Contextual effects in human gloss perception

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Abstract

The well-known simultaneous contrast effect describes how surrounding surfaces influence lightness perception. Similar contextual effects are ubiquitous in the lightness literature. Contextual effects in gloss perception however, have not yet been studied intensively. Here, we describe two distinct studies that investigate the role of spatial interactions between different glossy materials. In a first study we produced real surfaces that contain two different materials and compared perceived gloss in two conditions: in isolation and in context with a second material. Our results provide strong evidence that the context largely influences perceived gloss. Gloss ratings of identical materials differed depending on the presentation mode. In a second study we wished to quantify the strength of these contextual effects using Maximum likelihood conjoint measurement. We used glossy versions of the simultaneous contrast display and again found strong influences of albedo and gloss of the surroundings on perceived gloss and lightness. Both studies hint towards a profound influence of the context on perceived gloss. Investigating spatial interactions between materials within a scene has largely been studied in the lightness literature but only received moderate attention in the gloss literature. Our results provide confirmatory evidence that perceived gloss is shaped by other materials in the scene.

Introduction

On a daily basis we interact with a multitude of different materials that we can effortlessly identify. We add labels to the material's physical qualities like soft, hard, shiny, matte, for example. These labels are based on the visual appearance and the visual system's estimation of the underlying physical properties. However, mathematically visual perception is a highly underconstrained problem. The amount of light reaching our eye depends on the reflectance properties of the material, the illumination in the scene and the object's geometry. Estimating the intrinsic properties of materials requires a disambiguation of these different factors from one another. Perceived gloss is shaped by the illumination [1, 2, 3, 4, 5, 6], the shape of the object [7, 8, 9, 10, 11], the color of the object [12, 13] and many other features. However, gloss perception research broadly neglected the importance of the spatial context and the information available to the participant when confronted with a more complex scene. Spatial interactions and the role of the context have only been studied on matte and flat surfaces that do not contain any specular reflections [see 14 for an overview]. Many visual illusions are based on spatial interactions between different surface patches. The simultaneous contrast is a textbook example that shows how perceived lightness of a single surface patch changes with the surroundings. Objects humans interact with on a daily basis are often made out of various materials. Therefore, we attempt to study the contextual effects on perceived gloss of objects that are made from multiple materials. Contextual effects in gloss perception have not been studied intensively. Fleming [2] showed that perceived gloss is invariant to changes of the background. Doerschner et al. [15] however, showed that spray-painted glossy spheres appear glossier when presented in front of a black background, in contrast to a presentation in front of a white background. In the two current studies we investigate the effects of multiple materials on perceived gloss and attempt to quantify these effects using Maximum likelihood conjoint measurement (MLCM) [16]. MLCM has been successfully applied to investigate contributions of lightnes and chroma on color perception [17], to study the watercolor effect [18] and the influences of mesotexture on perceived gloss [19, 8]. In the first study we make use of a well-known phenomenon called contrast gloss [20, 13]. Darker surfaces appear glossier than lighter colored surfaces although the strength of their specular reflections is the same. Surfaces that are constructed by combining two different colors should therefore, also exhibit differences in perceived gloss within a single surface. These two different percepts might influence each other or they are entirely independent. In the second study we attempt to quantify the strength of contextual effects using MLCM. We will make use of simultaneous contrast displays that provide spatial interactions in lightness perception and attempt to investigate similar effects for the perception of gloss.

Study 1

Material & Methods

Stimuli

Based on a mathematically well-defined model, we produced molds that we cut out from polymer foam by the use of a CNC machine (see Figure 1a). These objects served as molds for a thermoforming machine. Surfaces were flat plastic sheets that were heated up inside the machine and then stretched onto the molds to take up their shape profile (Figure 1b). These plastic surfaces were then spray-painted using 5 different shades of gray based on the RAL color matching system (see Figure 1).

