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Fashion Versus Perception: The Impact of Surface Lightness on the Perceived Dimensions of Interior Space

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Objectives: We compare expert opinion with perceptual judgment regarding the influence of color on the perceived height and width of interior rooms.

Background: We hypothesize that contrary to popular belief, ceiling and wall lightness have additive effects on perceived height, whereas the lightness contrast between these surfaces is less important. We assessed the intuitions of architectural experts as to which surface colors maximize apparent height and compared these intuitions with psychophysical height and width estimates for rooms differing in ceiling, floor, and wall lightness.

Method: Experiment 1 was a survey of architectural experts and nonexperts. Experiments 2 and 3 presented virtual rooms varying in physical height, physical width, and surface lightness.

Results: In Experiment 1, both experts and nonexperts erroneously assumed that the lightness contrast between ceiling and walls influences perceived height. Experiment 2 showed that the lightness contrast does not determine apparent height but that ceiling and wall lightness have additive effects. Experiment 3 demonstrated a decrease in perceived width with physical height, whereas the perceived height was not related to physical width. Apparent width was unaffected by ceiling lightness.

Conclusion: Light ceiling and light walls make a room appear higher, whereas floor color has a weaker effect. We also found evidence for an asymmetric interaction between height and width.

Application: The question of how to color walls and ceiling to maximize the apparent size of a room can be answered empirically. Aesthetic considerations may interfere with the correct assessment of the effects of color in experts.

Keywords: room perception, architecture, architectural psychology, interior design, height, color, brightness, contrast, depth, psychophysics, visual perception, lighting, illumination, interior space, spaciousness, virtual reality

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INTRODUCTION

Surface color is assumed to play a critical role when designing interior space. For instance, when it comes to recommending a combination of ceiling color and wall color that will increase experienced spaciousness, textbooks, home improvement manuals, and Internet portals abound with sometimes very specific guidelines (e.g., Meerwein, Rodeck, & Mahnke, 2007; Miller, 1997; Neufert, Neufert, Baiche, & Walliman, 2000; see also www.homedesignfind.com/how-to-tips-advice/design-dilemma-dealing-with-low-ceilings/). The succinctness of such recommendations, however, is not grounded on empirical psychological studies. Very few such studies exist. Instead, the recommendations seem to rely on intuition and convention.

The conventions may be partly grounded in the art of painting, where far distance is often indicated by light bluish color (e.g., Helmholtz, 1867). Or the conventions may be grounded in nature observations. For instance, the light diffusion caused by fog has been reported to increase distance estimates (Ross, 1975). Note, however, that examples directly related to interior rooms do not come to mind. We have conducted a number of studies to put the existing conventions regarding interior space to a perceptual test.

One of the first psychophysical studies of this nature conducted in our laboratory revealed that surface lightness has a pronounced effect on perceived room height, which suggests that many effects attributed to color may be effects of lightness (Oberfeld, Hecht, & Gamer, 2010). Lightness or brightness (cf. Gilchrist, 2007) is one of the three dimensions of color; the other dimensions are hue and saturation (e.g., Kaiser & Boynton, 1996). The recommendations for room color selection voiced in the applied field (e.g., Neufert et al., 2000) seem to indicate that it is the dimension of lightness that exerts the strongest effect on the perception on interior space. This recommendation is, however, hard to evaluate, as psychophysical data concerning the effects of hue and saturation on perceived height have not yet been reported.

Notwithstanding this empirical question, in our study (Oberfeld et al., 2010), the psychophysical data did not support the often-voiced assumption that to make a room appear higher, it is important that its ceiling be painted in a lighter color than the walls (e.g., Neufert et al., 2000). Or put differently, the *lightness contrast* between the ceiling and the walls does not determine perceived room height. We did find that light ceilings make a room appear higher. However, the perceived height also increased with wall lightness, an effect that is virtually absent from practical guidelines promoted in the field of architecture, interior design, and home improvement. The effects of wall lightness and ceiling lightness were approximately additive, whereas floor lightness had no significant effect on perceived height. Our data also showed that the apparent room height is not determined by the overall brightness of a room.

Experiment 1 of the present study aimed at resolving the apparent contradictions between our findings (Oberfeld et al., 2010) and common rules of thumb concerning the selection of surface colors to maximize apparent room height. It is just hard to believe that practitioners should err or be misguided. Most likely, there is an answer that can explain and resolve such would-be contradictions. One simple explanation for the discrepancies could be that although the architectural experts are well aware of the effect of wall lightness on perceived room height, this effect has not found its way into the interior design literature because customers prefer slightly darker wall colors, such as the fashionable "Mediterranean" shade of brown combined with a white ceiling. Therefore, in Experiment 1, we conducted an Internet-based survey asking participants of different levels of expertise regarding architecture which ceiling and floor colors they would select to make a room appear as high as possible.

To find out how wall lightness could factor into these selections, each participant was asked to choose a color for the ceiling and one for the floor of two different rooms of identical physical dimensions: one room with white walls, and a second room with medium-gray walls. If the participants believed that the lightness difference between ceiling and walls was the critical factor, then the selected ceiling color should differ depending on the described wall color. If, however, the participants were aware of the fact that ceiling and wall lightness have an additive effect on perceived height, then the lightest ceiling color should always be selected, irrespective of the described wall color.

The results showed that with regard to apparent room height, the participants expected not only an interaction between wall color and ceiling color but also an interaction between wall color and floor color. To find out whether these expectations are mirrored in the actual perceptual experience of room height, in Experiment 2, we obtained psychophysical height estimates for interior rooms that varied in the lightness of ceiling, floor, and walls. In Experiment 3, observers judged interior rooms with respect to height and also with respect to width. The aim of this experiment was to test whether the effects of wall lightness on apparent height (Oberfeld et al., 2010) generalize in the sense that lighter ceiling colors cause a room to look wider and, more generally speaking, whether there is an interaction between perceived width and perceived height.

EXPERIMENT 1: AN INTERNET-BASED SURVEY

It is not easy to find out what the exact considerations are when an architect is designing the interior colors for a building. When informally talking to a number of successful architects, we noticed that their recommendations differed vastly, although there seemed to be some agreement on the choice of a light color for the ceiling. The experts also never expressed uncertainty but were rather adamant about their often idiosyncratic choices. To gain a systematic insight into the effects experts and nonexperts in the field of architecture and interior design predict surface lightness to have, we decided to provide a limited but clearly circumscribed scenario that could be easily communicated, in fact, so easily that an Internet-based survey would be feasible.

