Perceived glossiness in high dynamic range scenes

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We investigated how spatial pattern, background, and dynamic range affect perceived gloss in brightly lit real scenes. Observers viewed spherical objects against uniform backgrounds. There were three possible objects. Two were black matte spheres with circular matte white dots painted on them (matte-dot spheres). The third sphere was painted glossy black (glossy black sphere). Backgrounds were either black or white matte, and observers saw each of the objects in turn on each background. Scenes were illuminated by an intense collimated source. On each trial, observers matched the apparent albedo of the sphere to an albedo reference scale and its apparent gloss to a gloss reference scale. We found that matte-dot spheres and the black glossy sphere were perceived as glossy on both backgrounds. All spheres were judged to be significantly glossier when in front of the black background. In contrast with previous research using conventional computer displays, we find that background markedly affects perceived gloss. This finding is surprising because darker surfaces are normally perceived as glossier (F. Pellacini, J. A. Ferwerda, & D. P. Greenberg, 2000). We conjecture that there are cues to surface material signaling glossiness present in high dynamic range scenes that are absent or weak in scenes presented using conventional computer displays.

Keywords: surface gloss perception, high dynamic range, HDR, glare, effect of background, Gelb effect, lightness, color, surface material perception, illusory gloss

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Introduction

Beginning with Ullman (1976), researchers have sought to characterize the factors that lead the visual system to classify bright regions in a scene as self-luminous, i.e., light sources. Both the brightness and relative size of a region within the visual image alter the probability that it will be judged as self-luminous and the dynamic range of the scene in itself provides information about the possible presence of light sources (Bonato & Gilchrist, 1994, 1999; Gilchrist & Radonjić, 2009; Speigle & Brainard, 1996).

Light sources are also marked by spatial patterns of light referred to as "bloom" and "flare"—forms of glare—that are the result of optical scattering by the cornea, lens, and retina of the eye and diffraction in the cellular structure of the lens (Spencer, Shirley, Zimmerman, & Greenberg, 1995; Vos, 2003). This scattered light reduces contrast and detection ability in the vicinity of glare sources (veiling or disability glare; Stiles, 1929; Stiles & Crawford, 1937). Diffraction artifacts, caused by light diffracting from eyelashes when looking into a bright light source or reflection, are another potential cue to distinguish light sources in a scene.

The characteristic appearance of bloom and flare can alter the apparent brightness of a possible light source (Spencer et al., 1995) as illustrated in the reproduction of the oil painting[1] by Carl Saltzmann portraying Potsdamer Platz (Berlin) illuminated by electrical lighting shown in Figure 1. No region of the painting is self-luminous, but the characteristic spatial patterns of bloom and flare (see insets) that the artist has added enhance the illusion of a scene containing light sources.

Since a specular highlight can serve as a light source, the dynamic range of a scene or presence or absence of bloom, flare, or related phenomena in a scene is potentially a cue to surface gloss. Visual phenomena associated with gloss such as "*contrast gloss*—perceived relative brightness of

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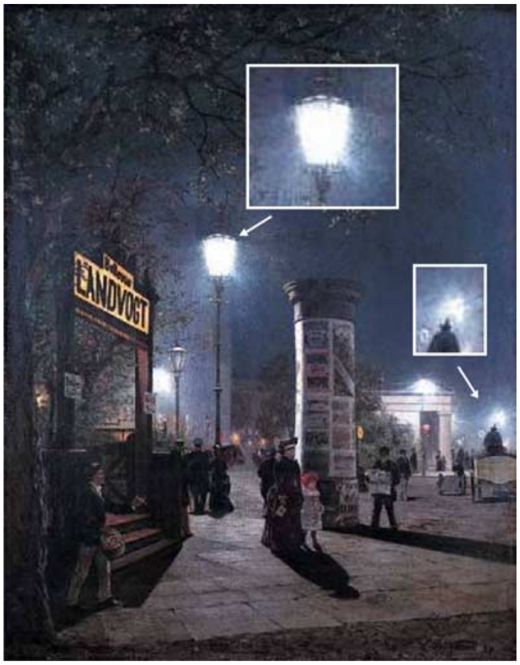

Figure 1. An oil painting of electrical street illumination in Postdamer Platz, Berlin. Carl Saltzmann, 1884. By permission. Museumsstiftung Post und Telekommunikation, Berlin. Two magnified details are inserted, illustrating how the artist portrayed bloom and flare lines. In scenes with actual light sources, bloom and flare are consequences of optical scatter within the eye. Bloom corresponds to the apparent blurring of the light source by convolution with a point spread function (Vos, 2003). There are separate contributions to bloom from light scattering in the cornea, lens, and retina. Flare refers to the apparent radial lines that are likely due to patterned variations of refractive index in the human lens (Spencer et al., 1995).

specularly and diffusely reflecting areas"—or "*specular gloss*—perceived brightness associated with the specular reflection from a surface" (Pellacini, Ferwerda, & Greenberg, 2000, referring to Hunter & Harold, 1987)—may also vary substantially depending on dynamic range.

