneity and randomness on the other hand.

Introduction

Appearance uniformity and reproducibility is crucial in textile manufacturing as it adds high value to the product by improving its aesthetic quality and guarantees the customer's satisfaction. It happens quite often when customers decide to renew the old worn out fabric of their sofa seats, and they sadly end up with a new fabric which hardly matches the old one on sofa arms and backs. The new fabric is probably product of a different batch via a different production process.

Appearance also serves as an indication of the quality of the product. Amongst various informational cues such as the fabric type, brand, style, and durability, it has been shown that after cost, appearance and aesthetic appealing of the product is primarily taken into account by the customers when evaluating the quality of a textile product [1]. Traditionally, some of the appearance-related parameters of textiles such as shade and color changes have been judged by trained experts [2]. Although the human visual system is always the final judge, objective quantification of appearance attributes is required in order to implement a reliable control on appearance consistency of textile products. Appearance is the result of a series of complex interactions of incident light with an object, which is influenced by the composition of incident light, the optical characteristics of the object itself, and the human perception mechanism. These interactions modify the appearance of the object which can be subdivided into at least four attributes, namely color, gloss, translucency, and texture [3].

Considering a piece of fabric, one could assume that color of the fabric is its prominent feature. However, a scrupulous observation reveals that the perceived appearance goes far beyond color. One of the strongest cues by which we are able to effortlessly distinguish between a red 'velvet' fabric and a red 'felt' fabric is their 'texture'. Although texture has been defined differently in various disciplines, in a general sense, texture refers to the arrangement of the basic constituents of a material [4]. From the human perception point of view, texture is a 'visual' or 'tactile' surface characteristic resulting in a certain appearance [5]. Tactile texture is the immediate tangible feel of a surface resulting from physical surface variations [6]. Visual texture refers to the sensations caused by the external surface of objects received through the sense of visualization [7]. Nowadays, both visual and tactile texture are widely used in industrial design, art, architecture, and fashion to convey aesthetic and quality information. Visual texture is especially used in image processing tasks and pattern recognition [8].

The fundamental question in texture analysis research is that which texture attributes are essential in texture perception, and how they are correlated. To answer this question, several works have been conducted on texture perception and classification. These studies, however, are mainly focused on visual texture. In one of the earliest studies on finding perceptual texture features, Tamura *et al.* [9] attempted to computationally model six basic texture specifications, namely coarseness, contrast, directionality, linelikeness, regularity, and roughness, which seemed to be common to all texture photographs in the Brodatz album [10]. Later in a similar work, Amadasun and King [4] studied five texture features of ten natural textures from the Brodatz album, namely coarseness, contrast, busyness, complexity and texture strength, and developed new computational models to perceptually describe these features.

In these works, however, observers were asked to evaluate some predetermined and predefined texture properties for which measurement models already existed. To avoid this limitation, Rao and Lohse [11], Heaps and Handel [12], and Long and Leow [13] used free sorting tasks, asking observers to sort photographs of textured surfaces into similar groups of their own choosing, without any prompts about the texture properties to use. In an attempt to investigate the visual complexity of texture, Guo *et al.* [14] found through the verbal description of the texture of twenty texture images from the Brodatz album, that the major characteristics of textures which affect human visual complexity perception are regularity, roughness, understandability, density, and directionality.

Jacobs *et al.* [15] studied the relationships between computational texture features and high-level judgments of various qualities of visual texture such as beauty, roughness, naturalness, elegance, and complexity, using 300 texture images. They found that a two-dimensional judgment space with axes closely related to the beauty and roughness judgments represents most of the perceived texture qualities.

Apart from visual texture, a great deal of research, particularly in the textile industry, has been carried out on both subjective and objective evaluation of tactile texture properties such as fabric softness, smoothness, etc. [16].

