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Illuminance Impacts Opacity Perception of Textile Materials

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Abstract

Opacity is an important appearance attribute in the textile industry. Obscuring power and the way textile samples block light can define product quality and customer satisfaction in the lingerie, shirting, and curtain industries. While the question whether opacity implies the complete absence of light transmission remains open, various factors can impact cues used for opacity assessment. We propose that perceived opacity has poor consistency across various conditions and it can be dramatically impacted by the presence of a high-illuminance light source. We have conducted psychophysical experiments asking human subjects to classify textile samples into opaque and non-opaque categories under different illumination conditions. We have observed interesting behavioral patterns and cues used for opacity assessment. Finally, we found obvious indications that the high-illuminance light source has a significant impact on opacity perception of some textile samples, and to model the impact based on material properties remains a promising direction for future work.

Introduction and Background

Appearance is a multiplex visual phenomenon that implies the perception of various attributes and properties. Eugène refers to CIE 175:2006 report [1] and its Technical Committee TC 1-65, providing the definition of visual appearance as ”the visual sensation through which an object is perceived to have attributes as size, shape, colour, texture, gloss, transparency, opacity, etc.” [2] He tries to further clear up the terminology stating that ”translucency occurs between the extremes of complete transparency and complete opacity.” According to ASTM Standard Terminology of Appearance [3] *opacity* is ”the ability of a specimen to prevent the transmission of light” or ”the reciprocal of the transmittance factor”, while the adjective *opaque* is defined as ”transmitting no optical radiation”. Even though the ASTM definition of the adjective *opaque* associates the concept with the lack of light transmission, other definitions leave room for interpretation and the question whether opacity is the extreme end of the transparency-translucency-opacity scale with zero transmission, or whether it is a section on this scale including the cases with little optical radiation transmitted, remains open.

In the previous communication [4], we described our psychophysical experiments asking human subjects to cluster objects into *opaque* and *non-opaque* categories and proposed that ”opacity does not imply the complete absence of transmission”. The amount of transmitted light, and whether the human-detectable amount of light is transmitted at all, do not depend solely on material properties. Considering the transmittance definition [3], transmitted radiant flux for given geometric and spectral conditions can be defined as:

$$\Phi_e^t = \Phi_i^t T \quad (1)$$

where Φ_i^t is the radiant flux received by the material; T is transmittance of the given material under given conditions; and Φ_e^t is the radiant flux transmitted by the material.

Therefore, if a cue for opacity judgment is the amount of detectable transmitted light, it should be strongly correlated with the amount of incident light too. Besides, Fleming and Bülthoff [5], as well as Xiao *et al.* [6] have demonstrated that translucency and the opacity perception depend on the illumination direction; particularly, backlit objects appear more translucent and less opaque.

Considering above-mentioned factors, we hypothesize that apparent opacity is not constant and it can be affected by the presence or the absence of a bright light source, whereas the object is located between the observer and the light source. Even though general observations have been reported for the first experiment [4], identifying clear indications that the illuminance of the light source, as well as illumination geometry, have a significant impact on opacity perception, no in-depth analysis has been conducted. The results are reported in the subsequent section.

While plastic objects have been used in the preliminary experiment, we decided to opt for textile materials in the follow-up study. The opacity of textile fabric is defined as ”the ratio between the surface luminance of layer over black background, and the surface luminance layer over white background.” [7, 8, 9] Although the theoretical value of the latter ratio should be equal to 1 for fully opaque materials, Zhao and Berns [9] consider that ”too restrictive” and use a value of 0.98 accounting for measurement uncertainties. It is worth mentioning that the opacity properties of textile do not only imply light reflection, absorption, and the scattering properties of the fiber itself, but can also be dramatically impacted by the texture, as well as by density or scarcity of the mesh the fibers are arranged into in order to form a textile sample. Brody and Quynn explicitly name internal voids and pores among the factors defining textile opacity value [10].

