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PREDICTING HAPTIC PERCEPTION OF TEXTILE TEXTURE AND ANALYSIS BETWEEN SMOOTH-ROUGH PREFERENCES THROUGH IMAGES

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ABSTRACT

Digital images of textile surfaces often trigger assumptions about their actual tactile properties. For any given textile cloth sample, visually perceived tactile properties may not always match with actual haptic sensations. But many decisions related to textiles, right from their manufacturing to end use stages, are often taken on the basis of visual perceptions alone. Smooth-rough modalities are a significant tactile property that influences such decisions. This paper examines "look and feel" and "touch and feel" impressions triggered by human haptic interactions with textiles. Smooth-rough perceptions obtained from high resolution and full images of textile samples were compared with actual haptic sensations derived from the same samples. A three phase experiment was conducted followed by a semi-structured interview with the participants and the results were statistically analyzed. The results indicate that there is a strong positive correlation between high-resolution image and real cloth haptic perception.

KEYWORDS

Haptics, Visual perception, Textile texture

1. INTRODUCTION

Textile is a type of composed material for multiple uses referred as fabric or cloth that provide enough flexibility to meet the demands presented by different environments from designer to consumer. The human perception of smoothness/roughness plays a vital role in the exploring tactile properties of textile material. The smooth-rough dimension impacts the textile finishing process at the phase of manufacturing. It also impacts product performance at the phase of end use. Predominantly, sense of smooth-rough acting in the direct cognition of the textile material. In general, it is the feel of fabrics that expressed as verbal stimuli referring texture related adjectives. The adjective labels 'smooth- rough' used in this investigation cross-referred with review of related literatures [1-3].

Textile textures have the visual and tactile attributes. Indeed, color and design are primary visual effects in clothing but textures also indicate a sense of touch. In addition to that, it also plays a vital role in preference of comfort in clothing which is habitual to humans. The tactile comfort between the textile product and the skin is critical for people particularly, who are sitting or lying for prolonged periods. Basically, textures are surface quality of textiles that consists of the physical structure of the material, construction, mechanical properties, surface properties and as a whole perceived by a combination of tactile and visual cognition.

Vision provides information on the position of textiles whereas touches sense the information related to material and surface properties. Most of the textile materials are using to covers the human body consistently and the user have the sensations that obtained from clothing surfaces through skin sensors. This shows the substantial relationship between textile materials and haptic perception. In the aspects of textiles, sensation by touching, holding or squeezing of fabrics along with its visual surface appearance referred as 'hand'. Smooth-rough perception is one of the major modalities of textile hand feel.

As far as online shopping is concerned, the significant challenge is that customers cannot touch and verify the product before the buying decisions. Thus, the perception of smooth-rough modalities may have limited to the quality of digital images. For instance, resolution is the vital factor in determining the image quality of textured materials. This lead the customers to assume the smooth-rough modalities of textiles from digital images impulsively.

In addition, well understanding of smooth-rough modalities is critical to manufacturers, garment designers, and merchandisers in developing and selecting textile materials that intended for use in apparel; especially when they communicate through images between local exporters and international buyers. In this context, the current study investigated the correlation between 'tactile feel by look' and 'tactile feel by touch' in the terms of smooth-rough perception.

2. REVIEW OF LITERATURE

In the domain of textiles, smooth-rough modalities are significant factors as it directly associated with the subjective tactile sensations by humans when they feel the cloths with their skin. In fact, it is very difficult to quantitatively characterize the 'haptic perception' as well as 'visual perception' of textile surfaces in a clear and precise manner through an objective assessment. For the reason that intricate anisotropic behavior of textiles can influence the assessment and make difficult to interpret the results. Besides, the complicated geometry of textiles consists of fiber to fabric, which undergoes a variety of construction processes. This effects on physical and mechanical properties of textiles that depend on the material used (fibers), fabric structure types (weaves) and surface textures (finishes). Moreover, the microstructures of textiles can be deformed by external forces while handling. On the other hand, the subjective approaches of textile hand feel assessment respects more into psychological aspects. After all, smooth-rough modalities were robustly explored under various research conditions; but most of them are dissimilar in terms of materials, adjectives, and methods involved in various experiments. This illustrates another difficulty to compare the results from previous studies. Keeping this in mind, the current study constructs the fundamental reasons for the psychophysical dimensions of smooth-rough modalities found in the various literature.

