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Perceptual Qualities of Optically Mixed Materials

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ABSTRACT
We present a novel setup in which real objects made of two different materials can be mixed optically in a linearly weighted manner. We conducted a psychophysical experiment in which observers rated optical mixtures of the three combinations of glossy, matte, and velvety green birds. The observers rated the materials on four scales: matte–glossy, hard–soft, cold–warm, and light-heavy. The judgments were found to be consistent and varied systematically with the weights of the contributions.

Keywords
Material perception, qualities, ecological optics, magic

1. INTRODUCTION
Natural materials cover a wide range of mutually very different optical properties[1, 3]. However, it has been suggested that they can be categorized into roughly a dozen types of canonical modes on the basis of their bidirectional surface scattering or BRDF (for this paper we do not con- sider spatial texture). The lobes of the Bidirectional Re- flectance Distribution Function may be described by their average direction, e.g. in the illumination direction (backscattering or retroreflection [4]), roughly in the specular direc- tion (forward scattering or specular reflection [3]), distributed over all directions (diffuse scattering [3]), along the surface (asperity scattering [3]) or perpendicular to it. This primary scattering direction is associated with certain visual characteristics or modes of material appearance, for instance for- ward scattering with glossy-/shiny-/specularness and diffuse scattering with matteness. The BRDF of generic materials typically consist of several of such lobes, e.g. a peach BRDF

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may contain a diffuse and a surface lobe, resulting in a com- bination of a matte and a velvety mode. Since the primary scattering direction is different for these modes, the salient features of the appearance modes usually show up at differ- ent locations too. Thus, similarly to descriptions of BRDFs as linear superpositions of scattering lobes, we can describe the appearance of 3D objects consisting of any materials as linear superpositions of 3D objects of different canonical ma- terials, e.g. a glossy object as the superposition of a specular and a matte object.

We are particularly interested in the perception of mate- rial qualities that are important for interaction with objects. Karana [2] inventorized perceptual properties of materials that are important for interacting with products. She found the following list: color intensity, colorfulness, ductility, elasticity, glossiness, hardness, odour, reflectiveness, roughness, strength, transparency, warmth and lightness. In our experiment we will study a selection of this list.

2. EXPERIMENT

2.1 Methods
We made a setup to optically mix two objects in a lin- early weighted manner, see figure 1. It consists of a black square box with 30 cm ribs in which we put a vertical semi- transparent optical mirror. The mirror was placed diagonally in the box, that is, at 45 degrees with respect to the viewing direction. One of the objects was seen through the mirror. The other object was seen via the reflection in the mirror. The objects were lined up symmetrically with respect to the mirror to superpose them. The illumination apertures consisted of 6 cm by 6 cm square openings in the top of the box, under which we affixed 6 cm long light baffles in order to prevent light from one side of the mirror to reach the object on the opposite side. The box was put in a Ganzfeld (fully diffuse light field). The stimuli in the box are viewed by way of a 50 cm long 15 cm wide black tube. The stimuli were optical mixtures of three objects of the same shape but finished with different materials: birds with matte green paint, with glossy green paint and with a green flock finish (the matte, glossy and velvety bird, respectively), see figure 2. The green color was matched via the RAL system (the matching is messed up in the photography, in the setup

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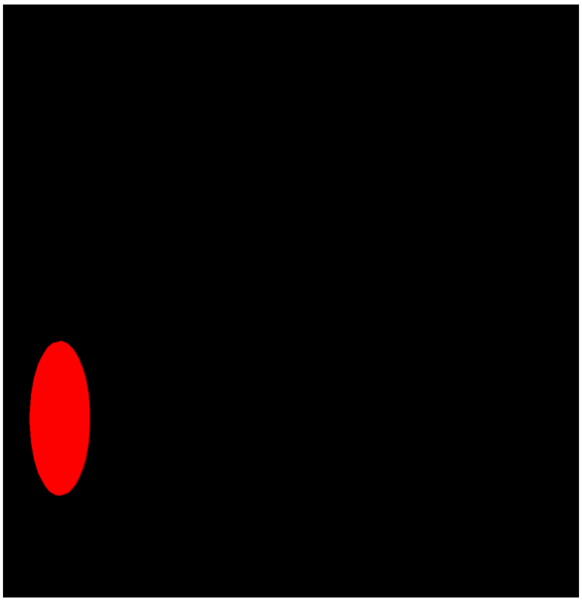