We provided written descriptions of a rectangular room that was empty and asked about the ceiling and floor colors the participants believed to maximize the apparent height of the room, given a predetermined wall color. To avoid color calibration problems, we limited the questions to so-called achromatic colors; that is, only black, white, and gray levels were considered. To further avoid artifacts attributable to display type and illumination in the participant's room, we provided written descriptions only.

Method

Participants. The online questionnaire was advertised in several German Internet discussion boards dedicated to architecture and on the home page of the Department of Psychology at the University of Mainz.

For the first experiment, 201 volunteers (126 female, 75 male) participated. They ranged in age between 16 and 60 years (M =27.6 years, SD = 8.3 years). Of the participants, 55 (27.4%) indicated that they either worked or studied in the field of architecture. No personal data, such as name or IP address, were recorded, but the participants were given the opportunity to leave their e-mail address on the last screen of the online questionnaire if they wished to receive information about the results.

Design and procedure. The online questionnaire comprised eight screens. On Screen 1, the participants were informed that they were about to answer nine questions and that filling in the questionnaire would take approximately 2 min. It was emphasized that there would be no right or wrong answers but that we were interested in their subjective opinion. On Screen 2, participants were asked to imagine a room (Room 1) with a width of 4 m, a depth of 6 m, and a height of 3 m and with either white or medium-gray walls. The task was to first select the ceiling color and then the floor color so that the room would appear as high as possible. For each surface, participants selected the lightness value they believed would maximize apparent height using a vertically oriented scale consisting of five radio buttons, labeled *white*, *light gray*, *medium gray*, *dark gray*, and *black* (in German, *weiβ*, *hellgrau*, *mittelgrau*, *dunkelgrau*, and *schwarz*). The polarity of the scale (i.e., upper item *white* or upper item *black*) was randomized between subjects to control for response biases.

On Screen 3, Room 2 was described with the same dimensions as Room 1 but with the other wall lightness (white or medium gray), and the same two rating scales as on Screen 2 were used by participants to select the ceiling and floor colors for maximizing apparent height. Thus, the described wall color was varied within subjects. The order of wall colors (i.e., room with white walls first or room with medium-gray walls first) was varied between participants. The polarity of the scales for the second room was always identical to the polarity used for the first room. Each participant was randomly assigned to one of the four (Scale Polarity × Wall Color Order) groups. On the remaining screens, the participants were asked to provide information about their age, education, and whether they were working or studying in the field of architecture. The response to the latter question was used to classify each participant as either an expert in architecture or a nonexpert.

It was not possible to proceed to the next screen without first having answered all questions on the current screen. Thus, all participants eventually submitting their questionnaire data to the server provided a complete data set without missing values.

Results and Discussion

The most important question in this experiment was whether the wall lightness had an effect on the ceiling color or on the floor color that participants believed would maximize the perceived height of the room. Figure 1, Panel A, shows the distribution of selected ceiling colors as a function of the described wall color. For both wall colors, the majority of participants selected a white ceiling, which, according to the results by Oberfeld et al. (2010), should indeed maximize the perceived height. With medium-gray walls, however, participants more frequently selected a light-gray or medium-gray ceiling than when the walls were white. This pattern is consistent with the lightness contrast idea described in the Introduction, according to which it is mainly important that the ceiling be lighter than the walls. However, according to the psychophysical data (Oberfeld et al., 2010), a white ceiling would have always resulted in the maximal perceived height, irrespective of wall lightness.

The effects of wall lightness, architectural expertise, and the interaction of the latter two factors on selected ceiling height were analyzed by a multinomial logit model for repeated measures (e.g., Chen & Kuo, 2001; Hartzel, Agresti, & Caffo, 2001; Hedeker, 2003). The model treated the responses as nominal while accounting for the correlated structure of the data, given the two

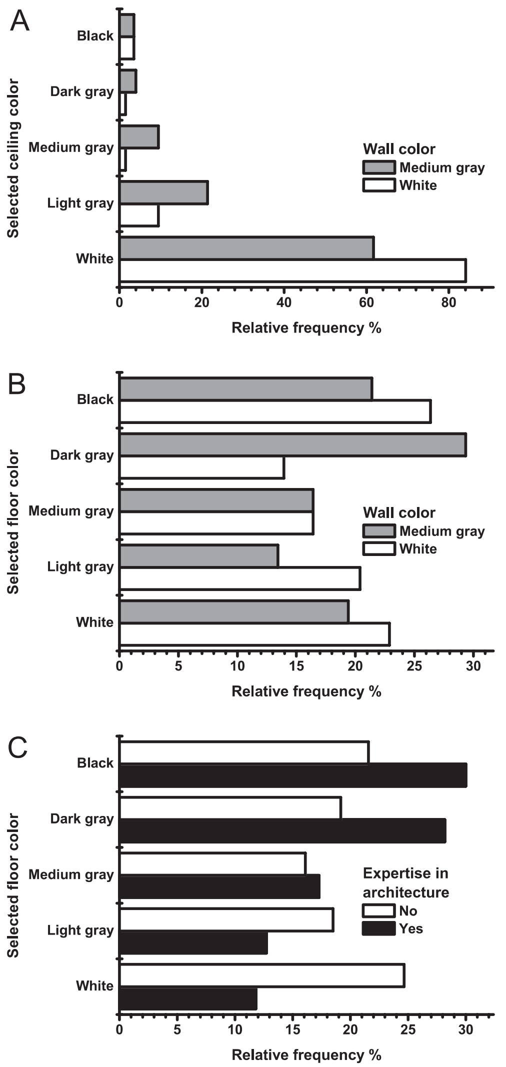

Figure 1. Experiment 1: (A) Selected ceiling color and (B) selected floor color as a function of the described wall color. (C) Selected floor color as a function of group (experts vs. nonexperts).

observations contributed by each participant. We fitted a marginal-effects model (also termed "population-averaged" model; cf. Liang & Zeger, 1993; Pendergast et al., 1996) using SAS 9.2 PROC GLIMMIX, as described by Kuss and McLerran (2007, p. 266). In this approach, the marginal (or population-averaged) expectation of the dependent variable is modeled as a function of the predictors (covariates). The covariates are related to the marginal probabilities, and the model treats the structure of the correlations between observations obtained from the same subject as a nuisance parameter.