In this article, we report an experiment in which we varied the background of a simple, achromatic scene illuminated by an intense collimated light source. We evaluated the perceived glossiness of surfaces in the scene. Our goal was to produce illusory *gloss* by creating a plausible spatial arrangement of small matte white dots on black matte spheres and then to vary the albedo of the background from black to white to produce the extreme contrast between dark and bright regions necessary for glare to occur. We compared perception of gloss in scenes containing only matte surfaces to perception of gloss in scenes containing a glossy black sphere.

This background manipulation also serves to test a conjecture by Fleming, Dror, and Adelson (2003; see also Hartung & Kersten, 2002) that the perceived gloss of an object is not affected by the background against which it is presented. Experimental and computational studies of gloss perception typically omit consideration of possible effects of the background on which stimuli are presented, both virtual (Motoyoshi, Nishida, Sharan, & Adelson, 2007) and real (Obein, Knoblauch, & Viénot, 2004). Indeed, if perceived gloss were in fact independent of background, then it would greatly simplify development of algorithms that could predict the degree of gloss assigned to any surface in a scene (e.g. Motoyoshi et al., 2007). We test whether this is true.

Almost all previous studies on gloss perception have employed rendered surfaces displayed on conventional CRT or LCD monitors (Berzhanskaya, Swaminathan, Beck, & Mingolla, 2005; Blake & Bülthoff, 1990; Fleming et al., 2003; Ho, Landy, & Maloney, 2008). Beck and Prazdny (1981) and Obein et al. (2004) are exceptions. Typically, objects displayed this way during psychophysical experiments do not exceed luminances of about 100–200 cd/m^2 and the dynamic range of such devices is considerably less than that of natural scenes. In natural scenes, the dynamic range of the scene can exceed the dynamic range of the human visual system when light sources are present in the visual field.

Moreover, it is scarcely surprising that glossy surfaces in rendered scenes presented on typical display devices do not appear very glossy if *high dynamic range cues* to glossiness such as glare are absent. Because of these, it is not clear whether the results of previous studies are applicable to real-world high dynamic range scenes. Here we sought to investigate how spatial pattern, background, intensity, and dynamic range affect perceived gloss in brightly lit real scenes.

We report one main experiment and, in two appendices, three further experiments testing specific aspects of the results of the main experiment.

Methods

Stimuli

Stimuli were three spheres 40 mm in diameter. Two spheres were matte black (acrylic paint, albedo ~0.05, Krylon Ultra Flat Matte spray paint), with either a 1-mm or 2-mm (diameter) circular matte white dot painted (acrylic paint, albedo ~0.8) on them. The edges of the white dots were sharp, not graded. We refer to them as the 1-mm *matte-dot sphere* and the 2-mm *matte-dot sphere* for convenience. The third sphere (the *glossy black sphere*) was produced by coating a black matte sphere with a glossy finish. Note that due to the limited transmissiveness of the coating material this sphere was darker than the two matte-dot spheres. Spheres were mounted on thin matte black rods for convenience. Two backgrounds (84.1 cm × 59.4 cm) were cut from flocked black paper (albedo ~0.05) and white matte paper (albedo ~0.7).

Layout

Spheres were positioned 353 cm away from the observer (visual angle of 0.64 degree), 13 cm in front of the background (see Figure 2). A collimated light source (halogen, 12 V, 20 W, 850 lumen) was placed to the left of and approximately 89 cm in front of the sphere, pointing directly at it. The shadow of the sphere fell on the lower right corner of the background, and the sphere and its shadow did not overlap when viewed from the observer's position. The light source illuminated only the spheres and background and was otherwise invisible, hidden in a black box. Except for this light source, the experimental room was dark during the matching part of the experiment.

Procedure

Observers were led into the room (lights on). They were shown examples of a glossy sphere (Christmas ornament, 60 mm in diameter) and a black matte sphere (80 mm in diameter) with a painted white dot. These objects were not used in the actual experiment. Observers were told that they would see both types of spheres in the experiment and that their task would be to match the gray level (albedo) and gloss level of the displayed sphere to reference scales presented on a computer display. They were then shown examples of the scales for albedo and the scales for gloss (rendered using Ward's (1992) model) used in matching (Figure 3A). The laptop display was placed 33 cm in front of the observer and was slightly elevated.[2] The reference stimuli on each scale were numbered. Observers responded by naming numbers aloud to the experimenter.

At the beginning of the experiment (lights off), the observer placed his head in a chin rest and one

Figure 2. An overview of the experimental setup. See text for dimensions and details.