Figure 1. *Stimuli construction. (a) Surfaces were first carved from polymer foam using a CNC machine. (b) These molds were later used in a vacuum-forming machine to create the plastic surfaces. Plastic surfaces were spray-painted in either a single color (c) or with two colors side by side (d). Figure reproduced from [22].*

The different shades of gray were selected by comparing RAL color samples to a Kodak gray scale that contained 20 different shades of gray in perceptually uniform steps. Based on a comparison of RAL color samples and the Kodak gray scale we selected 5 shades. The differences between these five shades were approximately equal. We used five gloss levels for each shade of gray, which resulted in a total of 25 different surfaces (Figure 1c). Each gloss level was carefully selected so that perceived differences in gloss between each level were perceptually equal. The selection of the corresponding gloss levels was based on data from a Maximum likelihood difference scaling experiment performed by [21]. Additionally, we spray-painted surfaces that contained two different colors side-by-side (Figure 1d). We combined two different shades of gray with the same gloss level. As mentioned in the Introduction, we expect perceptual difference in gloss between these two different colors. In total we used 4 different combinations of gray levels for each gloss level resulting in 20 additional bicolored surfaces. Due to the production process each surface contained some additional material on the outside, which was covered by a black light-absorbing velvety frame.

Apparatus and procedure

Surfaces were presented in a 1 × 1 × 1 m light box and illuminated homogeneously from above. Each surface was presented one-by-one inside the box in an upright position. A black velvety curtain covered all walls inside the box. Observers were instructed to rate the gloss of the surface on a scale from 1 to 7. Each subject passed three different conditions: In the first condition the unicolored surfaces were presented only. In a second condition observers were asked to rate the global gloss of the bicolored surfaces and in a third condition observers were asked to rate either the left of the right half of all bicolored surfaces. Before the beginning of the experiment observers saw the white matte and the glossiest black surface as examples of both extremes on the rating scale. Observers could take as much time as needed to respond. All responses were collected on a paper response sheet.

Observers

We collected data from 11 observers in total (7 female, age between 24 and 35). All experiments were done in agreement with the local ethics committee from TU Delft and the Declaration of Helsinki.

Results

The main goal of this study was to investigate whether gloss perception differs when materials are presented in isolation vs. when materials are presented in context with a second material.

Unicolored surfaces

Our experimental design is based on the effect that darker colored materials are perceived as glossier in comparison to lighter colored materials. We first plot the results from rating a unicolored surface to verify this effect. These results can then be directly compared to the results obtained from bicolored surfaces. Figure 2 plots gloss ratings against the five different gloss levels separately for each surface color.

A repeated-measures ANOVA with two within-subjects factors (surface color and gloss level) verified that gloss ratings were significantly affected by the surface color, $F(4, 40) = 15.17$, $p < 0.001$, and gloss ratings were affected by the physical gloss of the paint, $F(4, 40) = 290.5$, $p < 0.001$. Furthermore we found a significant interaction between surface color and gloss level, $F(16, 160) = 7.598$, $p < 0.001$.

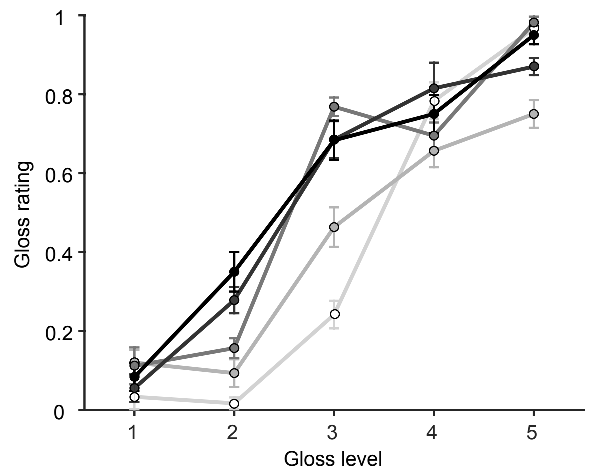

Figure 2. *Results from rating gloss on unicolored surfaces. Gloss ratings are rescaled from 0 and 1 and plotted against the five different gloss levels. Each color corresponds to one of the five surface colors. Gloss ratings are averaged across all observers ± 1 SEM. Figure reproduced from [22].*

Gloss averaging

In a second condition observers were asked to rate the overall gloss of the bicolored surfaces. Perceived gloss of each of the two colors should be taken equally into account when estimating the overall gloss. We compared perceived gloss of the bicolored surfaces to the average gloss ratings from the unicolored surfaces of the two corresponding colors (predicted gloss). Perceived gloss was well predicted by the individual gloss ratings: The slope (b = 1.01) was statistically tested against 1 with a one-sample t-test and did not deviate significantly from 1, $t(18) = 0.11$, $p = 0.91$.

