Highlight disparity contributes to the authenticity and strength of perceived glossiness

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The disparity of highlights on specular reflecting surfaces usually differs from the disparity of the surface points. A. Kirschmann (1895) proposed that this fact may be used as a binocular cue for gloss perception. This was confirmed by A. Blake and H. Bülthoff (1990) who found that subjects judged the glossiness of convex ellipsoidal surfaces as most realistic if the disparity of the highlights was close to the physical correct one. Extending on this finding, we investigate more closely whether the effect of highlight disparity depends on the sharpness of the highlight and the relative amount of diffuse and specular reflection. We measured the effect of highlight disparity on both perceived strength and perceived authenticity of gloss. We used complex, three-dimensional curved surfaces that were stereoscopically presented on a CRT. The reflection characteristics were varied using the Phong lighting model. Highlights were presented either with or without highlight disparity. In a rating experiment, subjects were asked to judge the strength and the authenticity of the perceived surface glossiness. The presence of highlight disparity lead to an enhancement of both the authenticity and the strength of perceived glossiness. The latter finding was confirmed in an additional matching experiment.

Keywords: gloss perception, highlight disparity, specular highlights, binocular vision, complex surfaces

Citation: Wendt, G., Faul, F., & Mausfeld, R. (2008). Highlight disparity contributes to the authenticity and strength of perceived glossiness. *Journal of Vision, 8*(1):14, 1–10, http://journalofvision.org/8/1/14/, doi:10.1167/8.1.14.

Introduction

Gloss belongs to the most fundamental perceptual dimensions of the overall appearance of objects. Empirical evidence suggests that glossiness, as a global surface feature, is elicited by simple local image properties. Many of these cues are already available under monocular viewing conditions and are used, for instance, by painters to evoke the impression of gloss in the beholder. Familiar monocular cues for gloss are the occurrence of local intensity peaks or "specular highlights" (Beck & Prazdny, 1981; Berzhanskaya, Swaminathan, Beck, & Mingolla, 2005; Forbus, 1977) or more complex light patterns on the surface of an object, which are interpreted as the specular reflection of the environment (Adelson, 2001; Fleming, Dror, & Adelson, 2003). Figure 1 demonstrates that monocular cues can evoke a striking gloss impression even in artificial and static displays.

From a phenomenological view, the appearance of glossiness is intimately tied to a segmentation of image intensities into two layers one behind the other, one layer pertaining to the level of the reflecting surface, the other to an illumination dependent component. The latter component is slightly and somehow indeterminately separated in depth from the first one. Due to this layered representation of glossiness, it suggests itself to investigate the role of binocular cues in the triggering of glossy appearances. Because of the reflection characteristics of a glossy surface—which reflects the incident light to a certain degree in a specular manner—and the distance between both eyes, the positions of the highlights are generally shifted relative to corresponding surface points between the two monocular half-images (Blake, 1985; Blake & Bülthoff, 1990; Kirschmann, 1895). Hence, the highlights have a different disparity (highlight disparity) than the surfaces and appear to be located in a different depth plane than the surfaces (Figure 2).

The possible contribution of binocular cues to the perception of gloss has been discussed for a long time. Actually, the starting point of the investigation of gloss as a perceptual phenomenon was, when Dove (1850) first described the phenomenon of stereoscopic luster—the emergence of a gloss impression as a result of discrepant intensity signals between both eyes. The lively discussion which followed after the discovery of this phenomenon resulted in different explanations concerning the role of binocular vision for the perception of gloss, ranging from physiological theories (where stereoscopic luster was assumed to be a simple side effect of binocular rivalry; see Brewster, 1861; and also Anstis, 2000; Burr, Ross, & Morrone, 1986) to psychological approaches in terms of "unconscious inferences" (Oppel, 1854; von Helmholtz, 1867). The idea that disparity information may be used in gloss perception (as depicted in Figure 2) was already mentioned by Ruete (1860) and Wundt (1862). Although

doi: 10.1167/8.1.14 Received June 20, 2007; published January 22, 2008 ISSN 1534-7362

Figure 1. This still-life from Pieter Claesz (1625) exhibits some parts that produce the impression of several materials. Some objects are perceived as glossy. The sphere, for instance, seems to mirror a broad area of the surrounding scene. Also, the intensity peaks on the drinking glass or the inside of the cap of the pocket watch are not simply perceived as luminance textures but as a global surface property, namely to reflect light in a specular manner (reprinted with permission from the Germanisches Nationalmuseum Nürnberg).

this suggestion was picked up by many other researchers (Bühler, 1922; Gräper, 1922; Hering, 1879; Kirschmann, 1895; Zocher & Reinicke, 1925; for a brief overview, see also Harrison, 1945), the amount of empirical work concerning this aspect is sparse.