Despite all such efforts, the fundamental question of how humans perceive texture still stands. Moreover, these works share an important limitation: they have used, as texture stimuli, some sets of photographic pictures of natural or manufactured textured objects and scenes, or their equivalent synthetic images reproduced under arbitrary illumination conditions. However, in everyday life, we would freely interact with real materials and objects when interpreting their various perceptual qualities, especially texture. The use of images as proxies for real world objects for psychology research has been increasingly questioned recently [17].

In the present study, attempts were made to find the most important perceptual criteria people use to evaluate the texture of a series of textile fabrics. To create a more realistic experimental set up, the texture evaluations were conducted in a room under a combination of natural and artificial daylight illumination, and the participants could freely interact with the textiles. They performed two separate experiments: firstly, a verbal description of the texture of the textiles, and secondly, rank ordering the textiles according to their correspondence with the most frequently used texture properties in the first experiment. The possible correlations between different texture properties were subsequently analyzed.

Experiment 1: Describing the 'Texture' of textiles

A fundamental question in texture analysis research is 'which texture attributes are essential in texture perception, and how they are correlated'. Although several works have been conducted on studying texture perception and classification, and various texture features have been proposed, there exists no general agreement on which texture properties are considered by people when evaluating and interpreting texture. The purpose of Experiment 1 was to determine the most important attributes associated with texture perception of textiles using physical texture stimuli and in a natural experimental environment close to real-life conditions.

Texture stimuli

A set of fifty-two natural and synthetic textiles, including fifty fabrics, as well as two leather samples, having different textures and colors, were selected for this experiment. Figure 1 shows the selected textile samples for this study. In order to determine whether the color (hue in particular) of the stimuli has any effect on how people perceive its texture, some of the textiles were provided in different colors/hues.

Figure 1. *The textile samples used as texture stimuli in this study*

Texture Description

Five graduate students, including three males and two females with computer science background from the Department of Computer Science at the Norwegian University of Science and Technology (NTNU) participated in the experiment. The participants were aged between 25 to 32 years old and had normal to corrected to normal color vision. The experiments were conducted in a meeting room with large windows providing natural daylight illumination. The room was also equipped with daylight fluorescent tubes. The participants sat at a table covered with a medium grey paperboard to provide a neutral background. The combined natural and artificial illumination on the working area on the table had a correlated color temperature (CCT) and illuminance of 6000K and 500 lx, respectively. After introducing a written instruction about the experiment, the participants were presented with a sample (i.e. a fabric or a leather) and asked to verbally describe the 'texture' of the sample as precisely as possible. To understand their spontaneous interpretation of texture, the participants were not provided with neither an explicit definition of texture itself, nor the texture properties. In fact, they were expected to employ their own knowledge and understanding of texture. None of the participants were native English speakers. However, they described the texture of the samples in the most popular language, namely English. They were allowed to freely touch the sample and evaluate it from a closer or further distance in an uncontrolled experimental condition. With their consent, the participants' voice and video were recorded by a video camera throughout the experiment. Each participant completed the verbal description of the fifty-two texture stimuli in two sessions. Each session was completed without any time restrictions, although it usually lasted 1.5 hours for each participant.

Analysis of data

The aim of experiment 1 was to determine the most important texture attributes participants use when interpreting the texture of textiles. To this end, the recorded videos of each participant were thoroughly analyzed, and all verbalized texture-related words were extracted. It is worth mentioning that all participants found the task of describing texture difficult at the beginning. However, after taking some time, they showed less hesitation and expressed more ease and comfort while doing the task. It was observed that initial cues participants used for recognizing texture were always visual, as they tended to start talking about the texture before touching the stimuli. However, they always showed an immediate intention for touching the stimuli afterwards in order to confirm the grasped visual information. In total, 120 different words including 65 adjectives such as rough, random, etc., and 55 nouns such as rectangle, strip, curve, etc., were collected. The most repeated words were then determined by conducting a frequency analysis on the data, through which the number of occurrence of each word was specified. Figure 2 shows the results of frequency analysis for ten of the most used words to describe the texture of textiles.