The method used by PROC GLIMMIX is based on marginal quasi-likelihood (e.g., Breslow & Clayton, 1993), which is closely related to the generalized estimating equations approach (cf. Liang & Zeger, 1993). The working correlation matrix was specified as being of type "unstructured"; that is, the procedure placed no constraints on the correlations across observations within a participant. In the analysis, the within-subjects factor was wall lightness (white or medium gray), and the between-subjects factor was expertise. An α level of .05 was used for all tests in this article. The effect of wall lightness was significant, $F(4, 796) = 4.34$, $p = .002$, confirming the observed differences between the selected ceiling colors for the two levels of wall lightness (Figure 1, Panel A). Neither the effect of expertise, $F(4, 796) = 1.61$, $p = .17$, nor the Wall Lightness × Expertise interaction, $F(4, 796) = 0.61$, $p = .65$, was significant.

The second dependent variable was the floor color selected to maximize apparent room height. For this dependent variable, the same type of multinomial logit model showed a significant effect of wall color, $F(4, 796) = 4.84$, $p < .001$. As Figure 1, Panel B shows, the participants selected very light or very dark floor colors more frequently if the described wall color was white. With medium-gray walls, a dark-gray floor was especially popular. As seen in Figure 1, Panel C, participants with a background in architecture showed a preference for dark floors, whereas among the nonexperts, the distribution of selected floor colors was closer to the uniform case. This effect of expertise was not significant at the .05 level, $F(4, 796) = 2.14$, $p = .074$. The Wall Lightness × Expertise interaction was also not significant, $F(4, 796) = 0.92$, $p = .45$.

As the numerical estimation process for the multinomial logistic model is not without pitfalls, we complemented the tests for the two main effects (wall lightness and expertise) with nonparametric tests. To test whether the selected ceiling color or the selected floor color differed depending on the described wall color, the Bowker (1948) test for symmetry in contingency tables was used. For selected ceiling color, the contingency table contained empty cells because of the very small frequencies of selected dark colors (see Figure 1, Panel A). Therefore, rather than using the χ^2 approximation (Bowker, 1948), we computed an exact test (Krauth, 1973) using a Mathematica (Wolfram Research, Inc.) package by Oberfeld (2010). The exact test showed a significant effect of wall lightness on selected ceiling color, $p < .001$. For selected floor color, the cell frequencies were sufficiently large to use the χ^2 approximated test, which also indicated a significant effect of wall color, $\chi^2(10) = 38.2$, $p < .001$.

To test for an effect of expertise on the selected colors, we computed Fisher's exact test for association between two categorical variables (Fisher, 1922). For the ceiling color selected with white and medium-gray walls, the exact *p* values were $p = .11$ and $p = .51$, respectively. For the floor color selected with white and medium-gray walls, the exact *p* values were $p = .082$ and $p = .076$, respectively. Thus, the nonparametric tests confirmed the pattern of results indicated by the multinomial logit models, that is, a significant effect of wall color on both the selected ceiling color and the selected floor color, but the effect of expertise on the selected floor color failed to reach significance at the .05 level.

To sum up the results, participants' selections of ceiling color reflected the use of the lightness contrast assumption, irrespective of the participants' background in architecture. When asked to select a floor color that maximizes perceived height, architectural experts tended to choose darker colors than did the nonexperts. Finally, the selected floor color depended on wall lightness.

EXPERIMENT 2: CONTROLLED MANIPULATION OF SURFACE LIGHTNESS IN VIRTUAL REALITY (VR)

Experiment 1 showed that experts in architecture as well as nonexperts consider the wall lightness when selecting a color for the ceiling to maximize the height of the room. Roughly compatible with the idea that the lightness difference between ceiling and walls determines apparent room height, slightly darker ceiling colors were selected if the walls of an imagined interior room were medium gray rather than white. Such a behavior is at odds with psychophysical data showing that irrespective of wall lightness, a white ceiling maximizes perceived room height (Oberfeld et al., 2010).

In Experiment 1, the selected floor color believed to maximize apparent height also depended on the wall lightness. Is the interaction effect of wall and floor lightness on apparent height assumed by the participants in Experiment 1 plausible, or do the selected combinations of floor and wall color merely reflect aesthetic preferences or habits? At present, no psychophysical data are available that would allow to decide between these two possibilities. In the experiments by Oberfeld et al. (2010), either the lightness of both the ceiling and the floor was identical (and was varied independently of wall lightness), or the lightness of ceiling and floor were varied independently while the wall color remained constant.

Therefore, in Experiment 2, we created a VR rendition of a room whose actual height and coloring could be easily varied from trial to trial. We independently varied the lightness of all the three surfaces (ceiling, floor, and walls). We expected ceiling lightness and wall lightness to have a roughly additive effect on perceived height, as in our previous experiments (Oberfeld et al., 2010). We expected no effect of floor lightness, and also no interaction of floor color and wall color, contrary to the statements of the participants in Experiment 1.

Method

Participants. For the second experiment, 21 observers (16 women, 5 men), ages between 18 and 28 years ($M = 21.7$ years, $SD = 2.6$ years), participated voluntarily. All had normal or corrected-to-normal vision and normal stereo acuity according to the Titmus stereo test (cf. Bennett & Rabbetts, 1998, p. 201). All participants gave written informed consent according to the Declaration of Helsinki after the course of the experiment, the motivation of the study, and potential risks were explained to them. They were uninformed about the hypotheses being tested.

Stimuli and apparatus. We presented rooms in a VR setting. We varied the physical height of the simulated rooms to be able to test whether the observers did indeed estimate the height of the rooms rather than judge a different attribute, for example, overall spaciousness (for a discussion, see Oberfeld et al., 2010). Observers viewed a rectangular virtual room with a constant depth of

6.0 m and constant width of 4.5 m, projected stereoscopically on a large projection screen. The ceiling height was varied between 2.9 and 3.1 m in steps of 0.1 m. All room surfaces were covered with a fine-grained, grayscale texture. The lightness of ceiling, walls, and floor was varied independently on three levels (dark, medium, light). The room was illuminated from the direction of the observer such that the luminosity of the rear wall appeared to be roughly uniform.