Opacity, i.e. obscuring power of textile fabrics is essential in clothing, particularly, in lingerie and shirting industries, as well as for curtains [7]. The capability of the textile to block light transmission upto certain levels can be a pivotal aspect of customer satisfaction. The backlit illumination geometry with a high-illuminance light source particularly corresponds to application conditions of curtains, which are expected to block bright sunlight and transmit no or negligible amount of light into the room. Therefore, studying opacity perception constancy on textile samples can have direct application in the industry.

We conducted psychophysical experiments asking subjects to cluster textiles into *opaque* and *non-opaque* categories and to place them on the transparency-opacity scale. In order to validate our hypothesis that illumination intensity impacts opacity perception and unveils the failure of the opacity constancy, the experiments have been conducted in two different conditions: with the presence and the absence of a bright light source. Apart from that, the objectives of the experiment have been observation on the opacity assessment process and identification of the cues used by human observers to assess opacity, their behavior, and the factors further impacting opacity perception. The study is primarily of a qualitative nature to outline the directions for future study, while the eventual goal is to model perceived opacity of textile samples as a function of material properties, sample geometric texture, and illumination conditions. While we are conducting a concurrent study to analyze the texture properties of the samples, this paper is primarily focused on the light intensity factors.

The paper is arranged as follows: in the next section, we summarize the quantitative and qualitative findings from the preliminary experiment conducted with spherical objects. Afterwards, we introduce an experimental setup for the follow-up study using textile samples. In the subsequent section the results are presented, followed by the corresponding analysis, discussion, and summary. Finally, we will outline future work based on the shortcomings of the previous experiments.

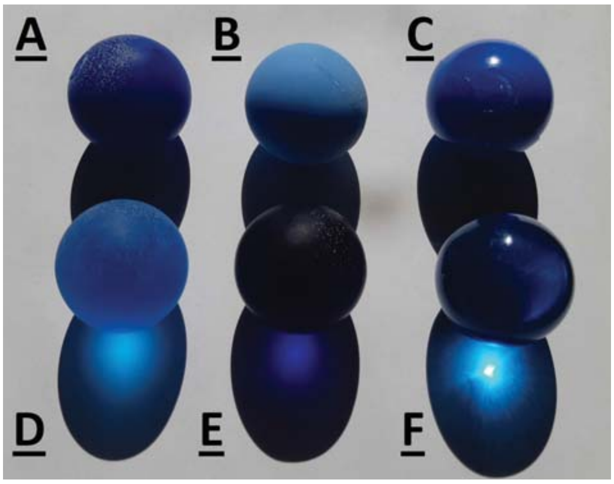

Figure 1. The objects used for the preliminary experiment. Caustics have been a strong cue for opacity assessment.

Revisiting Preliminary Experiment

The experiment has been a part of the larger experiment summarized in our previous communication [4]. Six blue spheres from the *Plastique* artwork collection [11] with different dye mixture, surface smoothness and translucency were used in the experiment. The objects are illustrated in Figure 1. The observers were asked to separate them into *"opaque"* and *"non-opaque"* categories and then revise their findings with the usage of a bright smartphone flashlight. The research question was to identify whether light intensity had an impact on translucency-opacity perception. While inconsistencies among subjects have been observed and reported that opacity does not necessarily imply the absence of transmission, no detailed analysis has been conducted. The deeper insight into the data led us to interesting findings. The initial expectation was the following: the observers were expected to classify objects A, B, C, and E as opaque without a flashlight, ignoring little transmission by the object E. Under bright directional light source object E starts to shine and our hypothesis was that only with the flashlight observers could consider it non-opaque. Objects B and C do not transmit a detectable amount of light, while objects D and F transmit a significant amount under most conditions, and thus, they were classified as opaque and non-opaque respectively by all observers without any exceptions.