An early study conducted by Bixby (1928) provided some phenomenological data. The reports of his observers (who were asked to give a phenomenological description of their visual experiences while viewing several gloss samples) often contain remarks that indicate that perceptually a spatial decomposition into a surface layer and a layer of reflected light has taken place.

In a matching experiment conducted by Blake and Bülthoff (1990), computer-generated spheres and ellipsoids were used which featured some depth simulating textures so that the stimuli could be perceived as surfaces with either a convex or a concave curvature. Monocular half-images of these stimuli were haploscopically fused by means of a stereo viewing system. The task of the observers was to maximize the perceived realism of surface gloss by adjusting the relative disparity of a highlight that was presented superimposed on the texture of the surfaces. They found (but exclusively for the convex shaped stimuli) that observers never placed the highlight perceptually on the surface to achieve a realistic gloss impression. Instead, they chose the relative disparities between the monocular highlights roughly as large as real glossy surfaces of the same curvature would produce them.

The results of Hurlbert, Cumming, and Parker (1991), who used similar stimuli to Blake and Bülthoff (1990), but a different task, also indicate that highlight disparity influences gloss perception. However, their data are not fully compatible with the findings of Blake and Bülthoff, because maximal glossiness ratings were obtained, in some conditions, for physically incorrect disparities.

Further findings have been provided by Obein, Knoblauch, and Viénot (2004) and Obein, Pichereau, et al. (2004), who used black-coated papers as stimuli within a pair comparison experiment. They found that the increase in the strength of perceived glossiness with increasing "physical gloss" is larger under binocular viewing conditions for "highly glossy samples." A drawback of the method used by Obein et al. is that it is not possible to compare the absolute strength of the gloss impression under monocular and binocular viewing. In particular, their data do not exclude the possibility that the strength of the gloss impression is lower in the binocular viewing condition.

The goal of the present study was to investigate more thoroughly how the availability of these binocular cues contributes to the triggering of gloss appearances. In contrast to extant studies, we explicitly distinguish between two different kinds of effect: First, it is possible that the availability of highlight disparity influences the perceived realism or authenticity of the gloss impression. This kind of effect is suggested by the results of Blake and Bülthoff (1990). We also considered a second kind of effect that is independent from the first: A change in the strength of perceived glossiness, where increasing the strength of perceived glossiness of a surface means that it is assigned a larger value on a subjective gloss scale. The necessity to distinguish between these two kinds of effect is especially obvious if one compares, for instance, a brushed aluminum sphere with a billiard ball: While these two objects clearly differ in strength of perceived glossiness, they presumably appear equally realistic. Furthermore, we considered another factor that may potentially modulate the influence of highlight disparity: In order to use highlight disparity as a cue, it is necessary to determine the relative position of the highlights. This should be more easily possible for sharp highlights, which leads to the expectation that highlight disparity has a stronger influence for highly glossy surfaces. To allow for such modulating effects, we systematically varied the reflection characteristics of the simulated surfaces.

We conducted two experiments. In the first experiment, the observers viewed stereo-pairs of computer-generated three dimensional surfaces with complex curvatures that either did or did not contain highlight disparity. The rendered surfaces varied in the strength of simulated gloss and the subject had to rate on two separate scales the authenticity and the strength of perceived glossiness of the stimuli. To anticipate our results, we found that the presence of highlight disparity strongly increased the authenticity of perceived gloss. A smaller but systematic increase could also be observed with regard to the strength of perceived glossiness. A second experiment was conducted in order to validate the latter finding. In this experiment the task of the observers was to match the strength of perceived glossiness of two surfaces, one

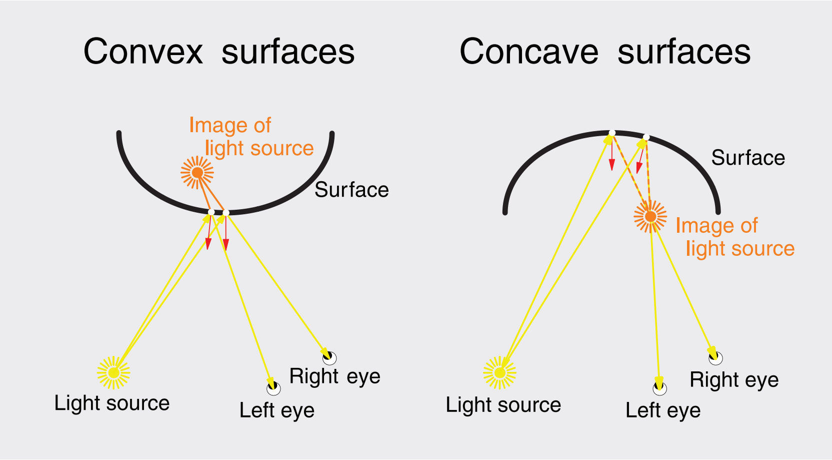

Figure 2. Depending on the curvature of a surface, the mirror image of a light source is perceived in a different depth plane than the surface. Generally, for planar and convex curved surfaces, the perceived location of the mirrored light seems to lie behind the surface; for concave curved surfaces, it seems to lie before it (adapted from Figures 2 and 3 of Kirschmann, 1895).