Smooth, soft, homogeneous, geometric variation, random, repeating, regular, color variation, strong, and complicated were ten of the most frequently used words by participants. These ten words were used 335 times throughout the experiments, covering approximately 31% of the entire collection of words accumulated in Experiment 1. These words were considered as the most important perceptual texture attributes for the texture stimuli used in this study. Figure 2 shows that 'smooth' and 'soft', which are mainly considered as tactile texture properties, are the most tangible texture attributes of textiles.

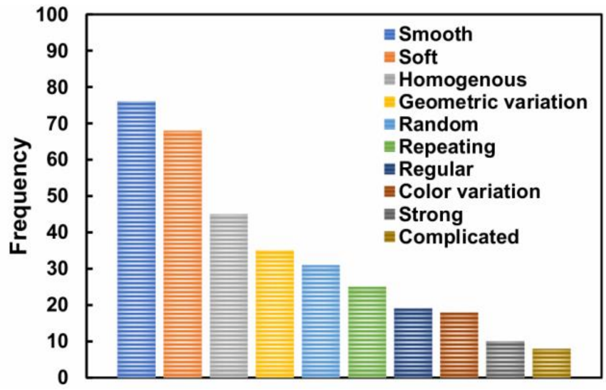

Figure 2. *Histogram of frequency distribution of ten of the most used words for verbal description of texture of textiles*

Although changes and variations in color of the textile was considered by participants as a texture property, i.e. 'color variation', it was interesting to find out that color itself has no significant effect on texture perception of textiles. Same fabric in different colors would be evaluated similarly in terms of texture.

Experiment 2: Correlation between perceptual texture attributes

Having determined the most important perceptual attributes participants use for evaluating the texture of textiles, the next step was to investigate how good people are at recognizing and interpreting these attributes. Moreover, the possible correlations between these attributes were sought after in Experiment 2.

Texture stimuli

Twenty-three textiles including twenty-one fabrics and two leather samples were selected from the same sample set used in Experiment 1. Since texture perception was found to be independent of color in Experiment 1, the chosen textiles for Experiment 2 had essentially different textures, but same hue.

Psychophysical method: Rank ordering

The well-known rank ordering method [18] was used for evaluation of the perceptual texture attributes. Ten graduate students of NTNU, including seven males and three females, aging between 24 to 36 years old, with normal to corrected to normal color vision participated in the experiments. Three of the participants had performed Experiment 1 as well. The rank ordering experiments were conducted in the same room with similar illumination and viewing conditions. Ten perceptual texture attributes selected from the texture description task in Experiment 1, namely smoothness, softness, homogeneity, geometric variation, randomness, repetitiveness, regularity, color variation, strongness, and complexity were investigated. Again, no predetermined definition of texture or texture attributes was given to the participants. The participants were presented with the twenty-three textiles, and asked to rank them on a table, according to how strongly they represent the texture attributes, from the least to the most perceived attribute. The order of presentation of the attributes was quite random for each participant. If they were unfamiliar with the meaning of the attribute, they were allowed to use online dictionaries to find the meaning. The experiment was not a forced-choice task, hence the participants were allowed to assign the same rank order to a number of samples, if needed. Figure 3 shows a participant performing the rank ordering experiment.

Results and discussion

The order of ranking of each texture stimulus was recorded for each texture attribute, and for each participant, separately. Since the range of rank values was different over the participants, the rank order data were re-scaled so that all values were within the range of 0 and 10. The re-scaled data were used to evaluate the participants' accuracy in assessing the texture properties of textiles.

Participant accuracy

The extent of accuracy of participants in terms of intra- and inter-observer variability was evaluated using the standardized residual sum of squares (STRESS) parameter [19]. The intra- and inter-observer variabilities estimate the within-observer, and between-observers errors, respectively. The average intra-observer variability of 10 participants was 24 STRESS units, indicating that all observers were reasonably internally consistent. The average inter-observer variability of participants for rank ordering of different texture attributes is depicted in Figure 4.