Interestingly, roughly 70% of the observers, i.e. 12 out of 17 considered object E non-opaque even without the flashlight, leaving no need for revision. This fact can be explained with poor experimental design. The experiment was designed under diffuse lighting conditions, and the transmission by the object E in those conditions was considered negligible. However, many observers took the experiment with direct visible sunlight that was responsible for projecting a clear caustic pattern on the white surface as shown on Figure 1. Caustics have been widely used for opacity assessment and it was a strong cue that the object was not opaque. However, three observers still behaved as expected: initially ignoring transmission by object E and considering it opaque, although re-classifying it to non-opaque after they observed it shine under the flashlight. One observer classified it opaque from the very beginning and refused to re-classify it even with the flashlight, explicitly mentioning that opacity does not necessarily imply the complete absence of transmission. One more observer ranked object E as non-opaque even without the flashlight. However, this observer scrupulously examined all objects under various lighting geometries and discovered slight light penetration and transmission through object A - the fact ignored by all other observers. He re-classified object A and placed it into a non-opaque cluster. Interestingly, this amount of light has not been considered enough for re-classification by any other observer.

The flaws in the design of the experiment did not allow us to draw strong conclusions. However, we observed that the threshold of the transmitted amount of light separating opaque clusters from non-opaque ones varies among observers and is not strictly consistent. Considering the obvious example of ignored transmission in object A by 94% of the observers, as well as that for object E by 23.5% of the observers, lead us to propose that opacity does not imply the lack of transparency. However, the follow-up experiment had to be planned to validate our hypothesis. As mentioned, the experiment was conducted in uncontrolled conditions under various illuminants, and smartphone flashlights also varied among the observers making the experiment non-reproducible. Thus, we decided to arrange a new experiment under controlled conditions. Apart from the practical application in the industry, the lack of the caustic cue was the further reason to study textile samples.

Experimental Setup & Methodology

Stimuli and Experimental Protocol

51 physical textile samples imaged and described in HyTexiLa [12] dataset have been used for the experiment (Figure 2). The experiment was conducted in controlled conditions and was composed of four steps: 1. The samples were introduced to the observers. They were located roughly 45 cm away from them. The subjects were asked to cluster the samples into two categories: *Opaque* and *Non-opaque*. They were allowed to touch the samples and freely interact with them. The illumination near observers' eyes (roughly 45 cm away from the table) was 307 lux with color temperature of 4518K, while at the table it was 466 lux with 6000K color temperature. The difference can be explained with the fact that light was directly falling onto the table surface from the fluorescent lighting system on the ceiling. The mea-

Figure 2. The samples used in the experiment.

surements were conducted using Konica Minolta CL-200 incident color meter, which was held in a vertical position to measure the light at the observers' eyes. In addition to the fluorescent lighting, negligible amount of daylight was also penetrating through the window blinds. The scene is illustrated in Figure 3; 2. After an observer had completed binary clustering, the scale from 1 to 10 was added to the experimental table. Objects classified as opaque were placed on the one end of the scale: at the category 10. An observer was asked to place all non-opaque samples on the scale, where 1 corresponded to perfect transparency and 10 corresponded to perfect opacity; 3. Afterwards, a bright diffuse light source was turned on. The lamp was located 180 cm away from observers' eyes, and 150 cm away from the edge of the table. It was placed right in front of the observer on the same plane as the table and the textile samples. The lamp increased illuminance at the observers eyes upto 733 lux with 4267K color temperature and at the table surface to 480 lux with color temperature equal to 7300K. Observers were asked to revise their previous decisions under new illumination conditions; 4. Finally, observers were interviewed to justify their decisions and share their impressions. The entire process was videotaped for the subsequent analysis.

Observers

In total 15, 6 male and 9 female subjects with normal or corrected-to-normal vision have participated in the experiment. The median age of the subjects was 30 years with standard deviation equal to 2.76. 12 of them had a background in color, vision, imaging, appearance, or related fields. It is also worth mentioning that all of the observers had prior experience with the samples, as they had participated in another experiment with the same samples. The experiment took roughly 40 minutes per observer.