with and the other without highlight disparity, by adjusting an "objective gloss parameter" in the matching stimulus. In accordance with the result of the first experiment, we found that a stimulus with highlight disparity needs less objective glossiness than a stimulus without highlight disparity to evoke the same strength of perceived glossiness.

General methods

Stimuli and equipment

As stimuli, we used computer-generated surfaces which exhibited complex curvatures (Figure 3). The surfaces had a square base in the x, z plane and the height profile (y-coordinate) was the sum of 15 randomly oriented sinus gratings:

$$y = f(x,z) = \sum_{k=1}^{15} \sin(\pi a_k[x/\lambda + \pi] + \pi b_k[z/\lambda + \pi]). \tag{1}$$

The coordinates x and z varied from $-\lambda/2$ to $\lambda/2$ in steps of 1, where $(\lambda + 1)$ is the number of discrete steps along the x and z axis (λ was 100 in Experiment 1 and 76 in Experiment 2). In Equation 1, a_k and b_k are pseudo-random numbers from the interval $[-4.0, 4.0]$. The size of the object (i.e., each (x, y, z) vector) was scaled with a factor s, which had the values of 0.08 in Experiment 1 and 0.12 in Experiment 2.

In each case, four neighboring vectors built the vertices of one quadrilateral facet of the surface. All stimulus elements were held in an achromatic color (along the space diagonal in RGB color space). The maximum luminance of our monitor was 85.0 cd/m^2. The background was set to relative RGB = (0.75, 0.75, 0.75). The gray scale value of each facet of the surfaces was calculated using the Phong (1975) lighting model. For this purpose, a virtual point light source was placed in the scene, located at (−4.38, 7.85, 4.38). The underlying equation to calculate the grayscale value of each facet of our stimuli was

$$I = k_a + (1-a)k_d \cos(\theta) + a k_s \cos^n(\alpha), \tag{2}$$

where I is the resulting grayscale value between 0.0 and 1.0, k_a is the ambient component with a constant value of 0.6, k_d and k_s are the diffuse and the specular components with a constant value of each 0.4, θ is the angle between the surface normal of the facet and the light source direction, α is the angle between the observer vector and the cardinal direction of reflected light, n is the Phong exponent (which determines the "shininess" of the highlights), and finally, a is a variable that takes values between 0.0 and 1.0 and was used to combine the diffuse and the specular component into a convex mixture (see also Figure 4).

The surfaces rotated around their vertical middle axes at a speed of approximately 45 deg/s; that is, the duration of a complete revolution was 8.0 s. These rotating axes were additionally tilted by 54 degrees towards the observer direction. The reason why we used rotating surfaces as stimuli was twofold: First, the use of non-static stimuli enhances the gloss impression because the highlights never seem to stick on the surfaces (Hartung & Kersten, 2002). Second, by this procedure, we could ensure that the observers were not able to consciously compare the positions of the highlights between the monocular half-images (by alternately viewing one of the half-images). So

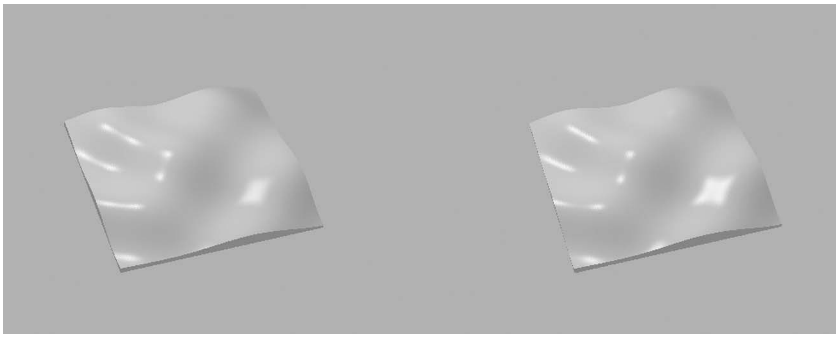

Figure 3. Screenshot of the two monocular half-images of one stimulus, as they were used in the experiments (here reduced in size). During the presentation, the surfaces rotated around their vertical middle axes.

there was no opportunity for the observers to find out in an unwanted way whether or not the stimulus contains any binocular gloss cues.