The inter-observer variability of participants ranged from 29 STRESS units for softness, to 47 STRESS units for repetitiveness, with a mean value of 38 units, which is larger than the average intra-observer variability (i.e. 24 STRESS units) as might be expected. The typical inter-observer variability of around 35 STRESS units for visual color-difference evaluation tasks has been reported [20]. Considering that evaluation of texture is seemingly a more difficult task due to its stochastic nature, this value indicates a reasonable degree of consistency between the participants. It should also be noted that participants were not given any explicit definition of the texture attributes under judgement.

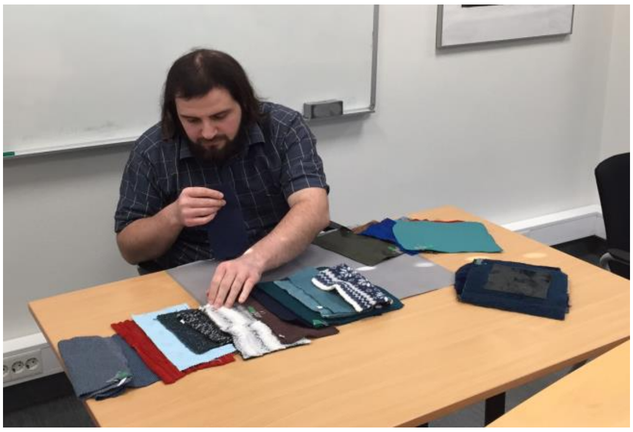

Figure 3. *Rank ordering of the textiles based to their correspondence with texture attributes*

The least average STRESS value belongs to softness, indicating that assessment of this attribute was easier for the participants than the other attributes. Most of the participants mentioned during their assessments that evaluating softness is easy for them. Softness was also the second most repeated texture attribute by the participants in Experiment 1.

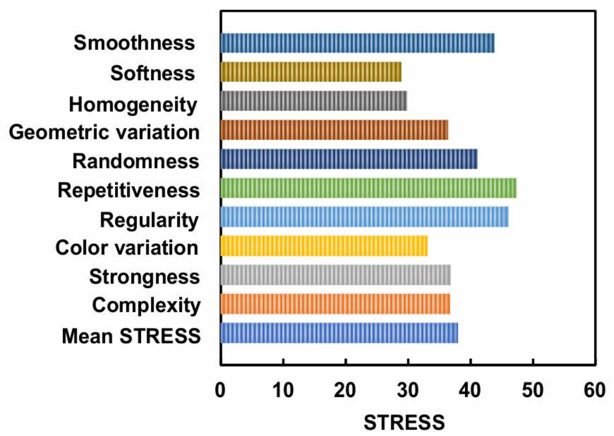

Figure 4. *Average Inter-observer variability of participants for evaluating the ten texture attributes in terms of STRESS. The percent STRESS values are always between 0 and 100. Values of STRESS near to zero indicate better participant consistency*

Although smoothness was the most frequently used texture word, participants showed a poor consistency in evaluating it with average STRESS value of 44 STRESS units. It means that it is probably easy to realize when a textile is smooth, but it is not always easy to tell how smooth/rough it could be compared to other textiles. The lowest participant consistencies belong to repetitiveness and regularity with average STRESS values of 47 and 46 STRESS units, respectively. Such poor consistencies could be attributed to the way the participants interpreted these two attributes. Some of the participants expressed their confusion regarding the true meaning of regularity and repetitiveness. A few of them explained that when there is no perceptible ‘texture element’, it means that such elements are too small to be observed, however, they are ‘infinitely’ repeating. Therefore, the texture is infinitely ‘repetitive’ and ‘regular’. According to the participants’ statements, here the term ‘texture element’ refers to the cues they used to distinguish the textiles ‘with texture’ from those ‘without texture’. For instance, comparing two texture stimuli Tex-6 and Tex-13 in Figure 5, they argued that “Tex-6 has no texture, while Tex-13 has a clear texture because it contains some shapes such as diamonds and flowers”. However, they would consider the Tex-6 as infinitely repetitive and regular.