Figure 1: A topview of the inner part of our setup. The setup consists of a box of 30x30x30cm, of which the inside is covered by black flocked paper. A semi- transparent mirror was placed vertically at the diagonal of the box - the reflection at the upper side of the mirror is clearly visible. The red ellipse depicts the viewing hole in the box (since the setup is viewed through a tube made of black flocked paper it was not visible in the photograph).

Figure 2: The glossy (left), the velvety (centre), and the matte (right) birds.

the colors did match to the human eye). The luminance of the two objects was equalized; to this aim we had to attenuate the contribution from behind the mirror with a 0.5 neutral density filter (NDF). The weights of the two contributions were varied by way of NDFs of various densities over the lighting openings in the box. We ran psychophysical experiments in the equalized condition and with NDFs of 0.5, 1 and 2 (corresponding with attenuation factors of 3.16, 10 and 100, or "weights" of 0.32, 0.1 and 0.01, respectively), resulting in 7 weighted combinations for each of the three material pairs. Thus we obtained 21 settings altogether. Participants did three repeated ratings in randomized block order. The ratings were collected using preprinted scales representing the matte-glossy, hard-soft, cold-warm and light-heavy dimensions on which the observers could indicate their rating by drawing a mark.

2.2 Results

We find very consistent results for the extreme (NDF 2) conditions (see figure 3 at the additional pages for aver- aged results), in which the object without the filter was extremely dominant. In these cases the primarily matte bird was judged to be rather average on all scales, the primarily glossy bird was judged to be extremely glossy, very hard, very cold and a little heavier, and the primarily velvety bird was rated to be quite matte, soft, warm and of average weight. We found the ratings to vary systematically as a function of the weights, see figure 4. The average ratings for the four properties correlated (R^2 range 0.74–0.92).

3. DISCUSSION

We constructed a novel type of setup with which we can optically mix real stimuli. Clear advantages of this setup are that we can use real objects (so that dynamic range and resolution are not an issue) and still vary their material properties in a very systematic way. Furthermore, the setup allows for a wide range of other possible manipulations, e.g. mixing objects and scenes / contexts and mixing different lighting settings. We are currently exploring various applications.

Superpositions of objects do not correspond to interpolated optical properties, such as linear combinations of BRDF's (e.g. matte plus shiny is assumed to represent glossy). This is due to interreflections [4] (at the micro-, meso- and macroscales!). Thus, the optically mixed stimuli cannot simply be considered as physical mixes. Instead, they should be considered as "painterly mixes" of the most salient features of the two components, for instance white highlights on the glossy green bird, smooth shading over the matte green bird and white contours on the velvety bird (the main characteristic of asperity scattering [3]).

We found robust and systematical results that vary according to the weights of our optical mixtures. Thus, our novel setup works as it is supposed to. Observers commented that they thought we actually presented birds made of varying materials and varying lighting. Another interesting finding is that our optical mixtures covary consistently in perceived glossiness, softness, warmth and heaviness, even though the latter three are properties that are not directly related to the optical properties.