Our stimuli included two different kinds of disparity: One kind of disparity (surface disparity) was associated with the 3D shape of the surfaces and was produced by using the glFrustum method of OpenGL (see below). The surface disparity was always present. The other kind of disparity (highlight disparity) only concerned the positions of the highlights relative to corresponding surface points between the two monocular half-images. This highlight disparity was one factor subject to variation within our experimental design. To apply highlight disparity to the surfaces, a different observer direction according to the interpupillary distance, and the global arrangement of the scene was fed into the lighting model to generate the monocular half-image for each eye of the observer (note that only the specular component in the lighting model depends on the position of the observer, see Equation 2). To eliminate the presence of highlight disparity, one and the same observer vector for both eyes was used, which was the mean of the two correctly orientated observer vectors. In this latter case, the highlight disparity was identical to the surface disparity; that is, the highlights were located exactly on corresponding surface points in the two half-images.

All stimuli were presented on a 22-in monitor (Sony Triniton Multiscan 500 PS), driven by a NVIDIA GeForce 7900 GTX graphic card. In order to realize stereoscopic features, two monocular half-images of all stimuli were

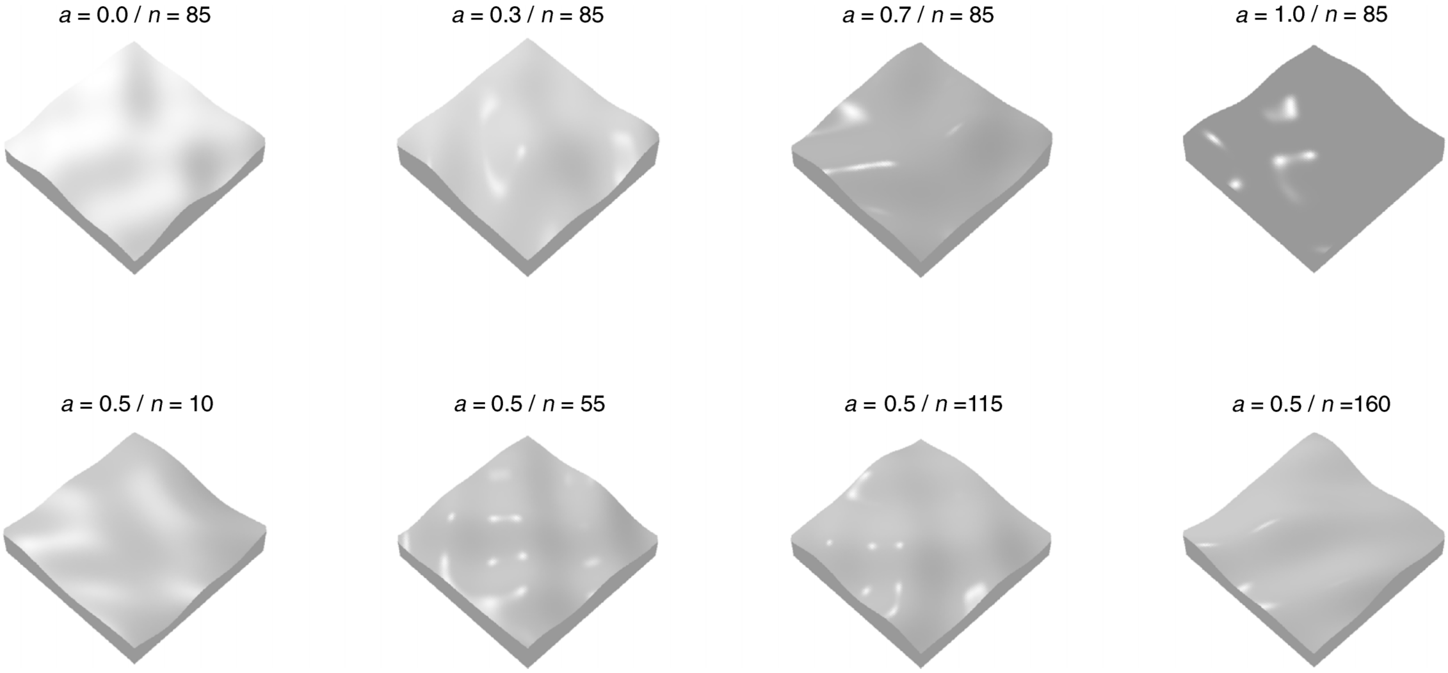

Figure 4. Some examples of our stimuli as they were used in Experiment 1 (reduced in size). The surfaces exhibit different combinations of reflectance parameters (‘a’ and ‘n,’ see Equation 2). The top row shows some examples from the first subset of stimuli, the bottom row some of the second subset. All eight 3D shapes which were used in Experiment 1 are shown.

generated, which were haploscopically fused by means of a mirror stereoscope (SA200 ScreenScope Pro). The side length of each quadratic half-image aperture on the monitor screen was 12.4 cm. All stimuli were rendered using the C++ programming language combined with the OpenGL module for 3D graphic applications. To achieve a perspective projection of our stimuli, the glFrustum method was used. The distance between the observer and the clipping plane (monitor screen) was 40 cm; the interpupillary distance was 6 cm. The center of our stimuli was located 10 cm behind the clipping plane into the virtual space.