The virtual room was rendered with use of the animation software Vizard (WorldViz, Santa Barbara, CA) on a Pentium IV computer (Dell Precision 650) equipped with an NVIDIA Quadro4 900 XGL graphics adaptor. The room was displayed on a large rear-projection screen (2.60 m horizontally, 1.93 m vertically). The projection allowed for stereoscopic viewing by use of two projectors with a resolution of 1,400 × 1,050 pixels each. The light of the two projectors was linearly polarized in orthogonal planes. Participants wore matching polarization filters such that each eye received a unique image. The refresh rate of the display was 60 Hz for each eye, noninterlaced. Individual interocular distances were measured and taken into account to set the stereoscopic disparity of the two images. The simulated observer (i.e., the virtual cameras) was placed at the center of the invisible front wall of the virtual room with the gaze oriented straight ahead.

The participant was seated at a distance of 2.0 m from the projection screen. The viewing configuration was as if the participant were looking through a window sized 2.60 × 1.93 m (i.e., the dimensions of the projection screen) into the virtual room (see Oberfeld et al., 2010, for a schematic depiction of the rooms). A height-adjustable chair combined with a chin rest ensured that the observer's eye height was aligned with the center of the projection screen. The horizontal and vertical viewing angles amounted to 66° and 51°, respectively.

Design and procedure. Five experimental variables were varied in a repeated-measures design. The physical height of the virtual room, wall lightness, ceiling lightness, and floor lightness were varied as described earlier. The observers freely viewed the displayed room on each trial and clicked the left mouse button when they felt comfortable to estimate its dimensions. Then a vertical slider with a scale ranging from 2.00 m to 4.00 m in steps of 0.01 m appeared on the projection screen. Observers adjusted the slider to express the perceived height of the room. To control for anchor effects, each room was presented once with the initial position of the slider set at 2.0 m and once with an initial position of 4.0 m. All factorial combinations (Physical Height × Ceiling Lightness × Wall Lightness × Floor Lightness × Slider Position) were presented to each participant, resulting in a total of 162 trials. Presentation order was randomized. The experiment took approximately 65 min, including four demonstration trials and a short break.

Results and Discussion

We analyzed the height estimates via a repeated-measures ANOVA using a univariate approach (e.g., Keselman, Algina, & Kowalchuk, 2001). The Huynh-Feldt correction for the degrees of freedom was used (Huynh & Feldt, 1976), and the value of the *df* correction factor $\tilde{\varepsilon}$ is reported. Note that this particular variant of a repeated-measures ANOVA performs comparably well even for small samples and non-normally distributed data (e.g., Keselman, Kowalchuk, & Boik, 2000). Partial η^2 is reported as a measure of association strength.

As seen in Figure 2, there was a significant increase in estimated height with physical height, $F(2, 40) = 31.15$, $p < .001$, $\tilde{\varepsilon} = .61$, $\eta^2 = .61$. The linear relation suggested by Figure 2 was confirmed by a significant linear trend, $F(1, 20) = 33.93$, $p < .001$, $\eta^2 = .63$, and indicates that the participants were indeed judging the room height quite consistently. Note that the fact that the estimates (on a meter scale) tended to be higher than the physical height (in meters) should not be overrated: Either participants overestimated, or their internal scale was not perfectly calibrated in meters.

Ceiling lightness had the expected significant effect on estimated height (Figure 3, Panel A), $F(2, 40) = 9.72$, $p < .001$, $\tilde{\varepsilon} = 1.00$, $\eta^2 = .33$. On average, the room with the light ceiling appeared 4.5 cm higher than the rooms with the darker ceiling, compatible with previous results (Oberfeld et al., 2010). As Figure 3, Panel B, shows, estimated height also increased with increases in wall lightness, $F(2, 40) = 5.80$, $p = .006$, $\tilde{\varepsilon} = 1.00$, $\eta^2 = .23$. As expected, the main effect of floor lightness was not significant, $F(2, 40) = 1.80$.

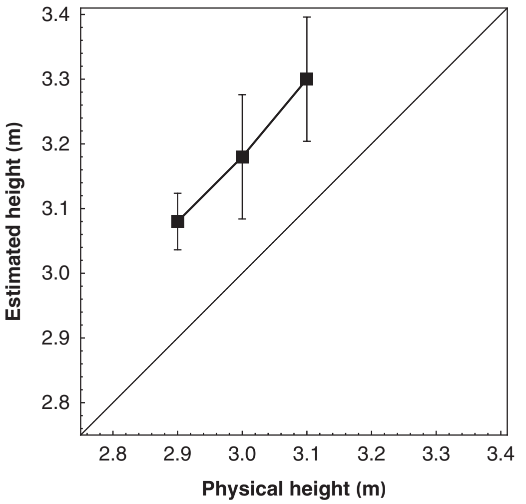

Figure 2. Experiment 2. Mean estimated height as a function of physical height. Error bars show ±1 standard error of the mean of the 21 individual estimates.

Do the data provide evidence for the presumed role of the lightness contrast between walls and ceiling? If the perceived height were indeed maximal for ceilings that are lighter than the walls, then a room with medium-light ceiling and dark walls should have appeared higher than a room with the same ceiling lightness combined with light walls. As Figure 3, Panel C, shows, our data are clearly not consistent with this pattern. Instead, the data indicate a roughly additive effect of wall lightness and ceiling lightness on estimated height, as confirmed by the nonsignificant Ceiling Lightness × Wall Lightness interaction, $F(4, 80) = 1.77$.

Contrary to our expectation, there was a significant Wall Lightness × Floor Lightness interaction, $F(4, 80) = 3.75$, $p = .012$, $\tilde{\varepsilon} = .85$, $\eta^2 = .16$. As seen in Figure 4, the increase in estimated height with wall lightness was most pronounced when the floor was light. Was the observed dependence of perceived height on the combination between floor and wall lightness compatible with the expectations of the participants from Experiment 1?