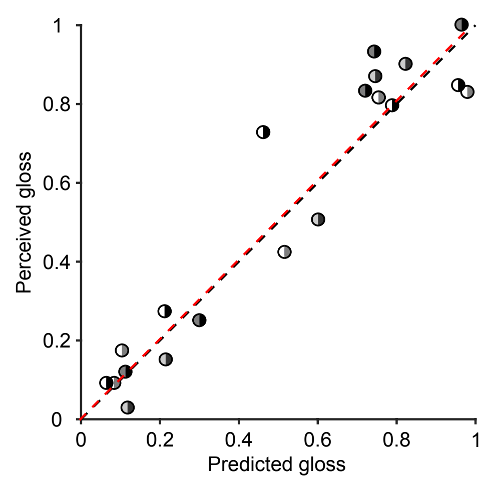

Figure 3. *Results from the gloss-averaging task. Perceived gloss of all bicolored surfaces is plotted as a function of predicted gloss. Predicted gloss is calculated based on the results from rating gloss on the two corresponding unicolored surfaces. Figure reproduced from [22].*

Contextual effects

The main question of this study was to test whether gloss ratings of the identical material change when these materials are presented in context with an additional material on the same surface. Figure 4 plots gloss ratings in context against the gloss ratings obtained from the same material but when presented in isolation. The upper diagram corresponds to all color combinations in which a lighter colored material is rated next to a darker colored material and the lower diagram corresponds to all ratings of a darker material presented next to a lighter colored material. Data points below the identity line correspond to the reduced ratings in the context condition and data points above the identity line correspond to an increase in perceived gloss in the context condition. Overall, gloss ratings of lighter colored materials were reduced when these materials were presented next to a darker colored material. The slope of the regression line deviated significantly from 1 (slope: b = 0.72): $t(18) = 4.87$, $p = 0.001$. However, gloss ratings of the darker colored materials were unaffected by the presence of a lighter colored material (slope of regression line: b = 1.04): $t(18) = 0.62$, $p = 0.55$.