Subjects

Three naive observers took part in our experiments. All were well experienced with psychophysical tasks and had normal or corrected-to-normal visual acuity.

Experiment 1

In Experiment 1, the subjects were asked to rate the strength of perceived glossiness ("how glossy is the surface?") as well as the authenticity ("how realistic is the gloss?") of a set of stimuli with or without highlight disparity.

Task and procedure

The main independent variable was the availability of binocular gloss cues. In one half of the entire set of stimuli, the surfaces exhibited highlight disparity and in the other half, this binocular information was not given. Furthermore, the reflection characteristics of our surfaces were varied by choosing different values for the weights for the specular and the diffuse components and the Phong exponent of the lighting model (see Equation 2). For one subset of our stimuli, we varied the relative amount of the diffuse and the specular component, choosing values for a between 0.0 to 1.0 in steps of 0.1 while keeping the exponent (n) constant at 85.0 (see top row in Figure 4). For a further subset of stimuli, we varied the Phong exponent (n) between 10.0 and 160.0 in steps of 15.0 while keeping the weight of the diffuse and the specular component constant ($a = 0.5$, see bottom row in Figure 4). Each of the 42 stimulus combinations [11 different a values for a constant n, 11 different n values for a constant a (the combination $a = 0.5$, $n = 85.0$ occurred in both subsets but was used only once in the experiment), each presented with and without highlight disparity] was presented 8 times (where 8 different 3D shapes for the surfaces were used), so a total of 336 trials resulted. The subjects made their judgments by manipulating the length of two continuous bars that were presented above and below the rotating surfaces on the screen. The relative lengths of those two bars were used as a measure for the perceived glossiness and the authenticity of the stimuli. The stimuli could be viewed as long as the subjects wanted but they were presented at least for 8 s (the time needed for a complete revolution of the surfaces). After the subjects confirmed their decisions by pressing a key, a 3-s dark adaptation period followed before the next stimulus was presented.

Results

Figure 5 shows the results for the strength (left column) and the authenticity (right column) criterion, separately displayed for the two varied parameters of the lighting model (rows). In all diagrams, each data point represents the average rating across all 3 observers. It is evident from the diagram that the two curves in each plot are of remarkably similar shape. The regular pattern of results and the correspondence between the curves is non-trivial because the subjects rated each stimulus in isolation, that is, without direct reference to other stimuli used in the experiment. This indicates that the subjects were indeed able to reliably judge the two perceptual dimensions "authenticity" and "strength" of glossiness. That the ratings of "authenticity" and "strength" of glossiness show different trends further suggests that the subjects were able to distinguish between these two perceptual dimensions.

The "strength of glossiness" ratings are positively related to both the Phong exponent and the relative amount of specular reflection. That the "strength of glossiness" ratings increase with increasing Phong exponent and with an increasing relative amount of the specular component is in line with the intended meaning of the parameters n and a in the lighting model. The curves that belong to the "authenticity" task, in contrast, show a slightly decreasing trend. Somewhat surprisingly, this shows that stimuli with the highest ratings for the glossiness strength appear less realistic than those with lower ratings for strength of glossiness. An anonymous reviewer of a previous version of this manuscript pointed to two possible reasons for this unexpected result. First, due to the limited range of displayable luminances, the brightness of the highlights may be lower than is to be expected under realistic conditions. Second, it would be possible that highly glossy surfaces are rare in typical environments and are therefore rated as less realistic.

Our data provide no clear evidence that the effect of highlight disparity depends on the reflection characteristic of the simulated surfaces. The limited effect of these parameters may in part be due to the fact that the surfaces used in the experiments always exhibited several highlights, and that the spread of the highlights does not only depend on the Phong parameter but also on the local

