Urban Experience Alters Lightness Perception

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OBSERVATION

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We present the first empirical evidence that experience alters lightness perception. The role of experience in lightness perception was investigated through a cross-cultural comparison of 2 visual contrast phenomena: simultaneous lightness contrast and White's illusion. The Himba, a traditional seminomadic group known to have a local bias in perception, showed enhanced simultaneous lightness contrast but reduced White's illusion compared with groups that have a more global perceptual style: Urban-dwelling Himba and Westerners. Thus, experience of the urban environment alters lightness perception and we argue it does this by fostering the tendency to integrate information from across the visual scene.

Public Significance Statement

Our perception of the lightness of a surface is often regarded to be driven not by experience, but by aspects of our visual physiology that are so fundamental as to be universal. In a cross-cultural study involving Western and non-Western participants, we found that the way in which human adults perceive lightness (measured in some classic visual effects and illusions) depends on how urbanized they are. We have shown for the first time that our experiences influence the way we perceive lightness.

Keywords: perception, lightness, experience, cross-cultural, urbanization
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Perceiving the lightness of an object or surface is so fundamental to vision that it is easy to believe arguments that it is hard-wired into our sensory physiology (e.g., Hartline, Wagner, & Ratliff, 1956; Troy & Enroth-Cugell, 1993). Here we use cross-cultural comparisons of two visual contrast phenomena—simultaneous lightness contrast and White's illusion—to show that experience determines lightness perception to a radical extent.

The Himba, a traditional seminomadic group with a striking local spatial bias in perception, showed enhanced simultaneous lightness contrast but reduced White's illusion compared with groups with a more global perceptual style: urban-dwelling Himba and Westerners. As we describe below, the pattern of cross-cultural differences found across these lightness phenomena is explained by differences in local-global perceptual style. We conclude that urban experience profoundly influences the way in which lightness information is sampled, and ultimately the way in which lightness is perceived.

In the classic demonstration of simultaneous lightness contrast, a gray target surface on a white background appears darker than an identical surface on a black background (Figure 1a). Simultaneous lightness contrast has long been considered an effect of purely local borders (Hartline et al., 1956; Troy & Enroth-Cugell, 1993) but is now known to be affected by a broader visual context (Gilchrist, 2013; Vladusich, 2012): in the classic demonstration of simultaneous lightness contrast, removal of the black–white boundary between target backgrounds enhances simultaneous contrast (Gilchrist, 2013; Yarbus, 1967). Thus, a reduced tendency to process this black–white boundary should enhance simultaneous lightness contrast. Traditional Himba observers, who have little urban experience, a marked local bias (Davidoff, Fonteneau, & Fagot, 2008), and a striking ability to focus attention on target information (Linnell, Caparos, De Fockert, & Davidoff, 2013) should, therefore, show greater simultaneous lightness contrast than both Westerners and urban Himba.