Recall that in the latter experiment, the participants frequently selected black or white floors when the walls were white but showed a slight preference for dark colors when the walls were medium gray (Figure 1, Panel B). For the light

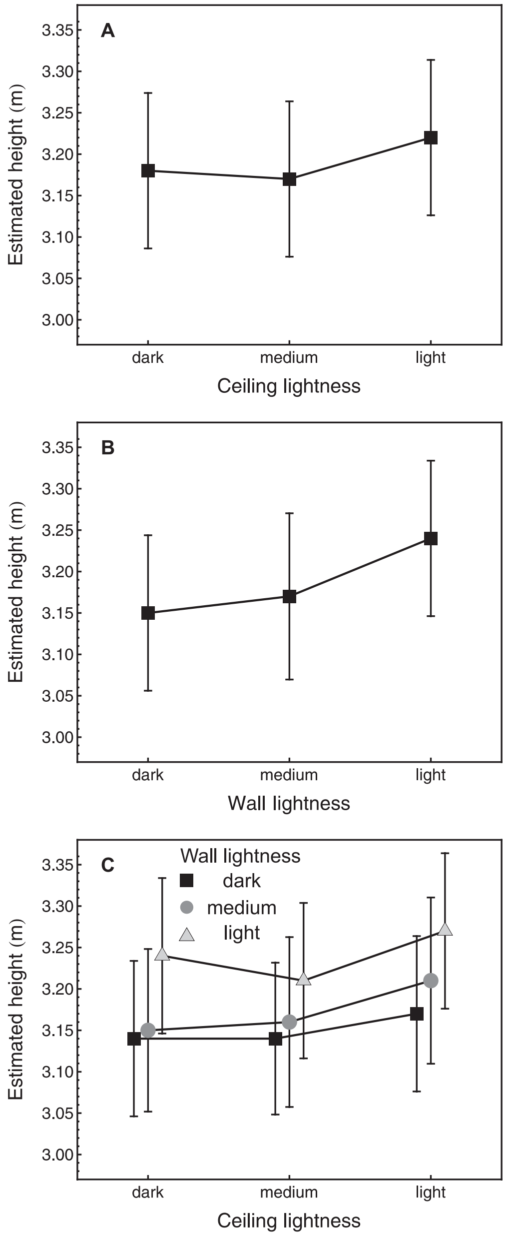

Figure 3. Experiment 2: (A) Mean estimated height as a function of ceiling lightness. (B) Mean estimated height as a function of wall lightness. (C) Mean estimated height as a function of ceiling lightness and wall lightness. Black boxes = dark walls; medium-gray circles = medium-light walls; light-gray triangles = light walls. Error bars show ±1 standard error of the mean of the 21 individual estimates.

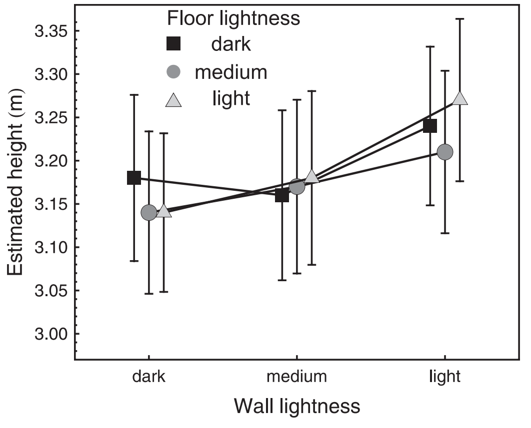

Figure 4. Experiment 2: Mean estimated height as a function of wall lightness and floor lightness. Black boxes = dark floor; medium gray circles = medium-light floor; light-gray triangles = light floor. Error bars show ±1 standard error of the mean of the 21 individual estimates.

walls, Figure 4 indeed shows a comparable ranking of the heights estimated with dark, medium-light, or light floors as in Experiment 1. Post hoc pairwise comparisons between all levels of floor lightness combined with light walls showed that with dark or light floors, estimated height was significantly higher than with a medium-light floor, $t(20) = 2.18$, $p = .042$, and $t(20) = 5.05$, $p < .001$, respectively (all p values reported in this article are two tailed). The difference in apparent height between the dark and the light floor was not significant, $t(20) = 1.86$, $p = .078$. For rooms with medium-light walls, however, the height estimates obtained with the different floor colors were virtually identical, a pattern that is not compatible with the expectations of the participants from Experiment 1.

The ANOVA also indicated a significant Ceiling Lightness × Wall Lightness × Floor Lightness interaction, $F(8, 160) = 2.80$, $p = .011$, $\tilde{\varepsilon} = .82$, $\eta^2 = .12$, probably because of the fact that with dark floor and dark walls, the estimated height showed a stronger increase with increases in ceiling lightness than in the remaining conditions. The remaining main and interaction effects in the ANOVA were not significant (all p values > .09).

To summarize the results of Experiment 2, we found that estimated room height increases with ceiling lightness and wall lightness. Floor lightness had no direct, main effect on apparent height but seemed to modulate the effects of wall lightness. In addition, we found no evidence for a role of the lightness contrast between ceiling and walls. These results support the findings by Oberfeld et al. (2010).

The results also show a dependence of perceived height on the combination between floor and wall lightness, partially compatible with the expectations of the participants of the Internet survey (Experiment 1).

EXPERIMENT 3: EXPANDING THE VIRTUAL ROOM, PERCEIVED HEIGHT AND WIDTH

Experiments 1 and 2 were concerned with the perceived height of interior rooms. What could be expected about the effects of surface color on other perceived dimensions of an interior room, for example, its perceived width? Do the effects of wall lightness on apparent height observed in Experiment 2 and a previous study (Oberfeld et al., 2010) generalize in the sense that lighter ceiling colors cause a room to look more voluminous and/or wider as well? On a more general level, is there an interaction between perceived width and perceived height? If so, then a potential framework for understanding these effects could be the perception of *volume*.

We propose that at least two principles could apply. If observers responded according to the principle of *volume constancy*, then, for example, a perceived increase in height should result in a decrease in perceived width. Alternatively, a perceived increase in height might cause an additional increase in perceived width, corresponding to *volume inflation*. If such a positive relation between perceived width and perceived height were observed, it could alternatively be explained by *proportion constancy.* Observers might, for instance, assume that the ratio between height and width remains relatively constant or corresponds to a value frequently exhibited by real rooms. Specifically, given that in real buildings, the room height typically shows much less variation than width or depth, for a small increase in physical height, participants might assume that the ratio between height and width remains the same and, as a consequence, produce a larger estimate of the width of the room.

To gain insight into these questions, judgments of the height and the width of interior rooms were obtained in Experiment 3. Both the physical height and the physical width were varied in a VR setting. The lightness of ceiling and floor was varied to test whether these surface colors have an effect on perceived width, just as the wall lightness influences perceived height.

Method

Participants. For the third experiment, 20 observers (12 women, 8 men), ages between 19 and 60 years ($M = 28.3$ years, $SD = 12.2$ years), participated voluntarily. All had normal or corrected-to-normal vision and normal stereo acuity according to the Titmus stereo test. All participants gave written informed consent according to the Declaration of Helsinki after the course of the experiment, the motivation of the study, and potential risks had been explained to them. They were uninformed about the hypotheses under test.