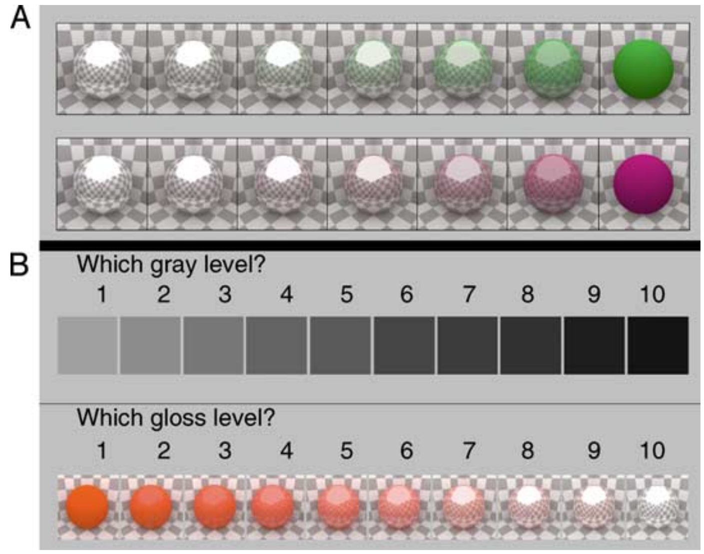

Figure 3. (A) Glossiness familiarization scales. Prior to the experiment, observers were shown examples of the kind of matching scales that they would encounter during the experiment. These scales were ordered—from most to least glossy—and contained objects of different colors and less entries than matching scales in the actual experiment. They also saw corresponding familiarization scales for surface albedo (not shown). (B) Experimental matching scales for surface albedo and gloss. The color of the glossy matching spheres was deliberately chosen to be different from achromatic, in order to make it easier for the observer to focus on gloss apart from albedo. The scales are shown in increasing order of albedo and glossiness, respectively. The albedo and gloss scales used in the actual experiment were randomly reordered from trial to trial.

experimenter held a black opaque board in front of the observer's eyes, such that the observer could not see the experimental scene. The restriction of head motion was crucial to eliminate possible motion cues to specular reflections.[3] The board blocked the observer's view of the test area. Stimuli were viewed monocularly to avoid possible stereo cues to specular highlights (Blake & Bülthoff, 1990).

At the beginning of each trial, the board blocking the observers' view of the stimulus was removed. Observers first matched the albedo and then the gloss level of the stimulus against the black background using the albedo and gloss scales in Figure 3B. For the *gloss matching task,* observers were instructed to disregard the surface color of the test and matching spheres. The order of the elements in both matching scales was randomized on each trial (Figure 3B). Observers completed six trials (3 spheres × 2 backgrounds), performing the two matching tasks on each trial. They then repeated all judgments with the black background replaced by the white.

After the experimental trials, the observer was asked to watch as something would happen in the scene and to describe later what—if anything—had changed. One experimenter moved the white background slowly behind the sphere, progressively covering the black background. This procedure was repeated as many times as the observer desired. The other experimenter took notes of the observer's verbal report as the new background was inserted and afterward.

Observers

Eleven NYU graduate students and postdocs participated in the experiment. None was aware of the purpose of the experiment. All had normal or corrected-to-normal vision and gave written consent prior to the experiment.

Results

Perceived glossiness

We first tested whether the matte-dot spheres and the glossy black sphere were perceived as glossy (and not matte) using a one-sample *t*-test. The gloss scale values for all three spheres on both the black and white backgrounds were significantly greater than matte (which corresponds to a scale value of 1) at the 0.05 level (1-tailed) or lower (Figure 4A). Surprisingly, all three spheres matched reference spheres near the midpoint of the gloss scales and both of the matte-dot spheres were rated to be more glossy than the actual glossy sphere but not significantly so. On the black background, the two matte-dot spheres were not perceived as significantly different in gloss from each other and the glossy sphere. On the white background, however, the 1-mm dot matte sphere was perceived as significantly more glossy than the glossy sphere ($t(20) = 2.95$, $p = 0.0136$, $alpha = 0.05$ (0.0167, *correcting for multiple comparisons*), 1-tailed).

Effect of background albedo on perceived glossiness

We then tested whether changing background from white to black affected the perceived gloss of the glossy black sphere and the matte-dot spheres. The glossy black sphere and the 2-mm matte-dot sphere were both perceived as significantly more glossy when presented in front of the black background than when presented in front of the white background (glossy sphere: mean difference between backgrounds: 2.4; $t(10) = 3.239$, $p = 0.004$, 1-tailed; 2-mm matte-dot sphere: mean difference between backgrounds: 1.8; $t(10) = 2.192$, $p = 0.026$, 1-tailed). The 1-mm matte-dot sphere was not significantly glossier on the black background though the trend is similar to that for the two other spheres (mean difference between backgrounds: 0.9).

Perceived albedo

We first determined whether the three spheres differed in perceived albedo (Figure 4B). On both the black and white backgrounds, both matte-dot spheres were not perceived as significantly different from each other and were, however, perceived as significantly (and correctly) higher in albedo than the glossy sphere (for $t(20) = 3.9445–9.1753$, $p = 0.0004–0.00001$, $alpha = 0.05$ (0.0167, *correcting for multiple comparisons*), 1-tailed).