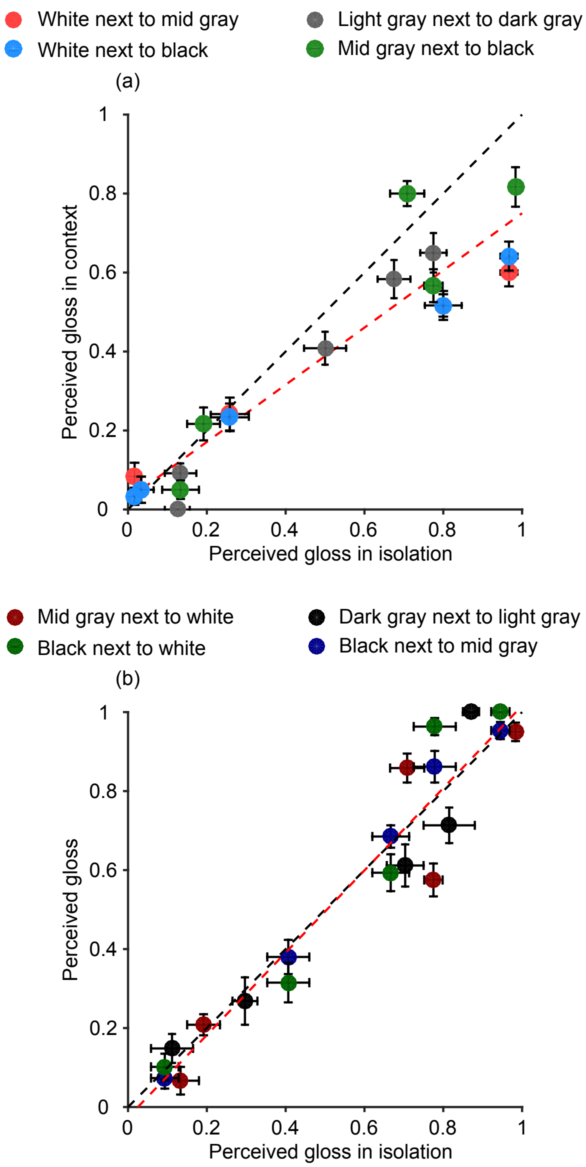

Figure 4. *Results from all observers judging gloss on bicolored surfaces. Perceived gloss in context is plotted against the ratings obtained from the corresponding material, but when presented on a unicolored surface. Each colored data point corresponds to one color combination on the surfaces. (a) Plots all color combinations in which gloss of a lighter colored surface is rated next to a darker colored surface. (b) Plots all color combinations in which a darker colored surface is rated next to a lighter colored surface. Figure reproduced from [22].*

Discussion

In the current study we investigated the contextual effects on a single surface containing two different materials. We found a gloss contrast effect showing that perceived gloss is reduced when a glossier material is spatially attached to the estimated surface patch. The reduction of perceived gloss is caused by the second material that is on the same surface. A possible explanation of this effect is that observers do not only rate one half of the surface and instead take the larger context into account. Observers might use the context as additional information to make their final judgment. Their estimation of gloss is a consequence of a relative judgment of both sides of the surface.

These results present the first evidence of spatial interactions on glossy surfaces. We also showed similar contrasting effects presenting photographs of surfaces to our observers [22]. We applied a simple rating task to estimate perceived gloss. A rating experiment does not contain any information about the strength of the contextual effect. To gain further insight into the strength of the contextual effects, we will implement a maximum likelihood conjoint measurement procedure in the second study.

Study 2

Material and Methods

We attempt to quantify the influential strength of the context, both for albedo and gloss. Again, we analyze the spatial interactions of different materials. Maximum likelihood conjoint measurement (MLCM) simultaneously estimates the influence of two different features on a single perceptual judgment. If two features (e.g. surface properties like mesotexture, gloss, or albedo) are manipulated simultaneously and observers are asked to judge one of the two features, we can precisely capture whether the second, the unattended feature, contaminates the judgment of the first feature.

Stimuli

Stimuli were glossy bumpy versions of the well-known simultaneous contrast display. We varied albedo and gloss of the background surface while keeping the central part the same. A frontoparallel plane was distorted along the z-axis to create a bumpy, rocky surface. We used three different images (3 different shapes) of Perlin noise as a displacement map. The luminance of the pixels in the Perlin image determined the height of the surface. The surface was then smoothed in the open-source software Blender (Blender 2.74) using the built-in smooth operator. All surfaces were rendered under the same “Uffizi” environment map [23]. Renderings were based on a Microfacet model using GGX for the microfacet distribution function and the Smith function to describe the shadowing and masking [see 23 for details]. We used the mixed shader with 90 % diffuse and 10 % gloss. We manipulated the width of the specular lobe to obtain five different gloss levels and varied the strength of the diffuse reflection to obtain five different albedos. The albedo of the surface ranged from dark to light gray. The central patches of the simultaneous contrast display were kept constant having a mid gloss, mid gray material. Figure 5 shows one example of a typical SC display. These manipulations resulted in 75 images in total (3 shapes × 5 gloss levels × 5 albedos).