Opacity Measurement

In addition to perceived opacity, physical measurements need also to be conducted using the scanning methodology proposed by Hajipour *et al.* [8] The authors introduce fabric opacity estimation by an RGB scanner and claim comparable performance to spectrophotometer-based methods. They scanned the samples on white and black backgrounds and used the ratio of the two scans, finding the mean colorimetric values over 1500×2000 pixel areas, converting RGB values into various color spaces. Considering their conclusion that CIE XYZ color space, and particularly luminance channel Y, demonstrated the highest correlation with spectrophotometer-based ground truth data, we decided

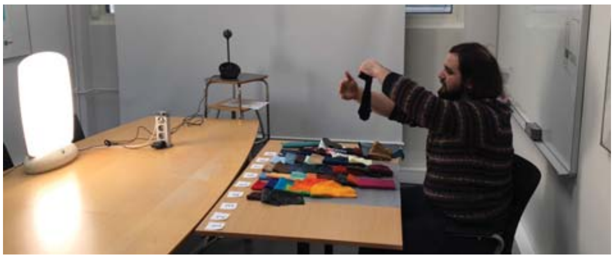

Figure 3. Example of the experimental scene. The photo was taken for the demonstration purposes only and does not depict the real experiment.

to use that color space. The opacity value is found as follows:

$$Opacity = \frac{Y_{\text{black}}}{Y_{\text{white}}} \tag{2}$$

We found scanning method relevant for our samples due to the highly textured and heterogeneous surface of our samples, as spectrophotometer measurements can be highly inconsistent at different points. Epson Expression 10000XL scanner has been used for scanning the samples. It was characterized using Kodak Q-60 IT8.7-2-1993 Color Input Target [13] and estimates of Y were obtained by a regression-based method. The transformation matrix was found using the least squares approximation.

Analysis of the Data

Frequency analysis has been conducted to identify whether the introduction of a bright light source changed the placement of the object across the transparency-opacity scale. In addition to that, we used a paired-sample t-test for each individual sample in order to test a null hypothesis that the presence of high luminance backlight has no impact on ranking across the transparency-opacity scale. We also tested another null hypothesis that presence of high luminance backlight has no impact on *Opaque/Non-Opaque* binary classification. McNemar's test [14] has been used to check the marginal homogeneity. Finally, we correlate the perceptual mean observer scores with the objective opacity metric obtained from the scanner measurements. In addition to quantitative analysis, we studied the opacity assessment process and interviewed the subjects. Below we will report qualitative observations and research hypotheses generated from these observations.

Results

Frequency Analysis

All 15 observers moved some samples from the *opaque* to the *non-opaque* category after turning on the lamp. However, the number of samples initially considered opaque, as well as the number of samples re-classified to non-opaque in strong backlit illumination, varied dramatically among observers (Figure 4). While on average 24.6 samples were initially considered opaque and on average 12 samples were moved into the non-opaque category in another condition, the standard deviation is 12.2 and 8.2, respectively. The number of the samples considered opaque by each observer before and after turning on the lamp is summarized in Figure 4. While cue usage, as well as behavioral patterns are consistent among observers, the definition of a threshold where opacity as a concept starts, is very subjective and individual. Introduction of the high illuminance backlight also changed ranking

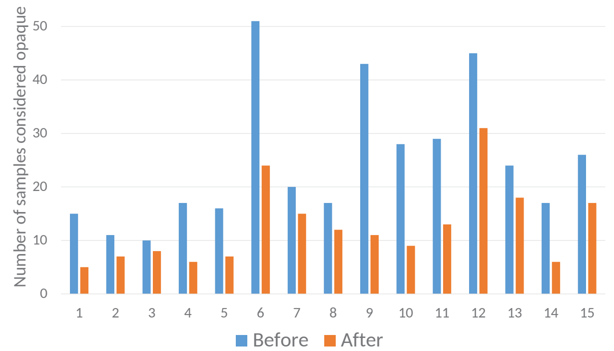

Figure 4. *The number of samples considered opaque by each of the 15 subjects. Blue bar illustrates the number of objects initially considered opaque. Orange bar corresponds to the number of objects considered opaque after turning on the lamp. All observers re-classified some samples.*