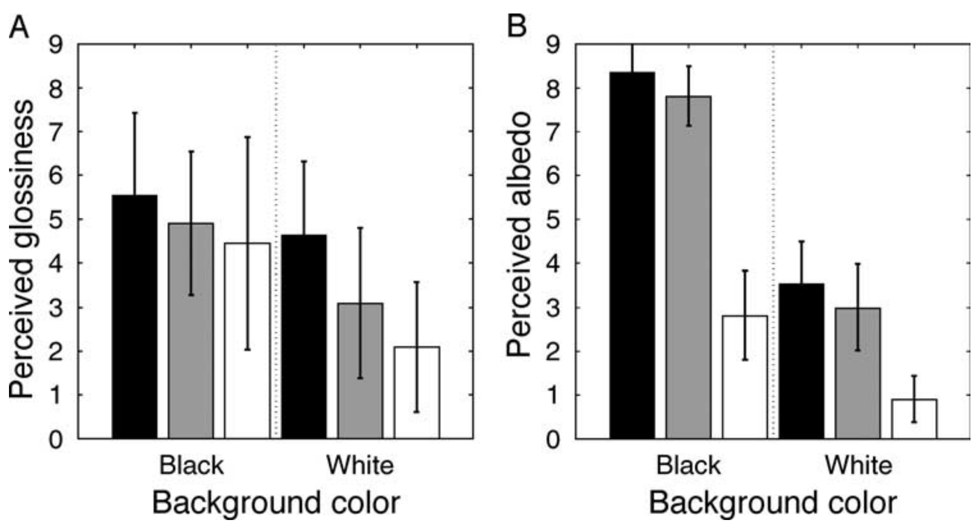

Figure 4. (Left) Results for perceived gloss. Black: 1-mm matte-dot sphere; Gray: 2-mm matte-dot sphere; White: black glossy sphere. Error bars are twice the standard error. (Right) Results for perceived albedo.

Effect of background albedo on perceived albedo

As expected, all three spheres were perceived as significantly lighter in albedo when presented in front of the black background than when presented in front of the white background (1-mm matte-dot sphere: mean difference between backgrounds: 4.8; $t(10)$ = 18.286, p = 0.0001, 1-tailed; black 2-mm matte-dot sphere: mean difference between backgrounds: 4.8; $t(10)$ = 11.404, p = 0.0001, 1-tailed; glossy sphere: mean difference between backgrounds: 1.9; $t(10)$ = 4.869, p = 0.0003, 1-tailed). The effect was less pronounced for the glossy sphere.

Observer verbal reports

In order to get a more detailed account of the background and illusory gloss effects, one experimenter moved the white background slowly behind one of the illusory glossy spheres, replacing the black background, as the observer watched. All observers reported that the sphere appeared to change from a light gray to a much darker shade of gray, and that the sphere also appeared to become duller, less glossy as the white background was introduced behind it. After turning the lights on in the room, and bringing the stimulus closer to the observer, so that he could see the sphere under ordinary illumination conditions, all observers were surprised to find that they had been looking at a matte sphere with a white dot painted on. None of the participants in the experiment were able to differentiate actual and illusory gloss under the conditions of the experiment.

Discussion

We examined perception of surface gloss in scenes consisting of matte and glossy achromatic spheres against an achromatic background. The matte spheres were black with a small white circular dot (matte-dot spheres). We illuminated part of the scene with an intense neutral collimated light source and examined how the visual system assigns graded surface material descriptors such as "glossiness" to the spheres. We varied the albedo of the background, which effectively altered the dynamic range of the scene. Any effects of bloom or flare—forms of glare due to light scatter and diffraction in the optics and retina of the human eye—were physically correct.

Classic Gelb effect

It is well known that in sparse settings as in ours the gray level of the background influences the perceived albedo of matte surfaces placed in front (Gelb, 1929; Gilchrist, 1977, 1994; Katz, 1935). Using 3D surfaces, we found that changes in background affected perceived albedo as expected (Figure 4B). Interestingly, for this type of surface material the effect is less pronounced than for matte surfaces. As noted above, the glossy sphere was darker than its matte counterparts. Hence, the weakened effect of background could be due to a floor effect. In future experiments, one could first match the perceived albedos of both matte and shiny objects (as in, for example, Xiao & Brainard, 2008), and then proceed to systematically study the effect of background luminance on the perceived albedo of glossy objects.

Illusory gloss

Under our experimental conditions—high intensity illumination, far distance, monocular viewing, restriction of head motion—matte-dot spheres were perceived to be as glossy as the real glossy sphere. That is, when one of the matte-dot spheres was presented, the visual system interprets the sphere as glossy although there is evidently a physically correct interpretation of the scene with the matte-dot spheres interpreted as matte spheres with white dots painted on them, namely the actual object. The photographs in Figure 5 approximate the effect but lacks the dynamic range of the actual scenes presented. The evident bloom in the right-hand picture is attributable to the camera used to record the scene. It is not the bloom or flare experienced by the subjects in the experiment.