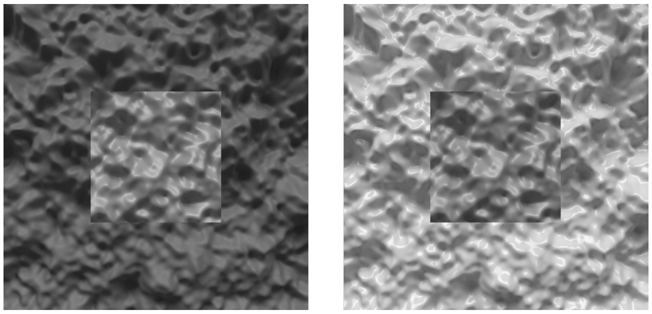

Figure 5. *Simultaneous contrast display used in the study Figure reproduced from [28].*

Apparatus and procedure

Each trial started with a fixation-cross displayed for 200 ms. Afterwards the observer was presented with two surfaces in succession. Surfaces were presented for 500 ms with a 200 ms inter-stimulus interval. After each trial observer's were encouraged to indicate which central patch appeared lighter (Experiment 1) or glossier (Experiment 2). The next trial began after pressing one of the response buttons. Each experiment consisted of 900 trials in total (300 different stimulus pairs × 3 repetitions) and lasted for about 45-60 minutes.

Images were displayed on a 24-inch calibrated LED monitor (Viewsonic V3D245) with a linearized gamma. The resolution was set to 1920 × 1080. All stimuli were displayed using Matlab R 2010a and Psychtoolbox-3 [25] that ran on a MAC Pro Quadro-Core Intel Xeon with OSX 10.5.8.

Observer

We conducted two experiments. In the first experiment observers were asked to judge the lightness of the central patch and in the second experiment observers were asked to judge the gloss of the central patch. 6 observers (Experiment 1: 4 female, age between 25-34; Experiment 2: 3 female, age between 25-35) participated in each of the experiments.

Analysis

Maximum likelihood conjoint measurement enables us to investigate the contribution of two separate features simultaneously on a single perceptual judgment. In the current study we varied the albedo and the gloss of background surfaces and investigated their influence on perceived lightness and gloss. Our data was analyzed using the MLCM package [26] in the open source software R [27] to estimate the weights and to model the contribution of albedo and gloss. We used the same procedure as described in [8] and [28]. The procedure is reproduced here for the reader's convenience. We describe the procedure based on an experiment in which gloss of a surface is judged. MLCM considers three different models: The independent model predicts that perceived gloss is only influenced by the gloss of the surface but independent of the surface albedo. The additive model predicts that the irrelevant dimension albedo can influence perceived gloss but the strength of this contamination is independent of the surface gloss. The third model, the full model predicts that the influence of the irrelevant dimension lightness is influenced by the gloss of the surface. This requires an additional interaction factor.

Each of the two presented surfaces is defined by its gloss level φ_i^g, φ_k^g and its lightness level φ_j^l, φ_l^l. Perceived gloss ψ^g depends on the gloss of the surface and maybe also on the albedo of the surface:

$$\psi_{ij}^{g} = \psi_{i}^{g} + \psi_{j}^{l} \quad (1)$$

The difference between both estimates is then computed:

$$\Delta(i, j, k, l) = \left(\psi_{i}^{g} + \psi_{j}^{l}\right) - \left(\psi_{k}^{g} + \psi_{l}^{l}\right) + \varepsilon \quad (2)$$

in which ε describes an unbiased normally distributed judgment error: $\varepsilon \sim N(0, \sigma^2)$. This corresponds to the additive model. In each trial the difference in gloss and lightness between the two surfaces is computed. If the surface albedo has no influence on the gloss judgment, the independent model is sufficient to describe the data:

$$\Delta(i, j, k, l) = \psi_{i}^{g} - \psi_{k}^{g} + \varepsilon \quad (3)$$

If the additive model (Eq. 2) is not sufficient to describe the data, results can be modeled using the full model that allows for additional interactions:

$$\Delta(i, j, k, l) = \left(\psi_{i}^{g} + \psi_{j}^{r} + \psi_{ij}^{gr}\right) - \left(\psi_{k}^{g} + \psi_{l}^{r} + \psi_{kl}^{gr}\right) + \varepsilon \quad (4)$$

All three models can be tested against each other using a likelihood ratio test. The interesting and novel aspect of our study is, that in contrast to other MLCM experiments [8], the primary dimension is not pre-determined. Both features of the background can equally influence the judgment of the central patch.