4. ACKNOWLEDGMENTS

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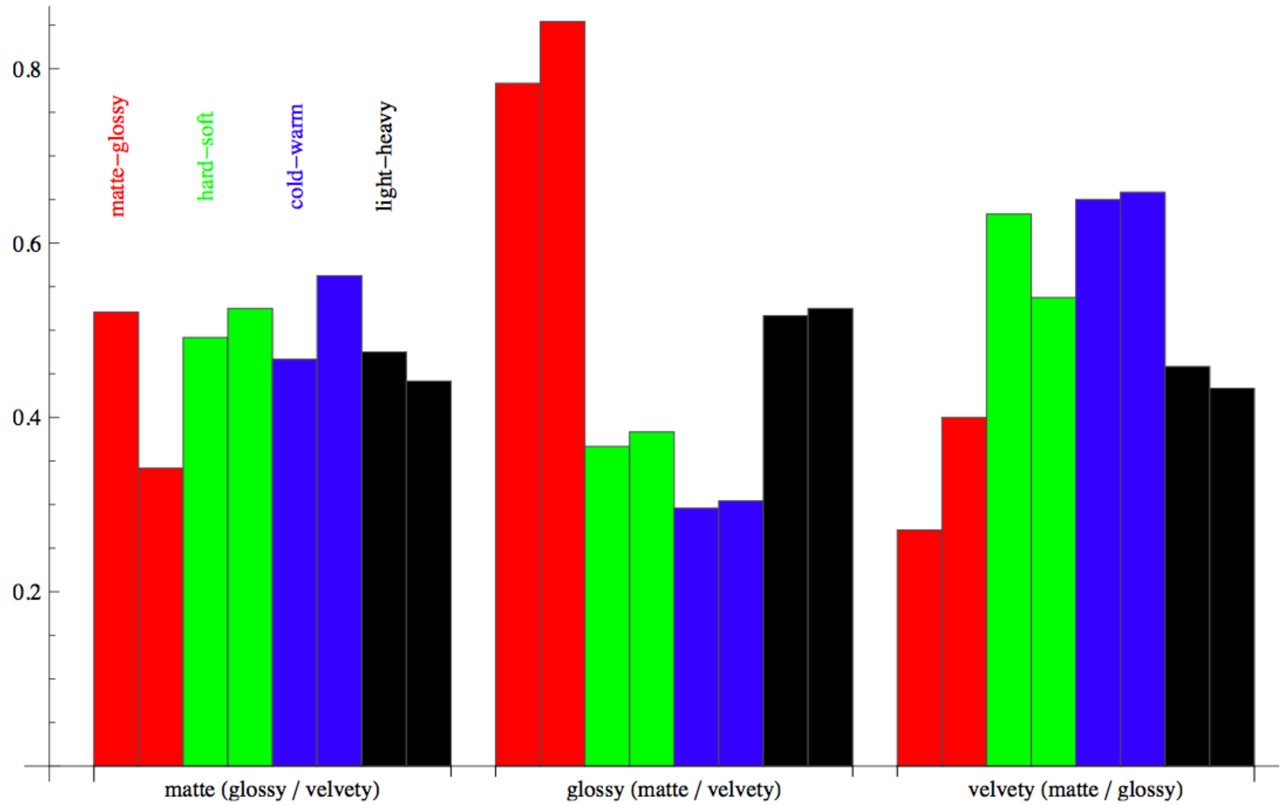

Figure 3: A bargraph of the average ratings for the NDF 2 cases. The different colors depict the ratings for the different properties, on a normalized range (of 0 to 1), with red for matte-glossy, green for hard-soft, blue for cold-warm and black for light-heavy ratings. The three main clusters represent the conditions in which, from left to right, the matte, glossy and velvety birds were dominant (no NDF or weight 1.0). For each rating we show two bars, representing the two possible object combinations (the second materials or the severely attenuated objects with weight 0.01 are noted between brackets below the graph). Note that in some cases the two bars differ, indicating an influence of the 100 times attenuated object.