Background and glossiness

We find that the perceived glossiness of a surface is influenced by background. Since certain visual phenomena associated with gloss such as "*contrast gloss*—perceived relative brightness of specularly and diffusely reflecting areas"—or "*specular gloss*—perceived brightness associated with the specular reflection from a surface" (Pellacini

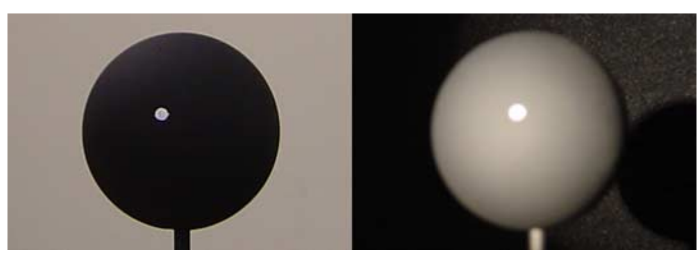

Figure 5. Examples of the stimuli. (Left) The 2-mm matte-dot sphere under ordinary illumination in front of the white background. (Right) The same sphere under experimental light conditions with black background (where matte-dot spheres appeared glossiest). Note that the highlight region appears now bigger due to veiling glare.

et al., 2000, referring to Hunter & Harold, 1987)—vary substantially depending on background and the associated change in dynamic range of the scene, the result is not unexpected.

However, some aspects of the result are surprising. One might predict that by surrounding the apparently glossy object with a white background the object may appear darker, and hence the perceived local *contrast gloss* may increase. However, our data indicated that the opposite occurred—spheres in front of the white background, though perceived as darker, appeared in fact less glossy. Why? There are several possible explanations. (1) It may be that the white background led to a compression of the perceived dynamic range in the scene,[4] and thus a possible reduction in glare and perceived glossiness. (2) Alternatively, it could be possible that the perceptual grouping of the highlight with the white background overrode the effect of the perceived decrease in albedo. This outcome suggests that both *contrast gloss* and *specular gloss* (Hunter & Harold, 1987) are affected by the object's background. This *Gelb Gloss Effect* is analogous to the classic Gelb Effect: a black paper is seen as white. Here, a matte surface is seen as glossy, and perceived glossiness varies with the introduction of a white background. The test spheres, glossy and matte, never looked matte on either background. (3) A third alternative explanation stems from previous research on the relation between luminance and relative area and self-luminosity thresholds (Bonato & Gilchrist, 1994, 1999; Gilchrist & Radonjić, 2009). According to the results of these studies, two factors could influence the self-luminosity threshold. First, as the relative area of the brighter surface in a simple scene decreases, the probability that it will be perceived as self-luminous increases. Second, for a surface to attain self-luminosity threshold, its luminance should be at least about twice of that of a surface perceived as white in the scene. In our black background scenes, the highlights—illusory or real—satisfy these two conditions.

When the white background is introduced, however, the degree to which the highlights are perceived as self-luminous decreases, because now the highlights are only slightly brighter than the white surface in the scene. This in turn could lead to a decrease in perceived glossiness of the spheres.

Open questions

We have shown that manipulations of background in very simple scenes can dramatically alter the perceived glossiness of surfaces. Further research is needed to assess how the spatial structure of the stimuli, changes in the dynamic range of the scene, the visibility of the spatial patterns associated with flare and bloom, and other cues that signal light sources are affected by background and in turn affect perceived gloss. It is plausible that the effect depends on the spatial structure of the matte objects themselves (the added white dots). We conjecture that, under the conditions of our experiment, the white matte dots on the black matte spheres were interpreted as glare sources by the visual system and the surfaces themselves as glossy.

The compelling demonstrations of Fleming et al. (2003) suggest a natural conjecture, that *only* the mean albedo of a background—and not its higher order image statistics—affects the perceived gloss of objects presented against that background. However, in backgrounds containing a range of albedos (and, once illuminated, a range of luminances) the rules determining how background affects perceived gloss may prove to be complex.

Not surprisingly, there is more to gloss perception than can be captured on a typical display device. Further research is needed to determine how the spatial structure of the object affects perceived gloss in stimulus configurations similar to ours (Fleming et al., 2003).

Appendix A

Control Experiment 1

In this control experiment, we wished to demonstrate that the scaling method used in the main experiment could reveal observers' gloss perception at a variety of gloss levels. Using a matte sphere, a glossy sphere, and a high-gloss sphere, we asked the observers to match glossiness and albedo as in the original experiment, and then asked the observers to sort the spheres in their gloss levels, and checked whether these two judgments were consistent with each other.

Methods

Stimuli

Stimuli were three spheres 40 mm in diameter. The first sphere was matte black (acrylic paint, albedo ~0.05, Krylon Ultra Flat Matte spray paint, same paint as in the original experiment). The second sphere was painted with a black glossy spray paint. The third one was the glossiest sphere, painted with a black glossy spray paint and then finished with an additional transparent glossy coating. One black background cut from flocked black paper (albedo ~0.05, same as in the original experiment) was used (see Figure A1).