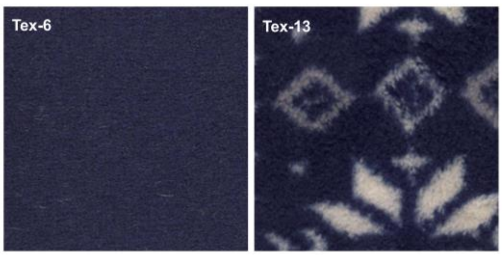

Figure 5. *Comparing two texture stimuli: according to the participants’ statements, Tex-6 has no special texture, while Tex-13 has a clear texture*

Correlation between different texture attributes

The rank scores (RS) of each texture stimulus were calculated from the re-scaled rank ordering data using Eq. (1):

$$RS_i = \frac{\sum_{i=1}^{n} jk_j}{N(n-1)} \qquad (1)$$

where n is the number of stimuli, k_j is the number of times the stimulus i is ranked at jth rank, and N is the number of participants. Figure 6 compares the RS values of the two texture stimuli, Tex-9 and Tex-20, separately for the ten texture attributes.

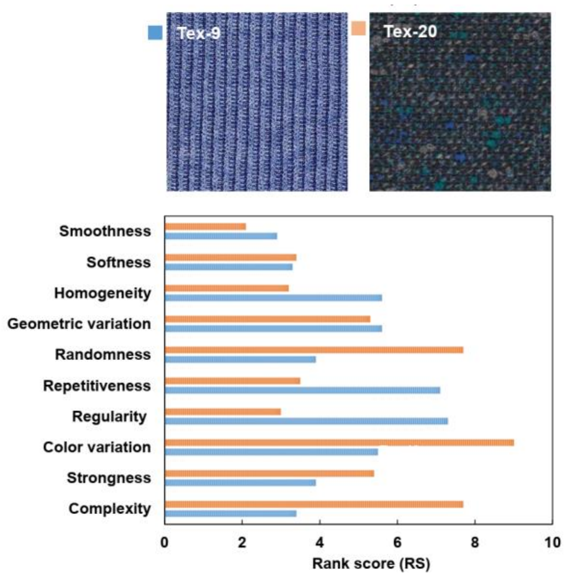

Figure 6. *Rank scores (RS) of two texture stimuli, Tex-9 and Tex-20 for various texture attributes. We see for instance that Tex-20 is found to be much more complex than Tex-9*

It is interesting to note at this stage that there seem to be some correlations between different perceptual texture attributes. For instance, smoothness and geometric variation could be expected to be inversely proportional. In order to investigate the possible correlations between different texture attributes, and determine to what extent they are interdependent, the correlation coefficient (r) between RS values of each two attributes for 95% confidence interval ($p<0.5$) was determined. Table 1 lists such correlation coefficients.

Table 1. Correlation coefficients between various texture attributes for 95% confidence interval (p<0.5)

	Smoothness	Softness	Homogeneity	Geometric variation	Randomness	Repetitivenes	Regularity	Color variation	Strongness	Complexity
Smoothness										
Softness	0.57									
Homogeneity	0.70	0.28								
Geometric variation	-0.57	0.17	-0.75							
Randomness	-0.72	-0.28	-0.87	0.75						
Repetitiveness	-0.44	-0.33	0.22	0.20	0.17					
Regularity	0.45	0.14	0.63	-0.53	-0.81	0.28				
Color variation	-0.57	-0.17	-0.85	0.59	0.66	0.33	-0.37			
Strongness	-0.71	-0.44	-0.91	0.63	0.86	0.45	-0.55	0.77		
Complexity	-0.62	0.17	-0.93	0.76	0.92	0.14	-0.77	0.79	0.88	