2.1. Haptic perception of smooth-rough

Smooth-rough modalities are referred to small-scale surface physical parameters that associated with an overall surface property of the material [4]. For example, Gescheider et al. [5] investigated the perceptual dimensions of textures. They used plastic trapezoidal dots that arranged in the manner of inter-dot spaces and asked nineteen participants to rate roughness of textured surfaces with 15-grade scale. This experiment revealed the roughness into macro and micro (fine) dimensions separately. Later, Jia & Hu, [6] states that texture scale is categorized into 'macro-roughness' and 'micro-roughness' based on the geometrical surface characteristics. The smooth-rough modalities are considering as the 'micro-spatial' aspects whereas 'macro spatial' aspects denote the shape and size. Thus smooth-rough is a local, micro feeling of the surface configuration, which describes the subjective response to the geometrical configuration of a material surface [7]. Broadly, in the physical sense, the term roughness indicates textural deviations on the surface towards height at a micro level. Although, based on the amount of height deviation from the surface roughness can be expressed in a number of ways that occur to different spatial scales [8]. Moreover, roughness refers to the topographical irregularities of horizontal and vertical distance between the 'peaks and valleys' or 'ridges and grooves' [9]. There are several studies demonstrated the smooth-rough modalities subjected to physical parameters of surface textures. Lederman & Taylor [10] suggests that the distance between raised ridges increases the roughness. Again, the height of the raised ridges also increases roughness meanwhile increased the size of the raised ridge width results a modest decrease in roughness [11]. Thus. greater the deviation denotes the surface roughness, whereas small the deviation provides smooth surfaces.

In the domain of perceptual mechanisms of smooth-rough, it is found that many of the researchers are investigated on surfaces-contact forces and surface friction-tangential forces. For instance, the study relevant to surfaces and contact forces shows that groove width, controlled force, and rate of hand motions are significantly affected perceived roughness [12]. This indicates that the finger area sliding through the groove width is an important factor of smooth-rough sensation. Another example is the study associated with tangential forces and kinetic friction to the subjective scaling of tactile roughness by Smith et al. [9]. They used eight flexible polymer surfaces to estimate the roughness. Two groups, each having six naïve participants (Those who have no previous experience of the experiment procedure.) volunteered for their experiment. The result of investigation disclosed that average friction and the tangential-normal force ratio were the better predictors of smooth-rough modalities. Despite the fact that smooth-rough modalities are critical to material evaluation in textile industries [13]. It not only regulates clothing tactile profile of the pleasure experienced by the end user but also plays a vital role in purchase decision-making process [14]. Anyway, it is noteworthy that touching increases the confidence in consumers on a product by evaluating the product's surface modalities such as smooth-rough rather than its macro-spatial aspects like the shape and size [15]. This argument is agreeing with the studies of Yoshida [16] and Tanaka et al. [17] as they explored smooth-rough as one of the first potential factors that influence the haptic dimension.