Layout

Spheres were positioned 258 cm away from the observer, 20 cm in front of the background (see Figure A2). A pin-spot light source, built by us using a halogen lamp (50 W) and a lens system, was placed 60 cm to the right of

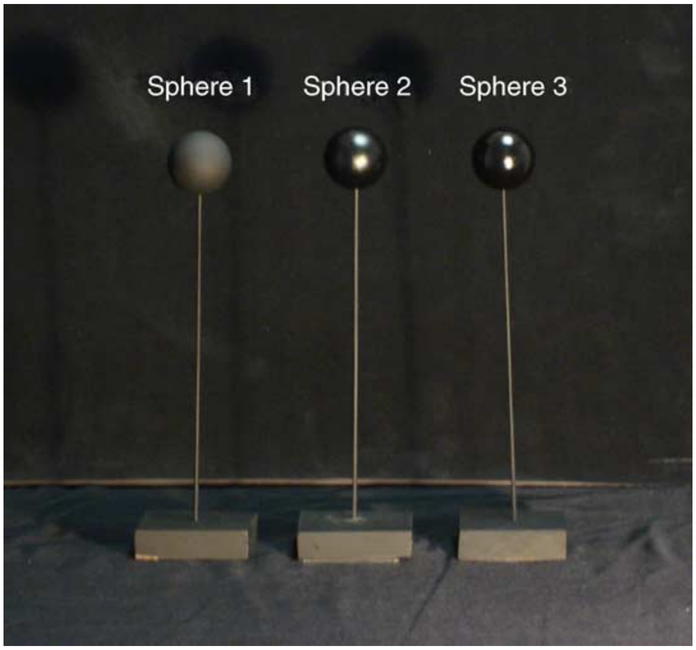

Figure A1. The stimuli. Three spheres used in Control Experiment 1 under normal room illumination. The spheres were all black, without a matte dot or other surface feature. They differed in glossiness.

and 160 cm in front of the sphere, pointing directly at it. The shadow of the sphere fell on the lower right corner of the background, and the sphere and its shadow did not overlap when viewed from the observer's position. The light source illuminated only the spheres and background and was otherwise invisible, hidden in a cardboard box. Except for this light source, the experimental room was dark during the matching part of the experiment.

Experimental software

The experimental software for the matching task was programmed using the Java platform. In each trial, a single adjustable matching stimulus was shown on the computer screen (either an albedo matching patch or a gloss matching sphere). Observers were able to adjust the albedo or gloss level of the matching object by pressing the up and down arrow buttons on the keyboard and finalize their decisions by pressing the space bar. The matching stimuli were otherwise identical to those used in the original experiment.

Procedure

Observers were led into the room (lights on). They were shown samples of a glossy object (a shiny telephone handset) and a white matte sphere (40 mm in diameter) both under normal room light and under the pin-spot light. These objects were not used in the actual experiment. Observers were told that they would see both types of surface material in the experiment and that their task would be to match the gray level (albedo) and gloss level of matching stimuli presented on a computer display placed right in front of them. They were then asked to perform the task on the sample objects until they fully understood the task. The experimental software randomized the order of spheres to be presented to the observers and specified the experimenters which sphere should be used in each trial. The rest of the procedures were similar to the original experiment, except that there were only three albedo and gloss level judgments, because we used only one type of background in the control experiment. In the end of the session, we showed observers all three spheres and asked to order them in gloss level.

Observers

Six Bilkent University students (graduate and undergraduate) and employees (research assistants and engineers) participated in the experiment. None was aware of the purpose of the experiment. All had normal or corrected-to-normal vision and gave written consent prior to the experiment.

Results

In the verbal description, all observers judged the third sphere as the glossiest and first sphere as the most matte. Quantitative results, shown in Figure A3, are consistent with this subjective measure. As the plots clearly demonstrate, perceived glossiness increases from first sphere to third sphere, and perceived albedo follows the opposite pattern. We further tested whether the differences in the results are statistically significant using a one-tailed t-test. For the gloss level judgments, we found that Sphere

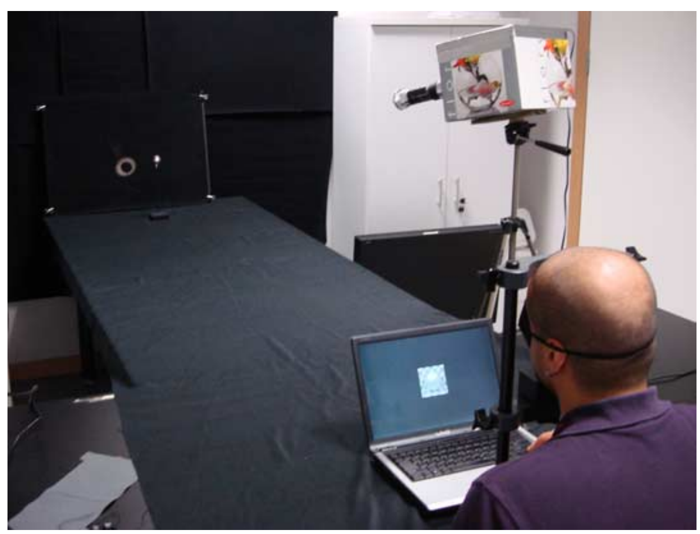

Figure A2. Experimental layout for the control experiments. The layout is photographed with normal room illumination. During experiments, normal room illumination was extinguished and stimuli were illuminated only by the pinpoint light source (upper right).