Results

In this study albedo and gloss of the central patch were held constant. Therefore, any deviation from the dashed line (Figure 6) must be caused by the background surface. Figure 6 plots the weights from fitting an additive model to our data. Figure 6a shows the results from the first experiment. Here observers were asked to judge the lightness of the central patch. Although the albedo of the central patch was constant, observers are influenced by both, the albedo and the gloss of the background. As expected from the well-known simultaneous contrast, the center appears lighter when it is surrounded by a dark background (light blue line in Figure 6a). Moreover, we found that glossy backgrounds reduce the strength of the simultaneous contrast (blue line). We performed a nested hypothesis test to verify the significance of this contamination and rejected the independent observer model for 5 out of 6 observers (at the Bonferroni-corrected p-level, 5 out of 6 observers: $p < 0.001$, 1 observer: $p = 0.57$). Figure 6b shows the weights from the additive model based on the data from Experiment 2. In Experiment 2 observers were asked to indicate which center appears glossier. Although the central patch was identical, gloss judgments were influenced by the albedo and the gloss of the background. Darker backgrounds lead to a glossier appearance of the center. The contribution of the gloss of the background on perceived gloss of the central patch was more complex and asymmetric. Matte backgrounds decrease perceived gloss of the central patch, whereas glossy backgrounds have almost no effect on perceived gloss of the center.

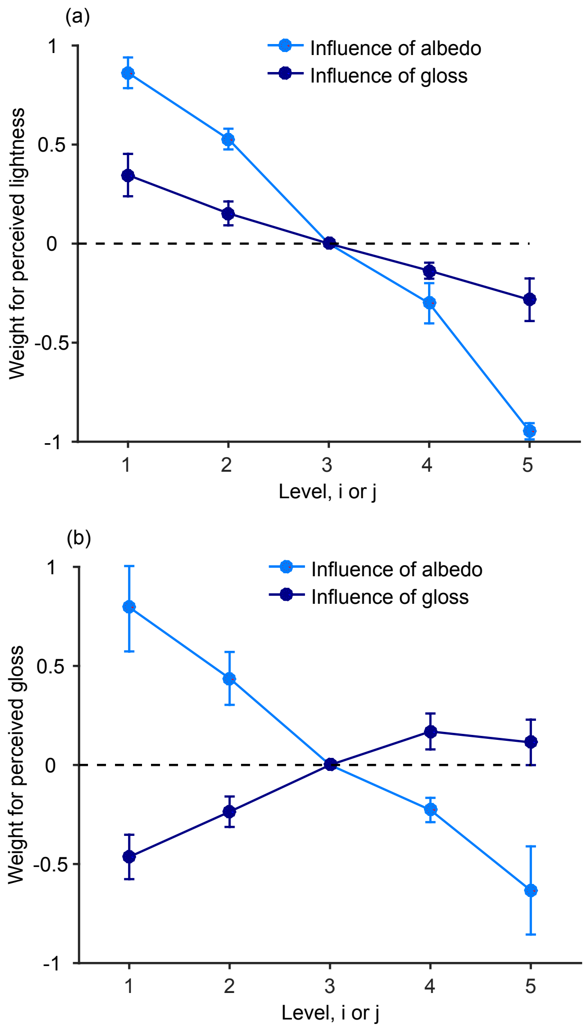

Figure 6. *Results from Experiment 1 and 2. Estimated perceptual scale values or weights from fitting an additive model to the data. The light blue line corresponds to the influence that the albedo of the background has and the dark blue line corresponds to the influence that the gloss of the background has. (a) plots the weights obtained for the first experiment in which the lightness of the central patch is judged. (b) plots the weights obtained for the second experiment in which the gloss of the central patch is judged. Figure reproduced from [28].*

As mentioned before, the contamination of the unattended feature can be independent of the attended feature (additive model) or the contamination should be modeled using an interaction factor (full model). A nested hypothesis test confirmed that for most observers the additive model is sufficient to describe the data: Experiment 1: 5 out of 6 observers: ns; 1 observer: $p < .001$; Experiment 2: 5 out of 6 observer: ns; 1 observer: $p < .001$. Therefore, we retain the simpler additive model.