The correlation coefficients range from -0.93 to 0.92, 20% of the absolute correlation coefficients are above 0.8, and 60% of them are above 0.5. Such high correlations surprisingly suggest that although the participants were given the least information about the purpose of the experiment, they were able to distinguish different texture attributes. Randomness-complexity (r = 0.92) followed by strongness-complexity (r =

0.88) exhibit the most positively strongly correlated attributes, while homogeneity-complexity (r = -0.93), homogeneity-strongness (r = -0.91), and homogeneity-randomness (r = -0.87) are the most negatively strongly correlated ones. This indicates that when the texture is perceived as ‘random’, it is also ‘complicated’ to understand. On the other hand, when the texture is ‘homogenous’, it is perceived as less ‘complicated’. Despite the strong relations between some of the attributes, some of them seem to be independent, having poor correlations with rest of the attributes. In other words, there seems to be some underlying correlations between various texture attributes.

Principal component analysis (PCA) was conducted on RS data in order to find the possible underlying dimensions of perceptual texture of textiles, and to see how various texture attributes are distributed in a hypothetical texture feature space. The first three components, PC1, PC2, and PC3, having eigenvalues of 31.3, 8.4, and 3.3, respectively, correspond to 90% of data variance. The PC1, PC2, and PC3 of the ten texture attributes are depicted in Table 2.

Table 2: Results of PCA on RS data, the first three principal component coefficients

Texture attribute	PC1	PC2	PC3
Smoothness	0.24	0.21	0.04
Softness	0.15	0.85	0.15
Homogeneity	0.44	-0.03	-0.04
Geometric variation	-0.35	0.41	-0.04
Randomness	-0.37	0.02	-0.37
Repetitiveness	-0.08	-0.17	0.47
Regularity	0.16	-0.07	0.46
Color variation	-0.40	0.04	0.11
Strongness	-0.34	-0.12	0.05
Complexity	-0.41	0.11	-0.15

The results in Table 2 show that PC1 has a strong positive association with homogeneity, and negative associations with complexity, color variation, and randomness. PC2, on the other hand, is strongly loaded positively by softness. PC3 is strongly positively associated with repetitiveness and regularity, and negatively associated with randomness. The distribution of the attributes in the loading plot of PC1 and PC2 is illustrated in Figure 7.

Comparing the coefficients for PC1 and PC2 in Figure 7 shows that softness, smoothness, homogeneity, and regularity have positive loadings, while geometric variation, color variation, complexity, randomness, and strongness have negative loadings on PC1.

Amongst all attributes studied here, softness seems to be the most independent one. Its corresponding small correlation coefficients with other attributes also confirm such independency (see the correlation coefficients in Table 1). In the textile industry, softness is an important aspect of the overall tactile sensation, which is commonly referred to as fabric handle to describe its comfort performance. There are several quantitative test methods for measurement of softness, none of which are well correlated with human sensory evaluation [21]. Although some researchers have considered smoothness as one of the aspects of softness and as an important criterion in assessment of softness [21], the PCA results indicate that smoothness was evaluated as an independent attribute of texture.

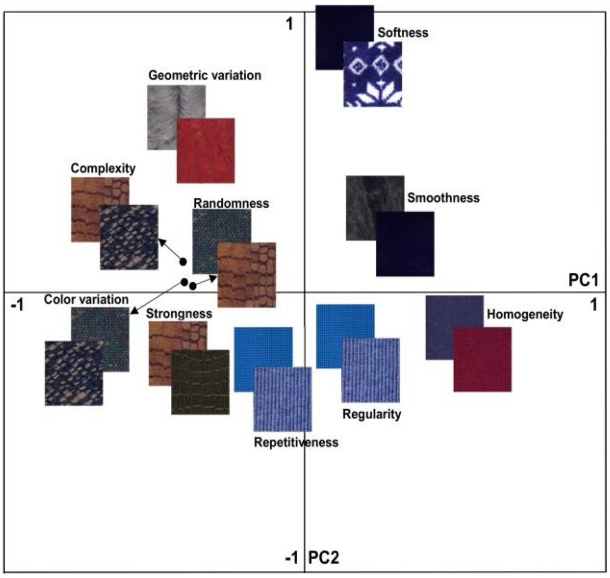

Figure 7. *Distribution of the ten perceptual texture attributes in loading plot of PC1 and PC2. The two textiles presented for each attribute represent the maximum RS for the corresponding attribute*