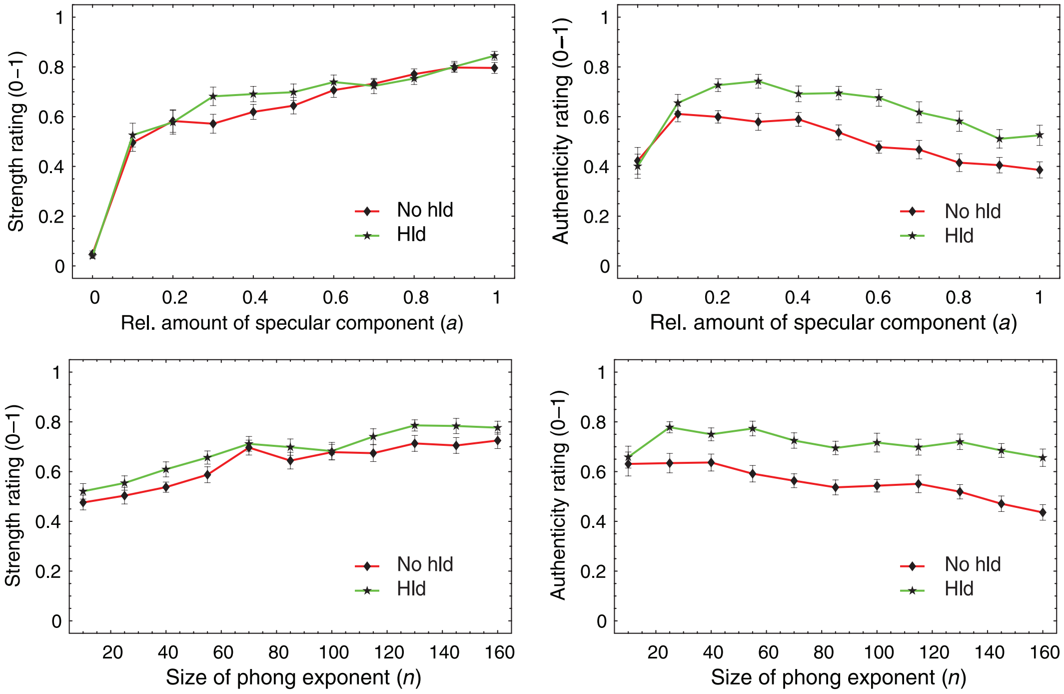

Figure 5. Results of the rating experiment, separately displayed for the two varied parameters of the lighting model (rows) and the two different rating criteria (columns). Each diagram shows the mean ratings for the two stimulus conditions "with highlight disparity" ('hld,' green lines) and "without highlight disparity" ('no hld,' red lines) across all observers. The error bars represent the *SEM* in both directions.

curvature of the surface. A further possibility is that mechanisms underlying intensity-based stereo (Arndt, Mallot, & Bülthoff, 1995; Mallot, Arndt, & Bülthoff, 1996) contribute to the detection of low contrast highlights or highlights that are widely spread.

A comparison of the stimulus conditions "with highlight disparity" ("hld") and "without highlight disparity" ("no hld") shows that the presence of this binocular information obviously has a larger impact on the perceived authenticity of the gloss impression: Except for the smallest values of both reflection parameters, there is always a clear difference in the mean ratings in favor of the stimulus variant which exhibits highlight disparity (see right column in Figure 5).

To a smaller extent, this binocular information also seems to affect the perceived strength of glossiness of the stimuli: At least for the subset of stimuli where only the Phong exponent was varied, the mean strength of glossiness ratings under the "with highlight disparity" condition lay consistently above the mean ratings that belong to the "without highlight disparity" condition (left bottom diagram in Figure 5).

Experiment 2

The results of Experiment 1 indicated that the availability of binocular gloss cues also leads, to a certain degree, to an enhancement of the strength of perceived glossiness. This aspect was examined in an additional matching experiment, testing the following hypothesis: A stimulus which exhibits such binocular information should need less "objective" glossiness than a stimulus that only exhibits monocular cues for gloss in order to be perceived as equally glossy.

Task and procedure

To test this hypothesis, our subjects were asked to perceptually match the glossiness of two surfaces. For this purpose, two stereo pairs were presented simultaneously on the screen, one pair above the other. The test surface always had the same 3D geometry. The matching surface was one of four different 3D shapes, none of them equal to the 3D shape of the test surface. Both the test and the match surfaces rotated during the presentation (see General methods section). The precise task of the subjects was to adjust the size of the Phong exponent (n, see Equation 2) in the matching stimulus. To define the step size for the adjustment, the Phong exponent n was transformed into scale m (referred to in the following as the "Phong index") that is approximately perceptual equidistant. Preliminary explorations suggested the following relationship: $m = \sqrt[4]{n}$.