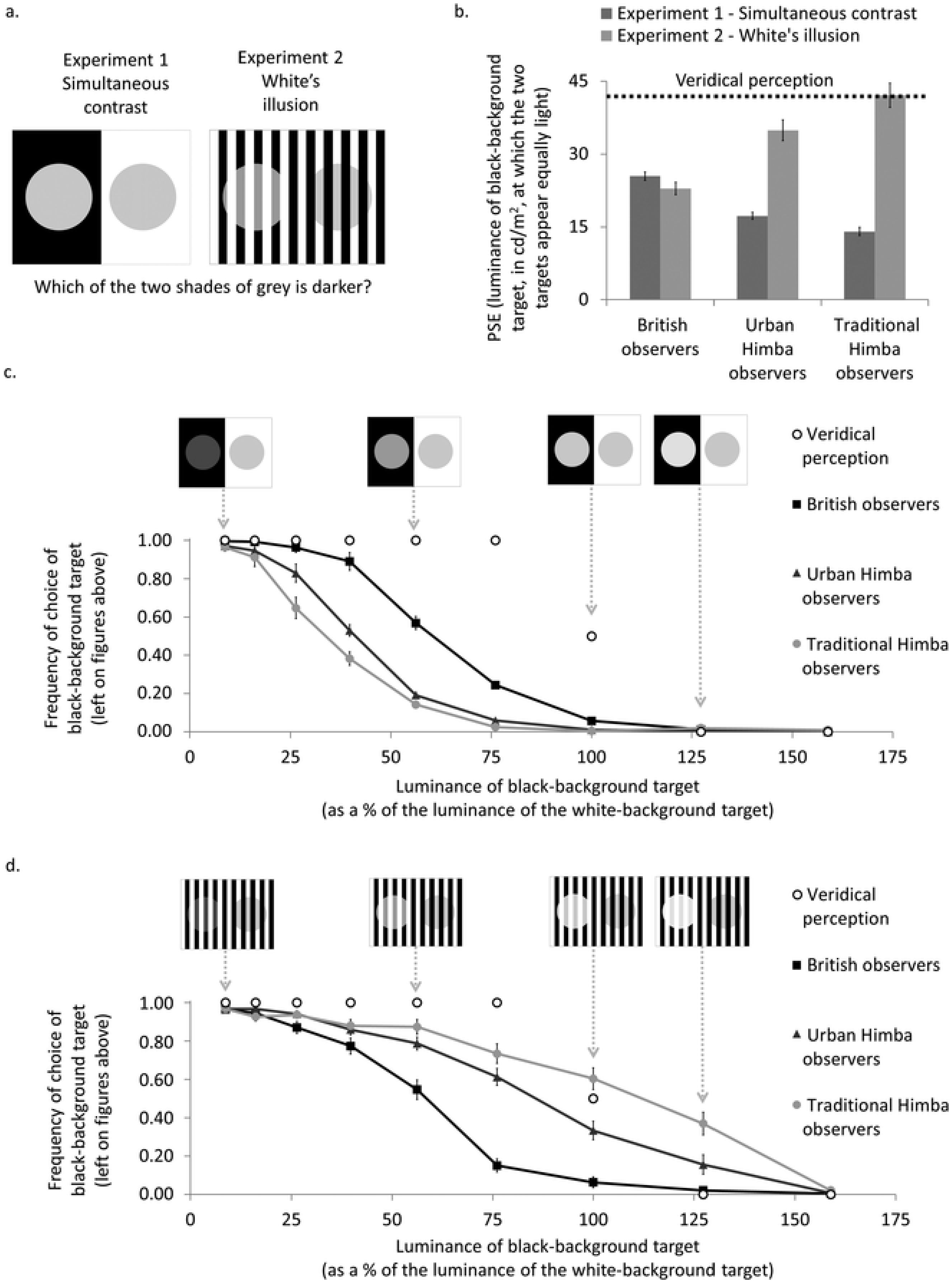

Figure 1. Effects of urban experience on lightness perception. (a) Classic demonstrations of simultaneous lightness contrast (left) and White's illusion (right). In both examples, the two

shades of gray are of equal reflectance, but observers typically identify the shade on the right as being darker. The psychophysical relationships between perceived lightness differences and actual differences in gray shade luminance for the three populations are plotted for the simultaneous lightness contrast stimuli (c) and White's illusion (d). Arrayed along the top of c and d are four examples from the range of stimuli. The far left and far right are examples from either end of the ranges. The second example from the left is a close approximation to the stimuli in which the gray shades were judged to be of equal lightness by Western participants. The third example from the left shows the two gray shades with equal reflectance. (b) Lightness PSEs in cd/m2 for British, urban Himba and traditional Himba participants for both simultaneous lightness contrast and White's illusion; higher PSEs indicate reduced simultaneous lightness contrast and perception that is more veridical.