It was observed during the describing experiment that softness, smoothness and geometric variation were evaluated by touching the samples. However, most of the participants stated that they can intuitively rate these attributes without touching, and by the aid of visual sensation only. However, it can be seen that they are clustered away from the rest of the attributes in the PCA loading plot. It confirms that these attributes are the attributes of tactile texture, while the rest of the attributes are mainly evaluated visually.

The three attributes of randomness, complexity, and color variation are clustered very close to each other in the loading plot. The respective correlation coefficients of randomness-color variation (r = 0.66), randomness-complexity (r = 0.92), and color variation-complexity (r = 0.79) also confirm such high correlations. This might suggest that these attributes could be essentially the underlying dimensions of the same perceptual texture feature. Homogeneity is strongly negatively related to this dimension. However, such a conclusion needs to be proven by further research. It is interesting that there exists a fairly high correlation between homogeneity and regularity (r = 0.63), indicating that when the texture is more regular, it also looks more homogenous. Although many of the participants agreed on that repetitiveness and regularity should be closely related, the correlation coefficient between these two attributes (r = 0.28), and the PCA results indicate otherwise. Looking at the RS data, it was found that regularity and repetitiveness have both the smallest standard deviations, namely 1.3 and 1.4, respectively, among all the attributes. The minimum and maximum RS values were 3.0 and 7.6 for regularity, and 3.5 and 8.4 for repetitiveness, respectively. This means that on average, the RS values of the texture stimuli were somewhat close to each other in terms of regularity and repetitiveness. As mentioned before, the possible explanation for this could be the way participants interpreted these two attributes: the stimulus with no texture element is infinitely regular or repetitive. Strongness was another challenging attribute for participants, as they would intuitively consider the mechanical strength of the textile material as the texture attribute under judgement.

In general, Figure 7 shows that there is a clear separation between tactile and visual texture properties. Additionally, there is a clear separation of perceptual texture attributes in terms of homogeneity and regularity on one hand, and non-homogeneity and randomness on the other hand. Variations in surface geometry and/or color creates texture which can be perceived visually and/or tactually as regular, random, complicated or strong. Further research using more texture stimuli should be carried out to verify the present results.

Conclusions

Two separate experiments were conducted to determine the most important texture attributes participants use when interpreting the texture of textiles. In the first experiment, a group of five participants described the texture of fifty-two natural and synthetic textiles, and their videos and voices were recorded for data analysis. It was observed that the task of describing texture was difficult for all participants, and initial cues they used for recognizing texture were always visual. They would, however, tend to confirm their visual interpretation by touching the sample. It was also found that color of the textile has no significant effect on its perceived texture. Ten perceptual texture attributes, namely, smoothness, softness, homogeneity, geometric variation, randomness, repetitiveness, regularity, color variation, strongness, and complexity were the most frequently used words to describe the texture of textiles. These attributes were rated via a rank ordering task in the second experiment. Although the participants were not given an explicit definition of the texture attributes, they showed overall good consistencies in their evaluations. However, some of them expressed confusion regarding the true meaning of regularity and repetitiveness. This means that some texture attributes are intuitively more complex than the others. High positive correlations were found between the rank scores of randomness and complexity, and high negative correlation were found between homogeneity and complexity. This suggests that there might be some underlying correlations between various texture attributes. The results of PCA also showed a clear separation between the attributes which are more related to a homogenous texture such as homogeneity and regularity, and the attributes which are more associated with non-homogeneity and the stochastic characteristics of texture such as randomness and variations in color and surface geometry. It was also found that tactile texture characteristics such as smoothness and softness are interpreted individually and separately from visual texture properties such as regularity and repetitiveness.