The Phong index m for the test surface was varied in 7 steps of 0.3 between 1.3 and 3.1, whereas the relative

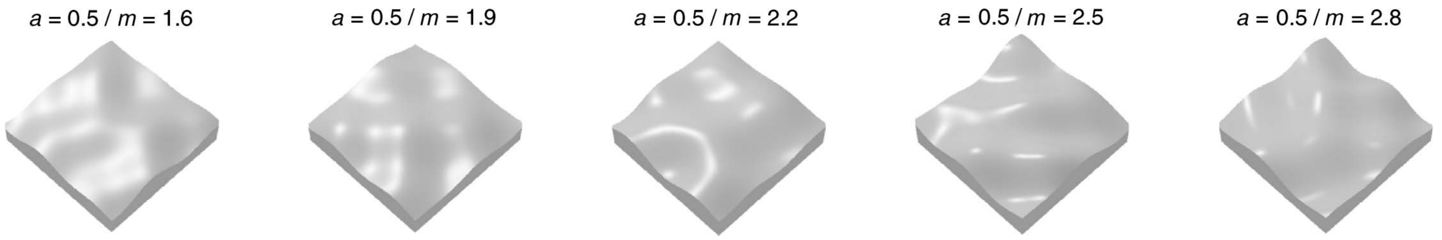

Figure 6. Some examples of our stimuli as they were used in Experiment 2 (reduced in size). The surfaces exhibit different Phong index values (m). The 3D shape of the surface on the left was used as the test surface; the remaining 4 surfaces have shapes that were used as matching surfaces.

amount of the diffuse and the specular component was kept constant ($a = 0.5$) for all surfaces. Furthermore, we chose 3 combinations regarding the availability of binocular cues for the test and the matching surface: (1) both surfaces exhibited highlight disparity (T+/M+); (2) none of the two surfaces exhibited highlight disparity (T−/M−); and (3) only the matching surface exhibited highlight disparity while the test surface did not (T−/M+).

For each of the 21 stimulus conditions (7 different Phong indices for the test surface × 3 different combinations of highlight disparity availability), 8 repetitions were made (each of the 4 different 3D shapes for the matching surface was presented twice, Figure 6), so a total of 168 trials resulted. The position of the test and the matching surface were balanced within the entire set of trials; that is, in one half of the trials, the test surface was presented on the top while the matching surface appeared on the bottom of the screen and vice versa. The subjects finished each trial by pressing a key followed by a short pause of 3 s during which the screen was black.

Results

The left diagram in Figure 7 shows a typical result of the matching experiment. It can be seen that the matches are nearly perfect in the two symmetric conditions "T−/M−" and "T+/M+" (i.e., highlight disparity either in both or none of the stereo pairs). In the asymmetric condition ("T−/M+"), however, systematically smaller Phong index values were chosen for the matching surface. The right diagram in Figure 7 shows the result of all subjects in a more condensed form. For each of the three conditions ("T−/M−", "T+/M+", "T−/M+"), the corresponding bar represents the mean of the deviation of the Phong index in the matching surface from that of the test surface, averaged across all subjects and all 7 steps of the Phong index. The mean matching value in the asymmetric condition differs significantly from the test value ($p < 0.001$, one-sided one-sample t-test). In accordance with our prediction, these results indicate that smaller Phong index values suffice in a surface that contains highlight disparity to make it perceptually as glossy as a surface that only exhibits monocular gloss cues.

Discussion

The goal of the present study was to examine the role played by binocular information in the perception of

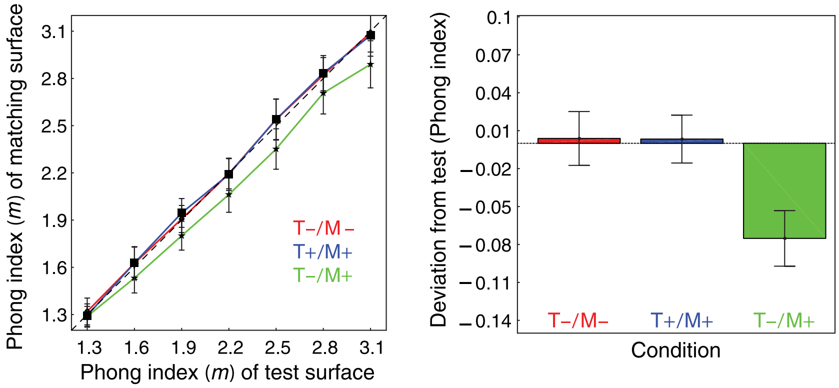

Figure 7. Left diagram: example results of one subject. Right diagram: the average deviations of the Phong index values of the matching surface from respective values of the test surface across all subjects and Phong index conditions. The error bars in both diagrams represent the *SEM* in both directions.

gloss. Although gloss is also perceived under monocular viewing conditions, our first experiment revealed that the authenticity of perceived glossiness is considerably enhanced when binocular gloss cues are also available. Most of our subjects reported that there was a noticeable qualitative difference between the gloss appearances of these two kinds of stimuli: Surfaces which exhibited highlight disparity seemed to have a much more "palpable," "vivid," and even "aesthetic" appearance than those which lacked it (the aesthetic content of gloss has been already brought up by Brewster, 1971; Dove, 1859). This part of our results thus fits well with the finding of Blake and Bülthoff (1990) that subjects choose a non-zero highlight disparity when asked to search for the "most realistic" gloss perception.