At the same time, traditional Himba should, because of their local bias, show reduced White's illusion (Figure 1a). White's stimuli produce a marked lightness illusion in Westerners who organize the target circles with their respective backgrounds, rather than with the overlaid bars. If the traditional Himba either complete the target circles less or focus their attention more on the local contours between the vertical bars and the target circle parts, then their perception of lightness should be determined less by contrast with the background and more by contrast with the vertical bars. Thus, as a result of their local bias, the traditional Himba should perceive reduced White's illusion compared with Westerners and urban Himba.

Method

The three populations studied were: (a) 39 traditional Himba (16 women, 23 men; mean estimated age = 25 years, age range = 16–45 years), (b) 49 urban Himba (24 women, 25 men; mean estimated age = 27 years, age range = 17–58 years), and (c) 43 British undergraduate students from Goldsmiths, University of London (26 women, 17 men; mean age = 26 years, age range = 19–53 years). Traditional Himba are seminomadic herders living on the Namibian/Angolan border who have little contact with Western artifacts (see supplemental Figure in the supplemental materials, and Biederman, Yue, & Davidoff, 2009, for examples of the two Namibian environments). On average, traditional Himba observers had visited the only local town (Opuwo) less than three times in their lifetime. Urban Himba had grown up in a traditional Himba village with traditional Himba parents but had moved to Opuwo (that has grown rapidly in the last decade) at an average age of 20 years (range 8–46 years) and had been living in Opuwo for an average of 7 years.

A previous study comparing the same demographic of traditional Himba and urban Himba with United Kingdom participants produced large effect sizes for group differences in perceptual bias (ηp^2 = .404 based on similarity matching with hierarchical patterns, and ηp^2 = .316 based on the Ebbinghaus illusion; Caparos et al., 2012). Given that perceptual bias does drive lightness perception, we can use these effect sizes for group differences in bias as estimates of the effect size for group differences in lightness perception, and conclude that the present sample size confers a power of 1.00 (based on matching data) and 1.00 (based on findings with the Ebbinghaus illusion).

All participants took part in both simultaneous lightness contrast and White's illusion experiments, in counterbalanced order. The traditional Himba and urban Himba participants received instructions via an interpreter who was naïve to the purposes of the study. The urban Himba and British observers were paid in return for participating. The traditional Himba participants were compensated in kind with sugar and flour. The study was approved by the departmental Ethics Committee at Goldsmiths. Experiments were run using a script constructed in E-Prime 1.0 (Schneider, Eschman, & Zuccolotto, 2002) and stimuli were presented on a 20-in CRT screen viewed from a distance of 70 cm.

To estimate simultaneous lightness contrast, on each trial, two gray target circles 12.0° in diameter were presented along the horizontal midline of the display with their centers 8.0° either side of the vertical midline, one on a white background and the other on a black background (see Figure 1a, left). Two vertical red arrows, subtending 7.2° in length and 2.4° in width, were superimposed, aligned with the target centers, and descended from the top of the screen so that their tips fell within the targets at 0.9° from the targets' upper edge. The observer was asked to signal which shade of gray indicated by the red arrows was darker, by pressing the left or right button on a response box. All participants were instructed to be as accurate as possible, and performed two blocks of practice trials and one block of test trials (see supplemental material for further details). Across the 54 test trials, the luminance of the white background target always remained the same (luminance = 41.8 cd/m^2) but the luminance of the black background target varied from trial to trial, between nine possible contrast conditions. In two contrast conditions, the black-background target (luminance = 53.2 or 66.4 cd/m^2) was higher in luminance than the white-background target, in one condition the targets were of equal luminance (luminance = 41.8 cd/m^2), and in the remaining six conditions, the black-background target (luminance = 3.7, 6.7, 11.0, 16.6, 23.5, or 31.8 cd/m^2) was lower in luminance than the white-background target. The resulting nine contrast conditions occurred equally often. The asymmetry of target differences in the stimulus set was implemented to avoid a large number of redundant conditions (the simultaneous contrast effect cannot occur when the black-background target is higher in luminance than the white-background target) and also meant that the condition in the middle of the range did not present equal luminance targets. Thus, neither random performance nor any strategy based on the range of black-background target shades could present as veridical performance. Accuracy was calculated for each contrast condition. Excluded from the analyses were all participants who did not achieve five out of six correct responses on two extreme conditions of the test block, that is, the conditions in which the black-background target was the highest (66.4 cd/m^2) and the lowest (3.7 cd/m^2) in luminance. This allowed us to filter for participants who had sufficiently understood the task while still allowing for one "inattention" mistake. These criteria led to the exclusion from the analyses of five traditional Himba participants (out of 39), three urban Himba participants (out of 49) and two British participants (out of 43).