2.2. Visual perception of smooth-rough

One of the remarkable studies yields greater insight into visual perception of smooth-rough was the 'duplex theory of tactile texture perception' proposed by Katz [18] (as cited in Hollins et al. [19]). Katz suggested that the elements such as size, shape, and distribution of surface are associated with the perception of coarse textures (macro) whereas vibrational cues obtained by figure motion on a surface are used for fine texture (micro) perception. Hollins et al. [19] explained that according to this theory fine textures convey by a distinct receptor system. From this, it can be observed that micro textures such as smooth-rough modalities are more associated with haptics than the visual perception. However, Lederman & Abbott [20] argue that there is no difference in visual, haptic and combined perception of smoothness and roughness. Later, Tiest & Kappers [8] conducted an experiment using ninety-six materials including cloths. Twelve subjects of seven male and five female students participated in the experiment. They were instructed to arrange the samples in the order of increasing roughness in a different haptic and visual conditions without detailing of the concept. The experiment result indicates that perceived roughness by touch are not to be the same as perceived roughness by vision. Again, this study rejected the arguments by Lederman & Abbott [20]. This contrast shows that there are many other parameters also affect the visual-haptic perception of smooth-rough modalities. Sebe & Lew [21] argued that the concept of texture (surface modalities such as smooth-rough) is the variation in intensity and color from certain repeated patterns that can be the result of physical surface properties. According to them texture often have a tactile quality but it will be recognized when we see, hence it is called as a visual texture. They justified their arguments with two aspects. One, within a texture there is the significant variation of intensity levels between nearby pixels; two, the texture is a similar kind of property at some spatial scale larger than the resolution of the image. For example, the series of two experiments by Xiao, et al. [22] reveals the effect of clothing tactile perception of an image by color information and fold of fabric, and how both of these have effects on visual and tactile matching. In their experiment. Forty-two respondents participated in twelve categories of fabrics such as satin, silk, linen, broadcloth, corduroy, velvet, denim, jersey, cotton shirting, flannel, chambray, and twill. They manipulated the cloth into different shape information like 2D flat, 3D draping, and 3D hanging under two color conditions- 'RGB (Red-Green-Blue) and the grayscale using photographs of cloth samples. The first experimental result showed that there was a significant effect of folding condition on color images but not on grayscale images. Whereas the second experiment showed that no statistically significant differences in matching accuracy. The overall observations of this experiment are specified that 3D drapes improved the impression of glossiness, which leads the observers to feel the smoothness of the fabric.

Furthermore, the haptic system has its own specialized pathways to encode an object by touch that substantially differs from a representation of an object encoded by a visual image [23]. Again, smooth-rough modalities can be perceived both visually and haptically but it could contradict each other as 'an object might look smooth but feel rough and vice versa' [24]. This observation is significant in micro (fine) roughness dimensions of smooth-rough modalities, especially applicable to textile cloth surfaces.

3. CONCEPTUAL FRAMEWORK

Humans are able to sense the textile surface modalities by visual as well as haptic. Nevertheless, there would be a difference in the judgments on surface modalities by visual and haptic even though the perception has been extracted from the same textile surfaces. In the context of online shopping, recognizing surface modalities of textile material from a digital image is further difficult because the observed image depends greatly on its resolution. For example, let's consider two images: First, which shot with a shorter distance away from the material that contains only a portion of the surface area, hereafter called as the 'high-resolution image' (HRI). Second, shot with longer distances away from the material that contains the whole surface area, hereafter called the 'full image' (FI). As long as both images are compared, they are communicating different perceptual experiences of same surface modalities. For the reason that the high-resolution image can impart more detailing of surface textures than a full image especially while considering the smooth-rough parameters. On the basis of this framework, the current study hypothesized that anticipation of individuals on smooth-rough modalities from the 'high-resolution image' (HRI) is proximate to the haptic perception of textile material than the full image (FI).

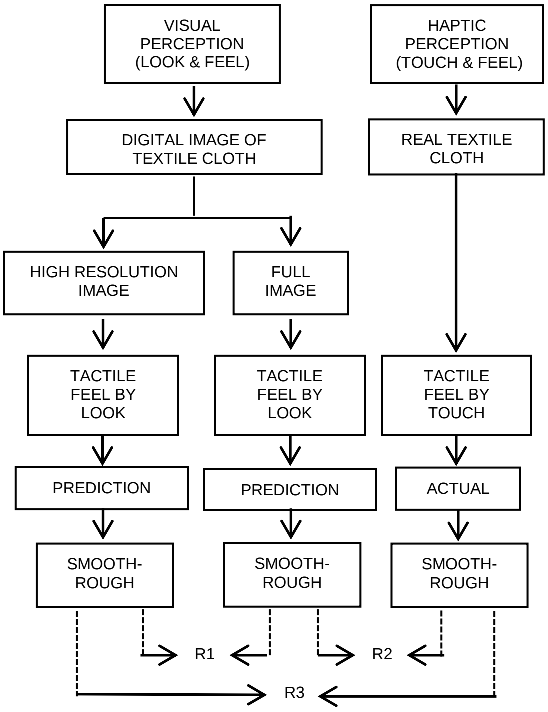

Figure-1 **Conceptual framework**: R1 shows the relationship between high-resolution image and full image. R2 shows the relationship between full image and real cloth. R3 shows the relationship between high-resolution image and real cloth.