References

[1] M.E. Swinker, J.D. Hines, “Understanding consumers’ perception of clothing quality: a multidimensional approach,” Int. J. Consum. Stud., 30, 218 (2006).

[2] ISO 105-A02:1993, Textiles - Tests for Colour Fastness - Grey scale for assessing change in colour, Geneva: ISO, 1993.

[3] CIE 175:2006 Report, A Framework for the Measurement of Visual Appearance, Central Bureau of the International Commission on Illumination, CIE, Paris, 2006.

[4] M. Amadasun, R. King, “Textural features corresponding to textural properties,” IEEE Trans. Syst. Man Cybern. Syst., 19, 1264 (1989).

[5] Texture and Analysis of Texture, available online at: https://sites.textiles.ncsu.edu/color-science-lab/current-research/texture-and-analysis-of-texture.

[6] G. Elkharraz, S. Thumfart, D. Akay, C. Eitzinger, B. Henson, “Making tactile textures with predefined affective properties,” IEEE Trans. Affect. Comput., 5, 57 (2014).

[7] W. Groissboeck, E. Lughofer, S. Thumfart, “Associating visual textures with human perceptions using genetic algorithms,” Inf. Sci., 180, 2065 (2010).

[8] R. Bormann, D. Esslinger, D. Hundsdoerfer, M. Haegele, M. Vincze, Texture characterization with semantic attributes: Database and algorithm, Proc. The 47th International Symposium on Robotics, pg. 149. (2016).

[9] H. Tamura, S. Mori, T. Yamawaki “Textural features corresponding to visual perception,” IEEE Trans. Syst. Man Cybern. Syst., 8, 460 (1978).

[10] P. Brodatz, Textures: A photographic album for artists and designers (New York: Dover Publications, 1966).

[11] A.R. Rao, G.L. Lohse, “Towards a texture naming system: Identifying relevant dimensions of texture,” Vision Res., 36, 1649 (1996).

[12] C. Heaps, S. Handel, “Similarity and features of natural textures,” J. Exp. Psychol. Hum. Percept. Perform., 25, 299 (1999).

[13] H. Long, W.K. Leow, “Perceptual texture space improves perceptual consistency of computational features,” IJCAI, pg. 1391 (2001).

[14] X. Guo, C.M. Asano, A. Asano, T. Kurita, Visual Complexity Perception and Texture Image Characteristics, Proc. International Conference on Biometrics and Kansei Engineering, pg. 260. (2011).

[15] R.H. Jacobs, K.V. Haak, S. Thumfart, R. Renken, B. Henson, F.W. Cornelissen, “Aesthetics by numbers: links between perceived texture qualities and computed visual texture properties,” Front. Hum. Neurosci., 10, 1 (2016).

[16] T.J. Mahara, H. Wang, R. Postle, “A review of fabric tactile properties and their subjective assessment for next-to-skin knitted fabrics,” J. Text. Inst. 104, 572 (2013).

[17] M.A. Gomez, R.M. Skiba, J.C. Snow, “Graspable Objects Grab Attention More Than Images Do,” Psychol. Sci., 29, 206 (2018)

[18] C. Cui, Comparison of two psychophysical methods for image color quality measurement: paired comparison and rank order, Proc. The 8th Color imaging conference, pg. 222. (2000).

[19] P.A. García, R. Huertas, M. Melgosa, G. Cui, “Measurement of the relationship between perceived and computed color differences,” J. Opt. Soc. Am. A, 24, 1823 (2007).

[20] M. Huang, H. Liu, G. Cui, M.R. Luo, “Testing uniform color spaces and color difference formulae using printed samples,” Color Res. Appl. 37, 326 (2012).

[21] M.L. Gulrajani, Advances in the dyeing and finishing of technical textiles (Woodhead Publishing, 2013).