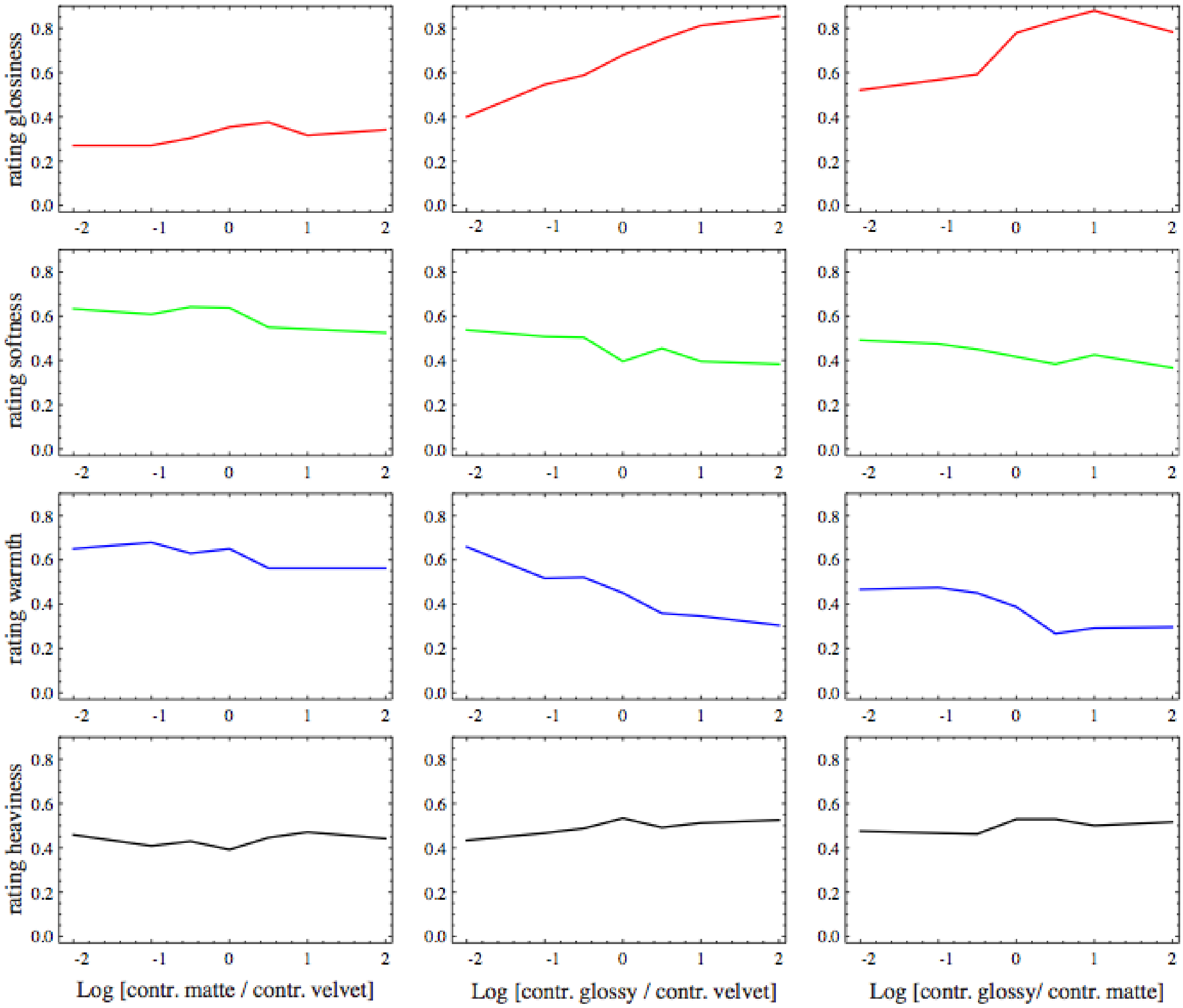

Figure 4: The average ratings (on a normalized range of 0–1) as a function of the difference between the NDF values, for the velvety – matte (left column), the velvety – glossy (centre column), and the matte –glossy (right column) birds combinations. The rows depict, from top to bottom, the ratings on the matte – glossy, hard – soft, cold – warm and light – heavy properties.