Figure-2 Figure *(a)* to *(m)* shows high-resolution images of cloth samples which were used in the first phase of the experiment. Figure *(n)* to *(z)* shows full images of cloth samples which were used in the second phase of the experiment.

Thus the conceptual framework (Figure-1) is described the perceptual relationship between the high-resolution digital image and full digital image (visual), and its real clothes (haptic).

(a) *(b)*

Figure-3 Figure *(a)* shows that the participant is rating their smooth-rough perception by watching the high-resolution images (first phase of experiment) and full images (second phase of experiment). Figure *(b)* shows third phase of experiment involving rating of smooth-rough perception against the real cloth sample by blindfold test. The figure *(b)* also showing a box kind apparatus, which only permit to put the participant's hand inside. The cloth samples hidden inside the apparatus, which does not visible to the participant.

4. EXPERIMENTAL DESIGN

4.1. Preliminary work

The aim of the experiment was to identify the rate of haptic and visual perception relevant to smooth-rough modalities from real textile material and its digital images. There were 13 samples of various surface textures selected for this experiment. The samples were chosen under 5 material categories such as cotton, silk, polyester, wool and viscose rayon, and all of them have come across daily human usages. Each of the samples was photographed based on 2 categories: high-resolution image (HRI) and full image (FI) as shown in the figure-2. High-resolution images were shot with a close-up in the 2D flat manner which represents only a portion of the cloth surface. Full images were shot in the 3D draped manner that represented the entire cloth. Nikon D810 DSLR camera with Nikon 60mm f/2.8 D AF lens was used for photography.

All photographed images of cloth samples were transferred from the camera to an Apple iMac desktop computer and saved as JPEG file format to set out display during the experiment. A box was specially designed to conduct the blindfold test. The box has three openings. One opening is at the back of the box to put the cloth sample. Other two openings are positioned at each side corner of the box to permit the hand inside. The box was placed on a table as shown in figure-3, b. Finally, the experiment was intended for 30 participants (15 men & 15 women) ranged between age from 18 to 33 years.

4.2. Measurement methods

Semantic differential (SD) method was carried out in the experiment for the evaluation of visual and haptic perception. SD method is one of the most widely used methods by a number of researchers, which was developed by Osgood et al [25]. This method prescribes that participants can be rated an attribute of a stimulus on a scale that represents two adjectives in a contradicting pair. The advantage of this method is that it permits to interpret basic tactile modalities without any additional endorsement. Accordingly, a 10-point scale, which degree from 1 to 10 was assigned to rate the smooth-rough perception of the participants against to the concerned task. Value 1 is denoted as extremely smooth whereas value 10 was extremely rough. There were no stipulations given in between the 1-10 values. Participants were allowed to perform in a one by one format during the experiment. There was no time limit given for all participants to complete each task.