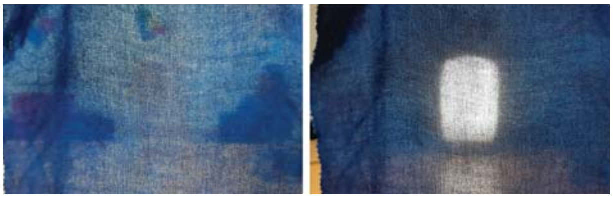

Figure 5. *The example of a transparent sample seen in the two conditions.*

across the transparency-opacity scale for the majority of the samples. The mean observer scores in the two conditions are shown on Figure 6 for each sample separately. The samples are ranked across the horizontal axis by their initial mean ranking score. As we see from the figure, the magnitude of the score change between the two conditions varies among samples. It is the largest for the samples allocated in the middle of the transparency-opacity scale, while change is more subtle for transparent objects and minimal or non-existent for opaque ones. The statistical significance of the impact made by the change in illumination conditions is analyzed in the subsequent sub-section.

Hypotheses Testing

We conducted a paired-sample t-test for each textile sample to test the null hypothesis that the presence of high illuminance backlight has no impact on ranking across transparency-opacity scale. The null hypothesis has been rejected for 31 out of 51 samples at the 5% significance level. The samples for which the null hypothesis was not rejected were the ones with very good light-blocking properties, as well as very transparent ones. This was expected, because the subject can see through the transparent objects well in both studied conditions, while the ones that can block a high luminance backlight from the lamp, were consistently considered opaque in all conditions. The example of such transparent sample is illustrated on Figure 5. This finding is consistent with the above-discussed magnitude of the changes shown on Figure 6. On the other hand, the null hypothesis was rejected for the samples where the presence of light transmission cues strongly depends on the illuminance of the light source and that block low illuminance diffuse light well, while transmit light from strong directional illuminant. However, those results might be biased due to the experimental design. Several observers complained that sampling across the transparency-opacity scale was too sparse and they needed more steps to reflect opacity differences among the samples. For this reason, when they re-classified some samples from the opaque to the non-opaque category after turning on the lamp, they shifted non-opaque samples towards the transparent extreme, in order to have space for allocation of the newly re-classified objects. Therefore, instead of studying the effect on mean observer scores, we re-formulated our null hypothesis as follows: *"Presence of high luminance backlight has no impact on considering a sample opaque."*. Instead of the raw observer scores, the binary representation of the results has been used, with 1 for opaque, and 0 for non-opaque. The null hypothesis was checked for each sample with McNemar's test. McNemar's test statistic has a chi-square distribution with 1 degree of freedom. The null hypothesis has been rejected for 22 samples at the 5% significance level. The null hypothesis was not rejected for any of the mesh-type samples, i.e. the ones that are loosely woven and have holes in fabrics. Also, the null hypothesis was rejected neither for any thick samples nor for any samples with clearly transparent parts. The samples that are significantly affected by the strong backlit directional light are the ones that have no or negligibly small holes but are thin enough to transmit some light. These samples completely cover the background in diffuse lighting conditions, but they transmit a significant amount of light when are backlit with a high-illuminance directional light. Examples of such samples are shown in Figure 7. We are currently studying texture properties of the samples. Whether correlation is found between the impact of the high luminance backlight and the texture properties, will be reported in the future communications.

Objective Measurements

The samples were scanned on the black and white backgrounds. Area of 500×500 pixels has been selected for each sample, and the opacity value was calculated according to Equation 2. Mean observer scores as a function of objective opacity measured with the scanner-based method is shown on Figure 8. Pearson's linear correlation between the two values is 0.5945. While there is a slight correlation, scanner-measured opacity is still a poor predictor of apparent opacity. There are some obvious errors in the measurements, as we can observe on the figure, some values are slightly above 1. This can be explained with the mismatch of the two 500×500 pixel areas, as the complex texture of some soft furry samples makes perfect registration impossible.