Apparatus. The same stimuli and apparatus as in Experiment 2 were used, with the following exceptions. Most importantly, the width of the room was varied between 4.4 m and 4.6 m in steps of 0.1 m. The lightness of the ceiling was the same as that of the floor on each trial. From trial to trial, the ceiling and floor varied on three levels (light, medium, and dark). We varied the lightness of ceiling and floor in parallel to achieve a maximum contrast between surface lightness in the “vertical” direction (ceiling and floor) and surface lightness in the “horizontal” direction (the walls). Because the effect of ceiling and floor lightness on height estimation was most pronounced in Experiment 1 by Oberfeld et al. (2010) at a medium lightness level of the walls, we decided to keep the wall lightness constant at this level to reduce the number of trials.

As in Experiment 2, the virtual camera was positioned in the virtual front wall of the room. The camera position in the frontoparallel plane was varied around the center of the front wall. The horizontal range of random displacement amounted to ±0.185 m around the center of the virtual room and the vertical range to 1.7 ± 0.125 m from the room’s floor. These displacements of the observation point were introduced to prevent observers from using the perceived edges of the viewing window instead of perceived height. We thought that such a strategy might become likely with the increased complexity of the task.

Design and procedure. In a repeated-measures design, we varied the physical height of the virtual room (2.9 m, 3.0 m, or 3.1 m), the distance between the walls to the left and right of the observer (i.e., the room’s physical width), and the lightness of the room’s ceiling and floor. Ceiling lightness and floor lightness were was always identical to each other. Each observer received each factorial combination twice with a height estimation task and twice with a width estimation task. Thus, the experiment comprised 162 trials. Presentation order was randomized and the position of the virtual camera was varied randomly.

As in Experiment 2, observers freely viewed the displayed room on each trial and pressed the left mouse button when they felt able to estimate its dimensions. Then either a vertical or a horizontal slider appeared on the projection screen. In the former case, observers adjusted the slider to match the perceived height of the room, as in Experiment 1. In the latter case, the room’s width had to be estimated. Importantly, only one estimate was required on each trial, but observers did not know in advance whether the width or the height should be estimated. Thus, they had to consider both dimensions while viewing the room to be able to deliver the appropriate estimate at the end of the trial. For height estimates, the slider ranged from 2.0 m to 4.0 m, and for width estimates, it covered a range from 3.5 m to 5.5 m. Both sliders could be adjusted in steps of 0.01 m, and the initial position was randomly set to either the smallest or the largest value of the scale on each trial. The next trial started after participants confirmed the adjustment. The experiment, including four demonstration trials for height and width estimation, respectively, lasted approximately 50 min.

Results and Discussion

The effects of the experimental parameters on the estimated height and width of the rooms were analyzed via two separate repeated-measures ANOVAs with the within-subjects factors physical height, physical width, and ceiling and floor

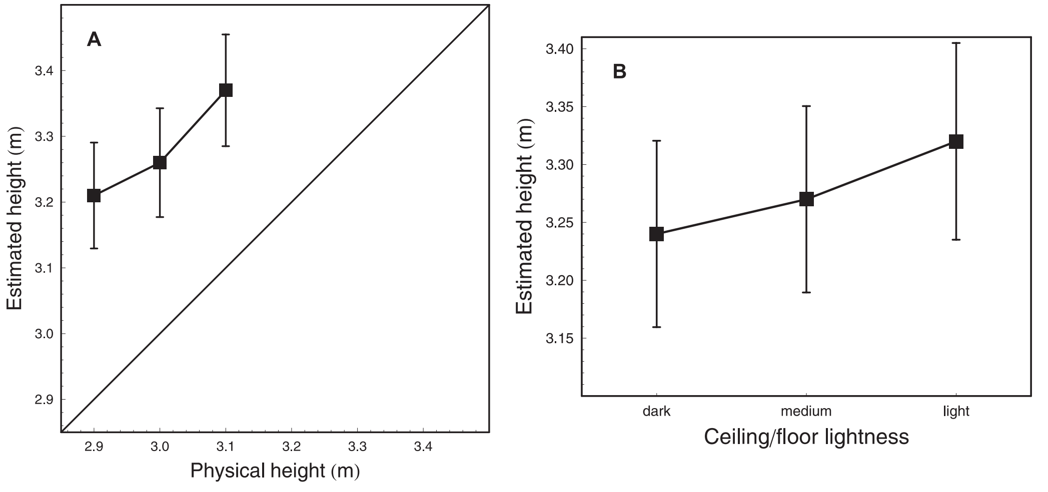

Figure 5. Experiment 3: (A) Mean estimated height as a function of physical height. (B) Mean estimated height as a function of ceiling and floor lightness. Error bars show ±1 standard error of the mean of the 20 individual estimates.

lightness. Data were aggregated across trial repetitions.

We first report the analysis of the height estimates. As can be seen in Figure 5, Panel A, physical height had an effect on estimated height, $F(2, 38) = 21.28$, $p < .001$, $\tilde{\varepsilon} = .70$, $\eta^2 = .53$. The physical width had no significant effect on estimated height, $F(2, 38) = 0.96$. Figure 5, Panel B, shows that the height estimates increased with the lightness of ceiling and floor. This effect just failed to reach significance at the .05 level, $F(2, 38) = 3.33$, $p = .065$, $\tilde{\varepsilon} = .712$, $\eta^2 = .15$. None of the interactions was significant (all p values > .5).

What can be concluded about the estimates of room width? As evident in Figure 6, Panel A, physical width had the expected significant effect, $F(2, 38) = 25.66$, $p < .001$, $\tilde{\varepsilon} = .961$, $\eta^2 = .58$. Figure 6, Panel B, shows that the width estimates *decreased* with physical room height, $F(2, 38) = 12.74$, $p < .001$, $\tilde{\varepsilon} = .853$, $\eta^2 = .40$. This negative relation between physical height and the width estimates would be consistent with a "constant-volume" strategy. The effect of ceiling and floor lightness on the width estimates was not significant, $F(2, 38) = 1.42$, $\tilde{\varepsilon} = 1.0$, $p = .254$. The remaining main and interaction effects were also not significant (all p values > .25).