From a naive conception according to which vision exactly mirrors physical world properties, one might object that our findings simply amount to the observation that a more realistic, that is physically more correct, rendering appears more realistic. Such an objection, however, would express a profound misconception of perception theory by confusing input and output of the perceptual system. The appearance of being "realistic" is an *achievement* of the perceptual system rather than a description of the input; and it is precisely the task of perceptual psychology to identify the relevant input parameters that function as a physical basis for such an achievement. Apart from the well-known fact that distal object properties are vastly underdetermined by image properties, the question which image properties are actually exploited by the visual system can only be answered empirically. Corresponding empirical investigation will, of course, be guided by attempts to identify regularities in images obtained from objects that usually evoke a certain perceptual appearance. Yet it remains a genuine task for psychophysics to empirically find out which regularities, within the class of physical candidates, are in fact used and how they are used by the visual system.

Beyond this enhancement of perceived authenticity, a further finding of our study was that also the strength of perceived glossiness seems to increase if binocular gloss cues are available. In contrast to the results of Obein, Knoblauch, et al. (2004), which suggest a slight contribution of binocular viewing predominantly for highly glossy samples (which show "distinctness-of-image-gloss"), our results indicate that the binocular cue "highlight disparity" enhances the perceived glossiness also for medium-gloss surfaces (that only exhibit isolated highlights instead of broad and complex mirror images of the surrounding; "specular gloss," see Hunter, 1975).

Our matching data (Experiment 2) also imply a certain kind of "gloss constancy" (cf. Fleming et al., 2003; Nishida & Shinya, 1998; Obein, Knoblauch, et al., 2004): Since the surfaces never had identical shapes, a simple matching of the spatial extensions of single highlights will not work because they depend on the 3D geometry of the surfaces. Nevertheless, the subjects were able to achieve an approximately perfect match in the symmetric conditions (see Figure 7). Therefore, the perceived glossiness of a surface seems to be invariant with respect to the 3D geometry of a surface. In the present experiment, the spatial frequencies of all surfaces were rather similar. The results of Nishida and Shinya (1998), who used monocular viewing conditions in a similar task, indicate that this constancy might be much weaker if surfaces with clearly different spatial frequencies are compared. However, it is presently unclear whether their finding generalizes to binocular viewing conditions when highlight disparity information is available.

Nevertheless, under the conditions realized in the present experiments, the visual system obviously has the ability to generate in some way an abstract representation of the global gloss property of a surface-or, in other words, to separate the input into components that are due to specular and diffuse reflection (cf. Fleming et al., 2003; see also Todd, Norman, & Mingolla, 2004). This aspect was already mentioned by Hering (1879, p. 576): "For a gloss percept to come up, a decomposition of sensation has to occur, by which one portion of the sensation is seen as the essential color of the surface, whereas other portions are seen as accidental lights and darks, located on or in front of the surface or which stem from the inside of an object." ("Soll sich Glanz zeigen, so muss eine Spaltung der Empfindung eintreten, bei welcher ein Theil der Empfindung in die Fläche als deren wesentliche Farbe, andere Theile aber als zufälliges auf oder vor der Fläche liegendes oder aus der Tiefe des Körpers kommendes Licht oder Dunkel gesehen werden.")

Clearly, the presence of highlight disparity information could potentially facilitate such segmentations enormously. However, the availability of highlight disparity does not seem to be a necessary condition for this kind of "gloss constancy." This is indicated by our finding that the precision of the glossiness matches were comparable under both symmetric conditions of Experiment 2 (compare the sizes of the standard errors in the right diagram of Figure 7): Given that the decomposition into different causal layers is a necessary prerequisite for matching glossiness, this finding would imply that the decomposition was also possible without the presence of highlight disparity. This does, however, not mean that highlight disparity is ineffective. An alternative explanation is that there is an additional cue that facilitates the decomposition when no highlight disparity information is available. A possible candidate in our experiment is the dynamic change of highlight positions due to the rotation of the surfaces. Demonstrations from Hartung and Kersten (2002) indicate that gloss perception is indeed influenced by motion induced information. To investigate the specific role played by highlight disparity and motion induced cues, we currently plan to conduct further experiments which compare the effect of highlight disparity in static and dynamic stimuli.

Acknowledgments

This research was supported by grants from the Deutsche Forschungsgemeinschaft (DFG). Gunnar Wendt and Rainer Mausfeld were supported by grant (MA 1025/10-2), Franz Faul by grant (FA 425/1-3).

Commercial relationships: none.

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