Discussion

The results from the present study confirm our results from the first study. Additional materials in spatial vicinity influence perceived gloss (and lightness). In comparison to the last study we explicitly quantified the strength of the contextual effects.

Perceived lightness was influenced by the albedo and the gloss of the background. Glossy backgrounds reduce the strength of the simultaneous contrast and thus, increase lightness constancy. Our results do not indicate whether improved lightness constancy is caused by the gloss per se or by the articulation of the background. Bright specular highlights on the background surface increased the overall luminance range of the image. Future experiments could rotate the highlights on the surface and present these modified backgrounds to the participant. Rotating the highlights will decrease perceived gloss on the surface [29, 30, 31]. However, the luminance histogram and the overall luminance range of the background remain unchanged by the rotation.

Similar to perceived lightness also the perceived gloss of the center varied with gloss and albedo of the background. A dark background enhances perceived lightness of the center but, simultaneously, increases perceived gloss. The lighter appearance of the center entails a lighter appearance of the highlights in that area. The perceived luminance range of the center shifts towards higher values. This shift is additive, similar to the shift of the luminance range that [14] describes as additive haze or glare. Similar to what we have observed in the first study, the effect of gloss of the contextual surface on perceived gloss of the target is asymmetrical. Our analysis has shown that maximum likelihood conjoint measurement is well suited to investigate contextual effects.

Conclusions

As described in the Introduction, multiple sources of information contribute to perceived gloss. To our knowledge our studies are a first attempt to investigate the role of spatial interactions between different glossy materials. The final percept of a material in a scene is not only shaped by its own material properties but also by additional information provided from other materials in the scene. The reduction of perceived gloss in the first study for example, can only have originated from the second material. The final percept seems to depend on a comparison with the second material before finally answering. We presumed that other materials in the spatial vicinity of a target surface provide the visual system with additional information about the scene characteristics. In natural scenes additional materials might be used as references and judgements are based on a comparison between materials.

Altogether the results of our studies hint towards a profound role of the context when estimating the gloss of a surface. Moreover, we explicitly point towards the importance of investigating spatial interactions between materials within a scene. This has largely been studied in the lightness literature but only received moderate attention in the gloss literature. Although the origin of the contextual effects need further investigations, we can clearly state that perceived gloss (and lightness) is highly dependent on the material and information in the direct vicinity.

Ackmowledgments

This work represents a component of the doctoral thesis of S. Hansmann-Roth and part of it has been published recently [22, 28].

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Author Biography

Sabrina Hansmann-Roth studied Biology at the University of Tü*bingen (Germany). She received her PhD in Psychology from the University Paris 5 in 2016 on the topic of gloss perception. She is mainly interested in material perception and currently a postdoctoral researcher at the Icelandic Vision Lab at the University of Iceland working on the visual representation of statistical variations in artificial displays and natural scenes.*

Sylvia Pont graduated in Experimental Physics in 1993 at Amsterdam University. She did her PhD in 1997 at Utrecht University. From 1997 to 1999, she studied computer aids at an institute for visually disabled people. Next, she returned to Utrecht University to investigate ecological optics. In 2008, she transferred her group and equipment to Delft University of Technology. Here she coordinates the perceptual intelligence lab (p-lab), Department of Industrial Design Engineering of Delft University of Technology and was appointed Anthonie van Leeuwenhoek Professor in 2016. Her group's research includes studies into design, perception, and *optics of light and materials, considering the physical and perceptual interactions between objects' shapes, materials, and light.*

Pascal Mamassian is the director of research at the CNRS in France. He received his PhD from the University of Minnesota and worked in Tübingen (Germany), New York (USA), and Glasgow (UK) before becoming the head of the Laboratoire des Systèmes Perceptifs at the Ecole Normale Supérieure, Paris. His research interests span a variety of aspects of visual perception and he has published over 70 research articles.