Taken together, the results from Experiment 3 confirmed the effect of ceiling lightness on perceived height and demonstrated an asymmetric interaction between width and height. The physical height influenced the perceived width, but the perceived height was not related to the physical width. In addition, apparent width was unaffected by ceiling lightness, whereas Experiment 2 and our previous study (Oberfeld et al., 2010) showed that apparent height is influenced by wall lightness. As discussed earlier, we did not vary the wall lightness in this experiment simply to keep the experimentation time for each participant at a reasonable level. However, this restriction of the experimental design was probably somewhat unfortunate, because it would have been interesting to complement the measurement of the effects of ceiling lightness on apparent width with a measurement of the effect of wall lightness on apparent height.

GENERAL DISCUSSION

Experiment 1 showed that people are rather consistent in selecting light ceiling colors to make the room appear high, regardless of their level of expertise in the domain of architecture. The perceptual data from the laboratory experiments confirm this choice to be a sensible one. A light ceiling makes the room appear higher. This finding is compatible with and qualifies previous findings of general nature that brighter rooms appear to be more spacious (Inui & Miyata, 1973).

When it comes to the floor color, however, interesting differences emerged. If the walls of

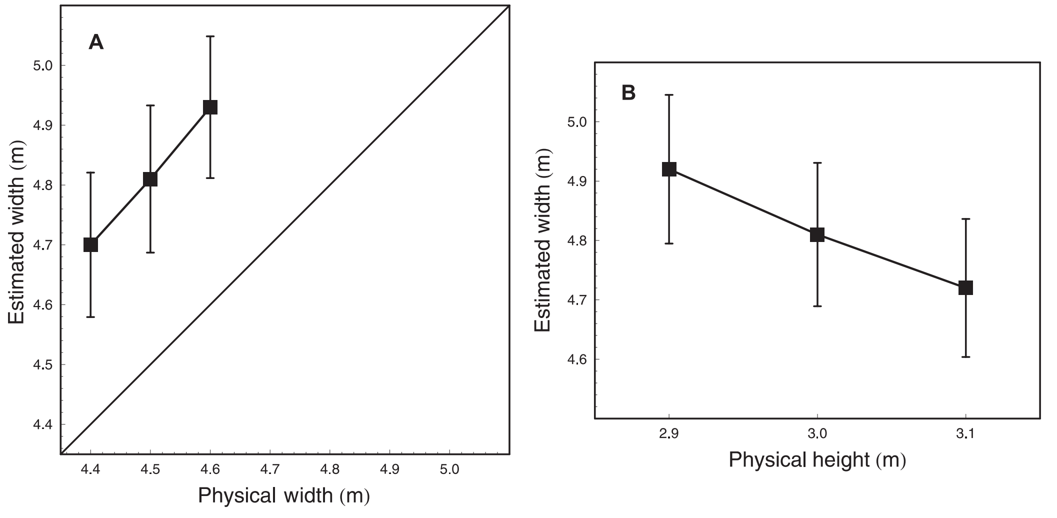

Figure 6. Experiment 3. (A) Mean estimated width as a function of physical width. (B) Mean estimated width as a function of physical height. Error bars show ±1 standard error of the mean of the 20 individual estimates.

an imagined room were gray, expert architects, more often than novices, believed that dark floors would make the room appear higher. This expectation was not supported by the psychophysical data from Experiment 2.

Experiment 3 revealed an asymmetry between the effects of wall and ceiling color. On the one hand, wall color does influence judged height. The effect of ceiling and wall color is additive, incompatible with the popular lightness contrast assumption. Thus, just like a white ceiling, a lighter wall makes the room look higher. Ceiling color, on the other hand, does not have the reciprocal effect. A white ceiling does not make the room look wider. Surprisingly, Experiment 3 also showed that making a room physically higher caused the unjustified impression that the room became narrower. In contrast, changes in physical width had no effect on perceived height.

What could be the origin of this asymmetry? Note first that the observation that increases in height reduced perceived width would be compatible with observers responding as if the volume of the room remained constant. Within this framework, an admittedly speculative explanation of the asymmetric influence of height on width might also be formulated. Studies on the perception of the volume of geometric solids demonstrated the so-called elongation bias, which describes the observation that objects with a higher height-to-width ratio are perceived as larger than less elongated objects of the same volume (e.g., Chandon & Ordabayeva, 2009; Frayman & Dawson, 1981; O'Shea, 1981; Piaget & Inhelder, 1966; Raghubir & Krishna, 1999; Wansink & van Ittersum, 2003).

There is also evidence that changes in height have a stronger effect on perceived volume than do changes in width. For example, if two identical cylinders are stretched into different shapes but are identical in volume, the cylinder whose height dimension is expanded appears larger (Been, Braunstein, & Piazza, 1964). Thus, making the cylinder wider has less perceptual effect than making it taller by an equal increase in volume. Applied to our data, an increase in room width could have resulted in a weaker increase in perceived volume weaker than that in height. As a result, if the observers adjusted their height and width estimates to represent a constant volume of the room, then our finding that changes in width had no significant effect on perceived height could be accounted for.

However, the empirical evidence that height dominates perceived volume is not unequivocal. For example, Matusiak and Sudbo (2008) found that among children, width has a stronger impact on the perceived size than does height. In addition, and probably even more important, it is entirely unclear whether volume judgments for solid objects (e.g., a cube) follow the same rules as volume judgments for *interior* space.

Might the asymmetry of effects produced by height and width have its roots in preferences for certain proportions? There seems to be a preferred room proportion (for a given floor area) that leads to maximal spaciousness. Stamps (2011) found that rooms with ceiling heights of 2.44 m or 3.66 m were judged to be less spacious when elongated, but ceiling height had no effect. Our ceiling heights (between 2.9 m and 3.1 m) were in the middle of this range and thus should not have triggered any height preference. Holmberg, Küller, and Tidblom (1966) also suggest a preferred width or, rather, aspect ratio. They had observers compare two model rooms. The first was of fixed size (100 cm wide, 50 cm high, and 100 cm deep). The second room could assume different widths by means of a movable right side wall. The position of the rear wall could be adjusted by the observer to equate the second room's volume with that of the first, fixed-size room. Results showed that rectangular rooms appeared to have larger volumes than square rooms.

Our Experiment 2 showed that floor color has an influence of on perceived height only in a rather indirect manner, namely, by modulating the effects of ceiling and wall lightness. This finding makes a clear empirical case against all those who believe that floor color is essential when attempting to make a room appear more spacious.