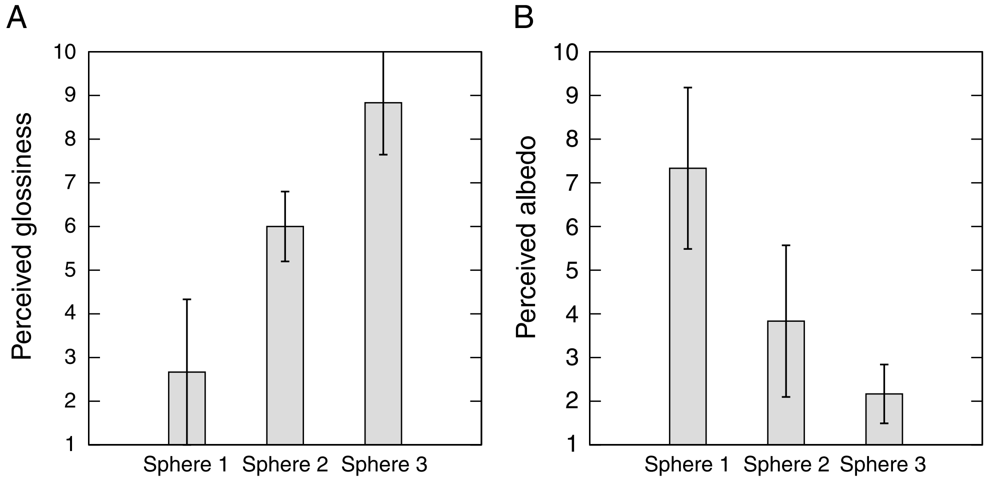

Figure A3. Results of Control Experiment 1. (A) Perceived glossiness. (B) Perceived albedo. The error bars mark 2 standard errors of the mean. All differences are significant at alpha 0.05 level.

2 was perceived significantly glossier than Sphere 1 (p = 0.00136), and Sphere 3 was perceived significantly glossier than Sphere 2 (p = 0.00074). For the albedo judgments, we found that Sphere 1 was perceived significantly lighter than Sphere 2 (p = 0.0064), and Sphere 2 was perceived significantly lighter than Sphere 3 (p = 0.03914).

Control Experiment 2

To further test the conclusion that a black matte sphere with a white dot painted on it is indeed perceived as glossy under the specific illumination conditions of our experiment, we conducted a second control experiment to investigate whether a black matte-dot sphere was perceived as significantly glossier than a matte sphere.

Methods

Stimuli

Stimuli were three spheres 40 mm in diameter. The first sphere was matte black (same paint as in the original experiment). The second sphere was a black matte-dot sphere (2-mm dot), and the third one, included as a control,

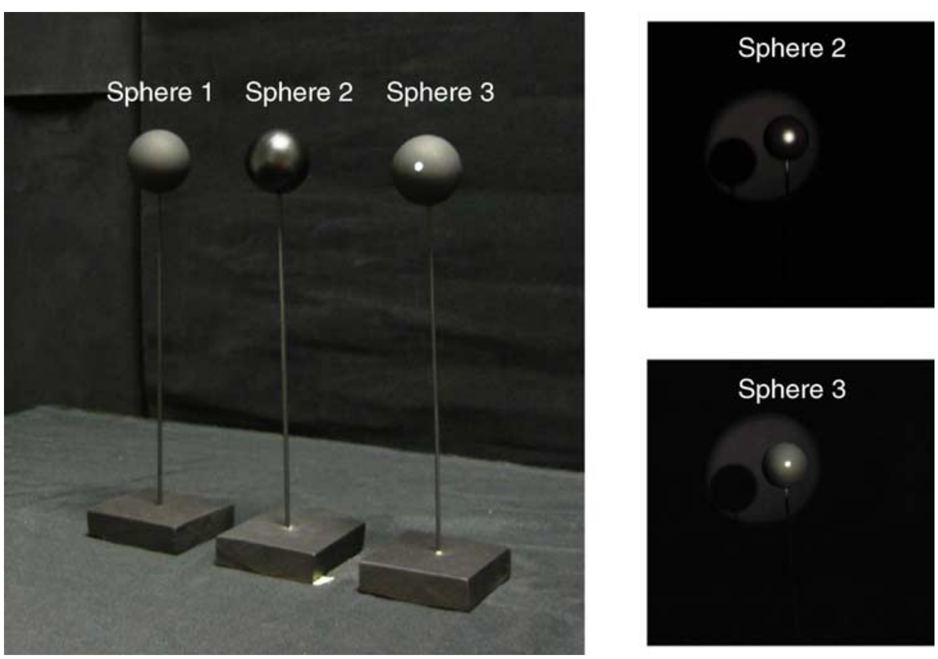

Figure A4. Spheres used in Control Experiment 2 and for luminance measurements.

was the glossiest sphere used in Control Experiment 1. Spheres were presented in front of a black background cut from flocked black paper (same as Control Experiment 1). Figure A4 shows the stimuli under normal and under experimental illumination conditions. Layout, experimental software, and procedure were as in Control Experiment 1.

Observers

Six Bilkent University students (graduate and undergraduate) and employees (research assistants and engineers) participated in the experiment. None were aware of the purpose of the experiment. All had normal or corrected-to-normal vision and gave written consent prior to the experiment.

Results

Figure A5 shows glossiness judgments for all three spheres. As expected, the matte-dot sphere was perceived as significantly glossier than the matte sphere (one-tailed t-test, $p = 0.01237$). Not surprisingly, also the glossy sphere was perceived as glossier than the matte sphere (one-tailed t-test, $p = 0.00778$). We found no difference in perceived gloss between matte-dot and glossy spheres. These results demonstrate that the matte-dot sphere was clearly perceived as glossy.