4.3. Experimental procedure

The experiment was conducted in 3 phases. Two set of images each consisting of 13 samples (total 26 images) has used in both phases. In the first phase, participants were asked to rate their perception based on high-resolution images (HRI). In the second phase, their rating has relied upon full images (FI). The rating scale was given below for each image. The display on the LCD monitor was organized in such a manner that participant could see one image at a time. Once the participants finished the first image task, they could click on 'next button icon' for a new image and continued their task one after another. The end of each phase they asked to click on 'submit button icon' to make sure that they have completed the experiment. The first and the second phase of experiments (Figure-3, a) have conducted without any interruption. The third phase was 'blindfold test' (Figure-3, b). In this phase, the participants were asked to rate their smooth-rough perception against the real cloth sample. Before the third phase experiment, participants were requested to wash their both hands with liquid soap. The purpose was to maintain the hygienic as well as to soften the skin of palm and finger area that increase the haptic sensation. Subsequently, participants were asked to keep the hands dry. During the experiment, the participants were sitting in front of the box at the opposite side of the experimenter. Then, the participants were directed to pass their both hands into the box. Meanwhile, experimenter put one cloth sample through the opening at the back of the box without intervening in any way and without being noticed by the participants. The participants were asked to begin the task of haptic observation as soon as they touched the cloth sample. Also, they have directed to drive the fingers on the surface of the cloth by circular or linear movements as recommended by Giboreau et al. [13]. Participants were allowed to repeat the touch and observation process till they recognized the feeling. Since it was a blindfold test, there were no images appeared on the screen except the rating scale. After the touching each cloth sample the participants rated their perception on the rating scale. Meanwhile, experimenter removes the existed sample from the box and substitute with a new one. The same sequence has followed until ratings were obtained for the last cloth sample. Finally, a semi-structured interview was conducted with participants to understand the overall experience from the experiments.

5. ANALYSIS

The initial data collected from 30 participants for 13 cloth samples were tabulated. This study hypothesized that the correlation between high-resolution image and full image enhance the actual haptic perception of the cloth. Thus, the obtained data has labeled under three variables such as high-resolution images perception (HRIP), full image perception (FIP) and real cloth perception (RCP). Accordingly, the mean was computed (Table-1).

Samples	HRIP	FIP	RCP
1	6.73	4.03	6.33
2	3.33	3.87	2.10
3	4.20	4.73	5.80
4	6.83	6.53	6.90
5	4.77	5.60	4.93
6	5.23	4.43	6.70
7	4.47	3.87	3.67
8	4.77	3.47	5.13
9	5.23	4.50	5.03
10	5.97	6.37	8.80
11	3.97	3.87	6.20
12	5.10	4.90	4.33
13	5.10	5.87	3.90

Table-1 Mean of Cloth Samples

The statistical method of Spearman's rank correlation coefficient was used to correlate these variables. "Spearman's rank correlation coefficient is a nonparametric technique for evaluating the degree of linear association or correlation between two independent variables. It is unaffected by the distribution of the population since it is a nonparametric technique" [26]. The computed outcomes of correlation between variables given as below:

The calculated $6\Sigma d1^2 = 927$; $6\Sigma d2^2 = 1464$; $6\Sigma d3^2 = 819$. As the count was 13, n(n2-1) = 2184. By substituting the values in to the formula the correlation of HRIP-FIP = 0.58 (*P*); FIP-RCP = 0.33 (*P*); and HRIP-RCP=0.63 (*P*).

6. RESULTS

According to the statistical estimation, the high-resolution image (HRIP) and full image (FIP) of the cloth samples shows a moderate positive correlation. This result indicates that both high-resolution and full digital image of textile cloth is influencing each other at a minimum level to the average perception of smooth-rough modalities. Although, the correlation between full image perception (FIP) and real cloth perception (RCP) is again positive but weak. This shows that visual perception from the full images impairs the meaningful information, which is associated with smooth-rough modalities of textiles. In contrast to the above result, there is a strong positive correlation between high-resolution image perception (HRIP) and real cloth perception (RCP).

7. OBSERVATIONS

All the observations ware based on the statistical results of experiments as well as the experience shared by the participants. The scope of this study consisting of two dimensions of smooth-rough modalities (1) from the real cloth (true) and (2) it's digital images (predictions). In this context, it was observed that smooth-rough predictions from high-resolution images have more association with real cloth haptics than the full images. The other observations show that the feel of cloth transparency from the digital images influenced the prediction of smooth-rough modalities. This observation was revealed by the blindfolded tasks. Also, it was found that previous experiences on usage ware influencing the visual-tactile evaluation. This was more prominent in full images but less in high-resolution images. The print patterns and woven structures also enhanced the predictions from the digital image. These predictions were more prominent in high-resolution images compare with full images. The color was also influenced the smooth-rough prediction, mainly in the full images but not in the high-resolution images.