More specifically, some of our experts queried in Experiment 1 were mistaken in assuming that floors need to be dark gray or even black to accomplish the maximal sense of height. However, their color choice may still be a good choice for other reasons. Here we were concerned only with spaciousness and not with other aesthetic or emotional aspects of room color. The latter effects clearly exist and can be demonstrated down to a physiological level (e.g., Küller, 1986; Küller, Ballal, Laike, Mikellides, & Tonello, 2006). Thus, it appears possible that the expert opinions on color choice may confound aspects of spaciousness with other aesthetic variables. Our experiments were able to unconfound them and to circumscribe the effects of color on spaciousness. Note that we use *spaciousness* to refer to perceived spatial quantities rather than the overall vague and complex feeling of spaciousness.

In recent years, lighting has become increasingly important as an architectural design element (cf. Michel, 1996; Society of Light and Lighting, 2009). In a real environment, the lightness of a room's surfaces is strongly influenced by lighting. In fact, some recommendations concerning, for example, the selection of light sources for an office environment are compatible with the effects of surface color on the perceived dimensions of rooms demonstrated in this study. For example, a light source that is situated on the ceiling and provides directed light from above will produce no light in the up-high (UH) and up-low (UL) zones in terms of the Illuminating Engineering Society of North America (IESNA) Luminaire Classification System (IESNA, 2007). This positioning can result in a dark ceiling and thus a cavelike effect. In contrast, a light source projecting light up against the ceiling (i.e., most light produced in the UH and UL zones) can increase the perceived room height (e.g., Zumtobel Staff, 2008, p. 12).

In consideration of our data, a simple explanation of these effects would be that the different ceiling lightness values result in different lighting conditions. Several studies investigated the effects of lighting scenarios on the subjective impressions of interior rooms (e.g., Durak, Olguntürk, Yener, Güvenc, & Gürcinar, 2007; Flynn, Hendrick, Spencer, & Martyniuk, 1979; Flynn & Spencer, 1977; Schierz & Krueger, 1995; Tiller & Rea, 1992). However, these studies focused on somewhat more complex and more holistic attributes, such as overall spaciousness, clarity, or pleasantness. Ratings of the perceived dimensions of the rooms (i.e., perceived height, depth, or width) were not obtained. More generally, next to nothing is known about potential effects of interactions between surface color and lighting on the perceived spatial dimensions of interior rooms, which is an important question for future research.

Note also that we studied only one of the three dimensions of color, lightness. Although we anticipate that this color dimension has a stronger impact on the perception of interior rooms than hue or saturation (for a discussion, see Oberfeld et al., 2010), experiments studying the effects of the latter parameters are desirable, especially given the rather strong hypotheses about the influence of, for example, different types of hues on perceived room size (e.g., Heller, 2008; Meerwein et al., 2007).

We used a VR approach, which enabled us to independently vary the physical dimensions and the surface colors (cf. Oberfeld et al., 2010). Can the effects found in the VR setting be expected to generalize to real rooms and viewing conditions? For example, it has been reported that egocentric distances in virtual environments are underestimated relative to distances in real environments (e.g., Witmer & Sadowski, 1998). Concerning estimates of room height, Franz (2005) found a comparably small underestimation in VR.

However, in Experiments 2 and 3 of the present study, we were not interested in the absolute accuracy of the height or width estimates, which in fact varied considerably across participants. Rather, the experiments studied the effect of different surface lightness values and different simulated room heights and depths on the estimates. As all estimates were made in the same virtual environment, any systematic distortion of, for example, estimated height would have affected all experimental conditions. Therefore, a potential compression of perceived space in a virtual environment does not affect the interpretation of the effects of surface lightness we observed. In general, we are convinced that the advantages of VR in terms of experimental design outweigh potential disadvantages, although ultimately, of course, this is an interesting empirical question.

Given that we find some of the experts' opinions to be reflected in psychophysical assessments of perceived space, whereas other opinions are not thus grounded, how does expert opinion come about? And can it be trusted? It appears that wherever expert opinion is unanimous, it correlates highly with the assessment of perceptual judgments. In areas where expert opinion is not unanimous, such as the effect of floor color on perceived spaciousness, we tend not to find significant effects in the psychophysical data. That is, when aggregated, expert opinion does match psychophysical assessment. Interestingly, the individual expert opinion seems to be felt with equal confidence regardless of whether it is backed by consensus. This makes the psychophysical assessment of perceived space particularly valuable for those cases in which expert opinion has not converged on a general perceptual truth.

CONCLUSION AND APPLICATIONS

Light ceilings and light walls make a room appear higher. This effect of interior space is qualitatively different from color effects exerted by solid objects viewed from outside. As Oberfeld et al. (2010) have discussed, it is surprisingly difficult to explain the effects of surface lightness on perceived height within the framework of studies on effects of brightness on the perceived distance of small objects. A bright object subtending the same visual angle as a darker object appears closer (e.g., Coules, 1955; Mount, Case, Sanderson, & Brenner, 1956), or more precisely, an object with a higher brightness contrast to the background appears to be less distant (e.g., Farnè, 1977; Ichihara, Kitagawa, & Akutsu, 2007; O'Shea, Blackburn, & Ono, 1994; Rohaly & Wilson, 1999).

If observers judge the room height by estimating the distance of the ceiling from their eye height (cf. Marcilly & Luyat, 2008; Wraga, 1999), then a light ceiling viewed before a background of darker walls should appear *closer*, and thus, the room should appear *lower* with a light as opposed to dark ceiling. This prediction is exactly the opposite of what our current data show, demonstrating that findings concerning the perceived distance of small, isolated objects cannot be generalized to the perceived dimensions of three-dimensional interior rooms (for an in-depth discussion, see Oberfeld et al., 2010).

The apparent height of interior rooms depends on the lightness of the ceiling and, to a lesser extent, on the lightness of the adjacent surfaces. Although we have now achieved a sound knowledge of the effects of surface lightness on perceived height, additional experiments are needed to answer the question of how the perceived width, perceived depth, or more global dimensions, such as the impression of overall spaciousness, are influenced by the color of ceiling, floor, and walls. On the basis of our results on apparent height, we would expect effects of the lightness of side walls on perceived width and an influence of the lightness of the end wall on perceived depth. The results of this study show that it is worthwhile to dissect the ingredients of perceived spaciousness of interior rooms.

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KEY POINTS

- Experts and empirical data agree that light ceiling colors increase the apparent height of interior rooms.
- The effects of wall color are often misjudged.
- Ceiling lightness and wall lightness have an additive effect on perceived height.
- Floor lightness has no direct effect on perceived height but modulates the effects of wall lightness.
- For interior rooms, width and height show an asymmetric interaction.

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