Qualitative Observations

Observation of the task performance process and the post-experiment interview with the subjects led to several interesting observations. First of all, all observers have explicitly relied on clearly defined cues. Although cues for the opacity and transparency perception differ. While the sole cue used for opacity judgment was the amount of transmitted light, for the transparency or translucency perception the clarity of the image observed through the object came into play. Some of the cues came with uncertainty: for instance, reflected glitter of a shiny textile has been mistaken by some observers as transmitted light. As the real samples come with artifacts, in contrast with usual computer-generated stimuli, uncertainty increased further. The threshold for the size of the holes in the sample where observers consciously ignored them and did not consider them an additional

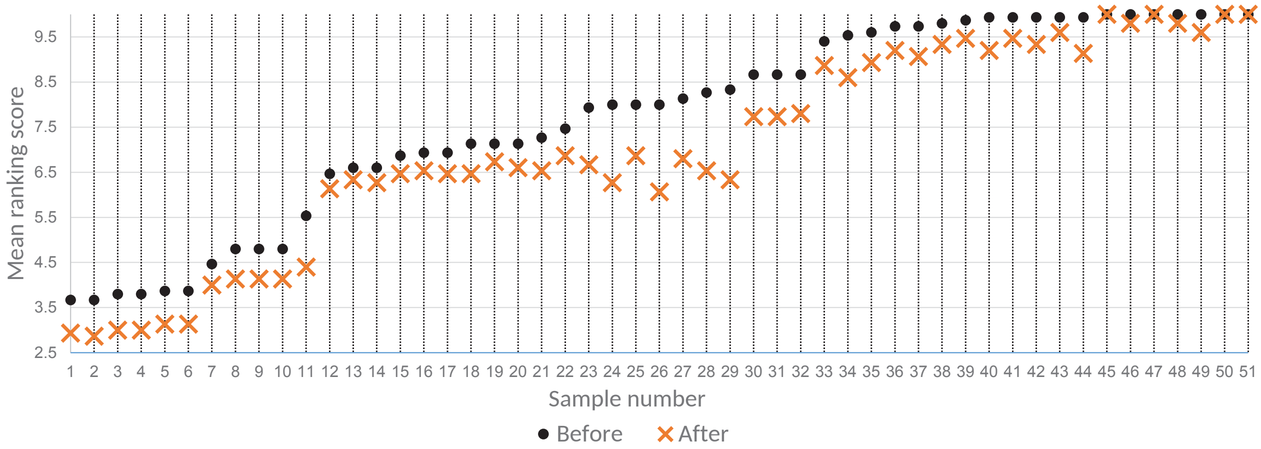

Figure 6. *Mean observer score for each sample. Black circles correspond to the values before turning on the lamp, while orange X corresponds to the values after revision. The samples are ranked by their initial mean ranking score. As we see, the magnitude of the change is largest for the samples allocated in the middle of the translucency-opacity scale, while it is smaller for transparent objects and minimal for the opaque ones.*

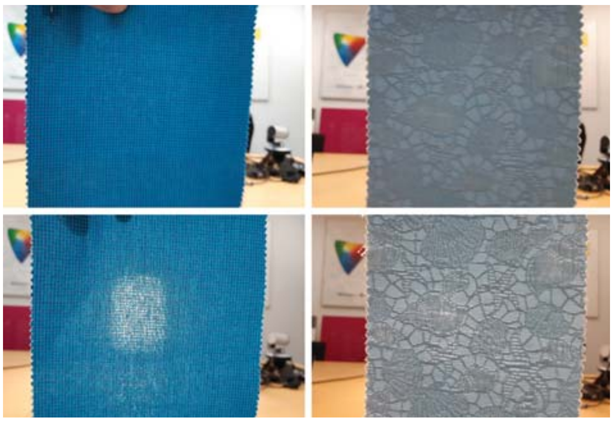

Figure 7. *Example of the samples, for which strong directional backlight has statistically significant impact on opacity classification. While they look more opaque in diffuse light conditions (top), they transmit significant amount of light when seen on a strong backlight (bottom).*

factor for opacity judgment of the entire material, varied among observers and needs to be quantified. Furthermore, considering the freedom given to the observers and the complexity of the task, the observers defined rules to themselves for consistent judgment among samples. The majority of them moved the samples with higher opacity to the brightest light emitter in the environment and looked through the sample to check the light transmission. For translucent samples moving hands behind the sample, as well as moving the samples over a textured background also came into play to observe the contrast, while for more transparent samples they tried to read a text through the material. Four observers identified that an observation distance is crucial for the opacity perception and explicitly fixed distance and observation geometry. Others have implicitly set a distance rule - judging samples with a fully stretched arm looking towards the wall in front of them.