8. DISCUSSION

This study evaluated the visual and haptic perception of same textile cloth; and suggests that the predicted feel of smooth-rough modalities from digital images depends on how it is visible to the viewer. Surface texture detailing appeared in the digital image play the major role in the prediction of smooth-rough modalities, but it again relies on the scaling of the image. Because high-resolution with the very enlarged image can mislead the perception. The visual distance from the digital image also a critical factor. In this circumstance, it is noteworthy that high-resolution image with average scale (size of the image) proportionate to a normal visual distance can provide better assumption about smooth-rough modalities. Indeed, size of the digital image and visual distance within the tolerance level required for predicting smooth-rough perception have not been addressed in this study. It is recommended that further research should be undertaken in this area. During the session of interview with participants, many of them point out that full images are much easier to predict than the high-resolution image. They indicated the reasons that shape, size, the way of folding, edges, thin-thick assumption, and weight of the real clothing in comparison with what they saw before. This shows previous experience is a strong influencing factor. At the same time, many of their predictions were quite differed compared to the real cloth haptics. The possible reason for this was factors like shape, size, the way of folding and so on misleads them to the multiple assumptions. For instance, smooth and soft; rough and stiff. The other influencing parameters which have to be considered are color, design, and weave. Color and design (print) are most possible factors to divert the attention while predicting smooth-rough modalities, particularly in full image as revealed in many previous studies. In the case of the high-resolution image, they are clearly visible but weave structure is more prominent. Many of the participants were noticed the size of the yarn and even the distance between them. They correlated these observations into the cloth texture that associated with friction following into smooth-rough modalities. It was noticed that cloths, which have solid colors ware less influenced the perception as compared to multi-colored cloths appeared in the full images. However, it can be reasonably assumed that there is a greater agreement between high-resolution image and real cloth on the basis of smooth-rough perception.

9. CONCLUSIONS

This study concludes that there is a strong positive correlation between high-resolution image and real cloth perception. This indicates that the smooth-rough modalities can be visually elicited from a digital image of a cloth surface, provided the image is of an appropriate scaling and resolution. This substantiate the fact that as compared to high resolution images, full Images of cloth surface considerably reduce the visual elicitation of smooth-rough modalities of the textile cloth. The factors which interact between high-resolution and full images have to be explored in future research. Also, it can be inferred from the above conclusions that since high-resolution images are effective at conveying smooth-rough haptic information, they could play a pivotal role in the business success of fashion designers, apparel merchandisers, quality controllers, digital interface designers and other major stakeholders in the clothing industry. However, the study also pointed out that visual textures cannot perfectly convey the modalities of physically perceived surfaces.

REFERENCES

[1] Lederman, S. J. (1983). Tactual roughness perception: spatial and temporal determinants. *Canadian Journal of Psychology/Revue canadienne de psychologie*, *37*(4), 498.

[2] Guest, S., Dessirier, J. M., Mehrabyan, A., McGlone, F., Essick, G., Gescheider, G., ... & Blot, K. (2011). The development and validation of sensory and emotional scales of touch perception. *Attention, Perception, & Psychophysics*, *73*(2), 531-550.

[3] Okamoto, S., Nagano, H., & Yamada, Y. (2013). Psychophysical dimensions of tactile perception of textures. *IEEE Transactions on Haptics*, *6*(1), 81-93.

[4] Dillon, P., Moody, W., Bartlett, R., Scully, P., Morgan, R., & James, C. (2001). Sensing the fabric: To simulate sensation through sensory evaluation and in response to standard acceptable properties of specific materials when viewed as a digital image. *Lecture notes in computer science,* 205-218.

[5] Gescheider, G. A., Bolanowski, S. J., Greenfield, T. C., & Brunette, K. E. (2005). Perception of the tactile texture of raised-dot patterns: A multidimensional analysis. *Somatosensory & motor research*, *22*(3), 127-140.

[6] Jia, Z., & Hu, Z. (2015). Evaluation methods of material surface macro-roughness. *Materials Research Innovations*, *19*(sup8), S8-293.