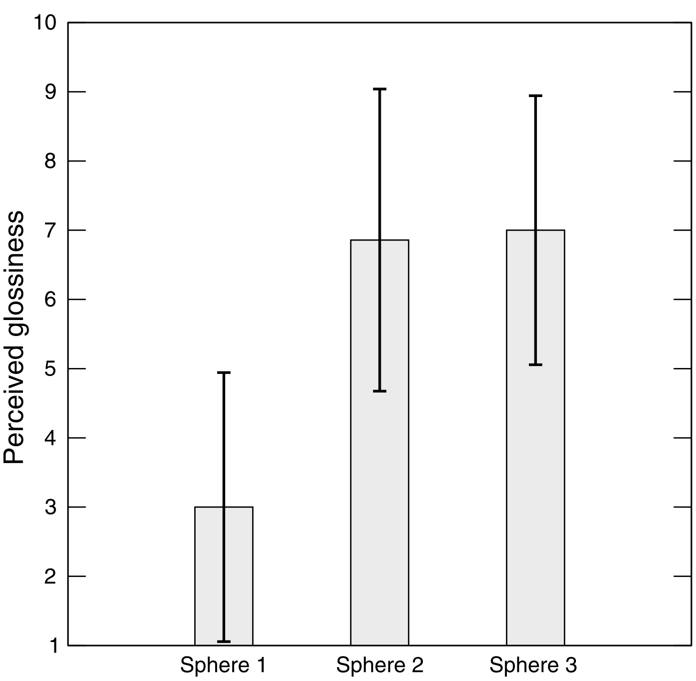

Figure A5. Results of Control Experiment 2. Error bars mark 2 standard errors of the mean. The differences between Sphere 1 and Sphere 2 and between Sphere 1 and Sphere 3 are significant at the 0.05 level.

Appendix B

The data reported in the main experiment were collected at New York University using apparatus that no longer exists. Because we did not perform luminance measurements of the NYU setup, we built a new version of the apparatus at Bilkent University and used it to replicate the basic pattern of results found in the main experiment for conditions where we could accurately measure luminance of surfaces within the scene and calculate dynamic range. For the measurements, we used the three spheres shown in Figure A4. Sphere 1 and Sphere 2 were the same spheres used in the control experiment in Appendix A. Sphere 3 was a black matte sphere (painted with Krylon Ultra Flat Spray paint) with a 4-mm white dot painted on it. The pin-spot light source was 180 cm in front of and 45 cm to the right of the objects. Under these conditions, observers' views of the spheres are shown in Figure A4. Before making the measurements, we qualitatively verified that (1) the white-dot-painted-black-matte sphere appeared indeed as glossy, and that (2) with a white background both the actual glossy and the illusory glossy spheres looked darker and less glossy. To do so, we asked two experienced observers (authors KD and HB) and three naive observers whether the white-dot-painted-black-matte sphere and the actual glossy sphere looked glossy. All observers reported that they perceived both objects as glossy. Then, we asked the observers to report changes in albedo and gloss level (if any) as we changed the background from black to white. All observers reported that the objects looked darker and less glossy with the white background, consistent with our findings in the original experiment.

After the above verification of the original effect, we measured the luminance values of the black and white backgrounds (SpectroCAL USB by Cambridge Research Systems). The luminance of the illuminated part of the white background was 547 cd/m^2, and that of the non-illuminated part was 0.7369 cd/m^2. The luminance of the illuminated part of the black background was 7.286 cd/m^2, and that of the non-illuminated part was 0.06698 cd/m^2. The average luminance of the matte ball (excluding the white dot) was 21.01 cd/m^2. The highest luminance on the matte ball was 28.31 cd/m^2, and the luminance of the white paint was 700.7 cd/m^2. This makes the dynamic range 700.7 to 0.06698, or about 10,000, in the black background condition. The luminance of the glossy sphere (Sphere 2, excluding the highlight) was 2.420 cd/m^2, and that of its highlight was 168.7 cd/m^2. Finally, we also measured the luminance of the glossiest sphere from the control experiment in Appendix A (Sphere 3 in Figure A1). Its luminance was 2.596 cd/m^2, and the luminance of its highlight was 694 cd/m^2.

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Footnotes

[1]We learned of this painting through Spencer et al. (1995).

[2]The laptop was elevated so that the subjects would not see any light from the experimental setup reflected in the tabletop.

[3]As the observer moves, a physically correct highlight will move relative to the object's surface. This motion can be a powerful cue to perceived specularity (Doerschner, Kersten, & Schrater, 2009; Hartung & Kersten, 2002). Thus, eliminating this cue prevents a cue conflict between specular highlight intensity and specular highlight motion for the matte-dot spheres.

[4]Though observers were free to move their eyes, no surfaces other than spheres, and background were visible, hence it is unlikely that anything else in room was perceptually included as "part of the scene". One could argue that if this wasn't the case then the dynamic range would not be changed by the local background manipulation.

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