All observers considered opacity a situation-based visual appearance attribute and not a static intrinsic material property. Opacity as a perceptual attribute has some constancy that fails with the change of illumination conditions. In the post-experiment interview all observers confirmed that they judged opacity based on the visual cues available to them in that particular moment, and neither thought of it as an intrinsic material property, nor tried to discard or ignore the effect of the strong backlight. Whether or not this factor complicates material identification across different conditions needs to be studied in future.

Interestingly, even though after the introduction of high illuminance light source observers tend to move samples towards the transparency direction, alternatively, two observers moved a few transparent samples towards the opacity extreme. The observers explained this by a ”blinding effect”, as they were not able to see the background clearly when looking towards the high illuminance light source. When the cue for the transparency or translucency perception is the image seen through the object, the bright light source might impair perception of low luminance and low contrast areas considering the limited dynamic range of the human visual system. This effect can be observed on Figure 5. In some cases, this can make an observer conclude that transparency of the material is low. Another explanation could be adaptation and color constancy: the observer adapts with the bright light source, but the luminance behind the light source remains the same, and the observer looking at the background perceives it dimmer. This phenomenon should be studied further in the future.

Discussion

The behavioral patterns and the cues used in the experiment were consistent among observers. However, the cues varied across the transparency-opacity scale. Considering the low thickness of the transparent samples, observers relied primarily on the clarity of the image seen through the sample, as well as contrast and color distortion. The textile sample was considered more like a thin screen, or a filter, and thus, the observations are very similar to Metelli’s principles of transparency perception [15, 16]. For the samples that obscured the background image, the pivotal cue for the assessment was the amount of light transmitted through the object. Considering that samples are thin, sometimes with holes, enabling photons to be transmitted without scattering, the impact

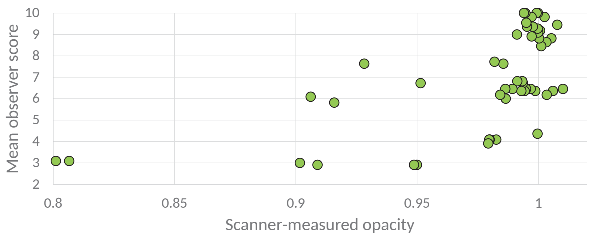

Figure 8. *Mean observer score as a function of an objective opacity measured with the scanner-based method. Slight linear correlation, as well as some erroneous values above 1 can be observed on the plot.*

of sub-surface scattering does not look dramatic, and the image cues proposed by Fleming [5] are not hence applicable. As the observers tried to quantify the amount of the transmitted light, the instrumental measurement of simple radiometric values might be an indicator for perceived opacity for these kinds of objects. However, finding a generic threshold might be extremely challenging. In other words, the minimum amount of transmitted light required for considering a material non-opaque, or the maximum amount of transmitted light tolerated for opacity consideration, is very subjective and varies among observers. However, our data has supported our previous proposal that opacity does not necessarily imply the complete absence of transmission. The secondary cue was the movement detection through the sample subjects moving their hands between the sample and the light source. While the impact of the colorimetric texture remains an open question, there is a clear impact of the geometric texture that needs to be addressed in future. All observers considered it challenging to judge heterogeneous materials, and the fiber meshes with holes inside. Depending on the size of the holes, the observers either ignored them as artifacts, or considered them an inherent part of the material, with varying thresholds similarly to that for the transmitted radiometric values. Besides, a need for an objective opacity metric that will be well-correlated with perception was also revealed. The further shortcoming was the scale resolution and the assumption that all opaque objects belong to the extreme category. Observers have expressed the will to have more categories in between the existing ones - especially, between category 9 and 10, as they considered that 10 steps were not enough to express all opacity differences among the samples. Moreover, we did not give observers an opportunity to differentiate the samples within the opaque category, and this might have biased the result.