[7] Zuo, H., & Jones, M. (2005). Exploration into formal aesthetics in design:(material) texture. In *Proceeding of 8th Generative Art Conference, Milan* (pp. 160-171).

[8] Tiest, W. M. B., & Kappers, A. M. (2007). Haptic and visual perception of roughness. *Acta psychologica*, *124*(2), 177-189.

[9] Smith, A. M., Chapman, C. E., Deslandes, M., Langlais, J. S., & Thibodeau, M. P. (2002). Role of friction and tangential force variation in the subjective scaling of tactile roughness. *Experimental Brain Research*, *144*(2), 211-223.

[10] Lederman, S. J., & Taylor, M. M. (1972). Fingertip force, surface geometry, and the perception of roughness by active touch. *Attention, Perception, & Psychophysics*, *12*(5), 401-408.

[11] Blake, D. T., Johnson, K. O., & Hsiao, S. S. (1997). Monkey cutaneous SAI and RA responses to raised and depressed scanned patterns: effects of width, height, orientation, and a raised surround. *Journal of neurophysiology*, *78*(5), 2503-2517.

[12] Lederman, S. J. (1974). Tactile roughness of grooved surfaces: The touching process and effects of macro-and microsurface structure. *Perception & Psychophysics*, *16*(2), 385-395.

[13] Giboreau, A., Navarro, S., Faye, P., & Dumortier, J. (2001). Sensory evaluation of automotive fabrics: the contribution of categorization tasks and non-verbal information to set-up a descriptive method of tactile properties. *Food quality and preference*, *12*(5), 311-322.

[14] Salvia, G., Rognoli, V., & Levi, M. (2013). (Un) conventional engineering tests to predict fabrics sensorial properties. *International Journal of Computer Aided Engineering and Technology 8*, *5*(2-3), 159-176.

[15] Peck, J., & Childers, T. L. (2003). To have and to hold: The influence of haptic information on product judgments. *Journal of Marketing*, *67*(2), 35-48.

[16] Yoshida, M. (1968). Dimensions of tactual impressions (1). *Japanese Psychological Research*, *10*(3), 123-137.

[17] Tanaka, Y., Tanaka, M., & Chonan, S. (2006, October). Development of a sensor system for measuring tactile sensation. In *Sensors, 2006. 5th IEEE Conference on* (pp. 554-557). IEEE.

[18] Katz, D. (1925). Der Aufbau der Tastwelt [The world of touch]. *Leipzig, Germany: Barth*.

[19] Hollins, M., Bensmaïa, S. J., & Risner, R. (1998). The duplex theory of tactile texture perception. In *Proceedings of the 14th annual meeting of the international society for psychophysics* (pp. 115-121).

[20] Lederman, S. J., & Abbott, S. G. (1981). Texture perception: Studies of intersensory organization using a discrepancy paradigm, and visual versus tactual psychophysics. *Journal of Experimental Psychology: Human perception and performance*, *7*(4), 902-915.

[21] Sebe, N., & Lew, M. S. (2001). Texture features for content-based retrieval. In *Principles of visual information retrieval* (pp. 51-85). Springer London.

[22] Xiao, B., Bi, W., Jia, X., Wei, H., & Adelson, E. H. (2016). Can you see what you feel? Color and folding properties affect visual–tactile material discrimination of fabrics. *Journal of vision*, *16*(3), 34-34.

[23] Klatzky, R. L., Lederman, S. J., & Reed, C. (1987). There's more to touch than meets the eye: The salience of object attributes for haptics with and without vision. *Journal of experimental psychology: general*, *116*(4), 356.

[24] Kappers, A. M., & Tiest, W. M. B. (2015). Tactile and haptic perceptual organization. In Wagemans, J. (Ed.), The Oxford handbook of perceptual organization. Oxford Library of Psychology, Oxford University Press.

[25] Osgood, C. E., Suci, G. J., & Tannenbaum, P. H. (1957). The measurement of meaning. Urbana: University of Illinois.

[26] Gautheir, T. D. (2001). Detecting trends using Spearman's rank correlation coefficient. *Environmental forensics*, *2*(4), 359-362.