Conclusion and Future Work

We have conducted a psychophysical experiment, asking subjects to classify textile samples into opaque and non-opaque categories, and to quantify opacity on a 10-level scale. The task was performed twice - with and without a high illuminance backlight, and the results for the two conditions were compared. While the effect of the backlight is subtle for very transparent and very opaque samples, it is statistically significant for other samples in between the two extremes. Although behavioral patterns and used cues are very consistent among observers, the thresholds where a sample starts to be considered opaque are very subjective. However, the data supports our original proposal that opacity does not imply the complete absence of transmission. As the eventual goal is to build a model quantifying perceived opacity of a textile sample based on its material properties and illumination conditions, one of the future directions is to identify the correlation between perceived opacity and texture properties of the sample. While a few subjects mentioned the impact of color, a systematic study is needed to identify the possible role of colorimetric values in opacity perception. Finally, more diverse samples and a reliable framework for material property measurement are needed in order to build the model. In the future, computer graphics can be used for stimuli generation, to control material properties, on the one hand, and to increase dataset diversity, on the other hand.

References

[1] "CIE 175:2006 A framework for the measurement of visual appearance," International Commission on Illumination, 2006, 92 pages.

[2] Christian Eugène, "Measurement of "total visual appearance": a CIE challenge of soft metrology," in *12th IMEKO TC1 & TC7 Joint Symposium on Man, Science & Measurement*, 2008, pp. 61–65.

[3] "ASTM E284-17 standard terminology of appearance," ASTM International, West Conshohocken, PA, 2017.

[4] Davit Gigilashvili, Jean-Baptiste Thomas, Jon Yngve Hardeberg, and Marius Pedersen, "Behavioral investigation of visual appearance assessment," in *Color and Imaging Conference*. Society for Imaging Science and Technology, 2018, pp. 294–299.

[5] Roland W Fleming and Heinrich H Bülthoff, "Low-level image cues in the perception of translucent materials," *ACM Transactions on Applied Perception (TAP)*, vol. 2, no. 3, pp. 346–382, 2005.

[6] Bei Xiao, Bruce Walter, Ioannis Gkioulekas, Todd Zickler, Edward Adelson, and Kavita Bala, "Looking against the light: How perception of translucency depends on lighting direction," *Journal of Vision*, vol. 14, no. 3, pp. 17–17, 2014.

[7] TH Morton, "Opacity and obscuring power of textile fabrics," *Journal of the Textile Institute Transactions*, vol. 56, no. 5, pp. T260–T273, 1965.

[8] Abbas Hajipour, Ali Shams Nateri, and Alireza Sadr Momtaz, "Estimation of fabric opacity by scanner," *Sensor Review*, vol. 34, no. 4, pp. 404–409, 2014.

[9] Yonghui Zhao and Roy S Berns, "Predicting the spectral reflectance factor of translucent paints using kubelka-munk turbid media theory: Review and evaluation," *Color Research & Application*, vol. 34, no. 6, pp. 417–431, 2009.

[10] H Brody and RG Quynn, "Measurement of opacity in fibers," *Textile Research Journal*, vol. 35, no. 6, pp. 524–529, 1965.

[11] Jean-Baptiste Thomas, Aurore Deniel, and Jon Y Hardeberg, "The Plastique collection: A set of resin objects for material appearance research," *XIV Conferenza del Colore, Florence, Italy*, p. 12 pages, 2018.

[12] Haris Ahmad Khan, Sofiane Mihoubi, Benjamin Mathon, Jean-Baptiste Thomas, and Jon Yngve Hardeberg, "Hytexila: High resolution visible and near infrared hyperspectral texture images," *Sensors*, vol. 18, no. 7, 2018.

[13] "Color input targets," *Technical Data/Color Paper. Kodak publication No. TI-2045*, 2003.

[14] Quinn McNemar, "Note on the sampling error of the difference between correlated proportions or percentages," *Psychometrika*, vol. 12, no. 2, pp. 153–157, 1947.

[15] Fabio Metelli, "The perception of transparency," *Scientific American*, vol. 230, no. 4, pp. 90–99, 1974.

[16] Fabio Metelli, "Stimulation and perception of transparency," *Psychological Research*, vol. 47, no. 4, pp. 185–202, 1985.