The same stimuli and procedure were used to estimate the strength of White's illusion except for the following differences. During the second practice block and during the test block, vertical white stripes were superimposed over the black background and its target, and vertical black stripes were superimposed over the white background and its target (see Figure 1a, right). The stripes measured 1.6° in width and were also separated from each other by 1.6°. Once again, red arrows were introduced, one in the center of each half of the display, and participants were instructed to decide which shade of gray pointed to (left or right) was darker by pressing the left or right button on a response box. Accuracy was calculated for each contrast condition. Excluded from the analyses were all participants who did not achieve five out of six correct responses on the two extreme conditions of the test block. These criteria led to the exclusion from the analyses of seven traditional Himba participants (out of 39), six urban Himba participants (out of 49), and three British participants (out of 43). See supplemental material for further details of the method.

Results

To measure simultaneous lightness contrast, we varied the luminance of the gray circle on the black background and asked the participants which of the two shades of gray looked darker. To estimate White's illusion, we used the same procedure but asked the participants to decide which of the two shades of gray looked darker, while ignoring the superimposed vertical lines. For both tasks, we plotted the frequency with which each participant chose the black background target. The psychophysical relationships between perceived lightness differences and actual differences in gray shade luminance, for the three populations (Traditional Himba, Urban-dwelling Himba, and Westerners), are plotted for the simultaneous lightness contrast stimuli (Figure 1c) and White's illusion (Figure 1d).

For both stimuli, the psychophysical data were fitted with the model: $p = \varphi([k—d]/\sigma)$, where p is the probability of choosing the black background target, $\varphi(z)$ is the inverse cumulative distribution function for a standard normal distribution, k is the required threshold for deciding that the black background target is the darker one, d is the difference between the luminance of the two targets (in cd/m^2) and σ is the *SD* of the normally distributed noise from all sources.

We then computed the point of subjective equality (PSE) of the lightness of the two gray targets, expressed in terms of the luminance of the black background target at which it was perceived to be of equal lightness to the white background target (that always had a luminance of 41.8 cd/m^2). PSEs closer to 41.8 cd/m^2 were more veridical. Typically, where a simultaneous lightness contrast effect is present, PSEs are significantly lower than veridical.

The key results are presented in Figure 1b. One way analysis of variance (ANOVA) revealed an effect of Group (traditional Himba, urban Himba, and British) on the mean point at which equal lightness was perceived (PSE), for both the simultaneous lightness contrast stimuli, $F(2, 118) = 42.19$, $p < .001$, $\eta p^2 = .417$, and the White's illusion stimuli, $F(2, 112) = 24.90$, $p < .001$, $\eta p^2 = .308$.

Follow-up comparisons (Bonferroni corrected) of simultaneous contrast effects showed that mean PSE was higher in the British (25.4 cd/m^2, *SD* = 5.3) than in the urban Himba observers (17.3 cd/m^2, *SD* = 5.7), $t(85) = 6.89$, $p < .001$, $d = 1.49$, and that the urban Himba observers had a higher PSE than the traditional Himba observers (14.5 cd/m^2, *SD* = 5.0), $t(78) = 2.29$, $p = .048$, $d = 0.53$. Thus, the more urban groups showed a reduced simultaneous lightness contrast effect and a more veridical perception of lightness in this context.

Follow-up comparisons (Bonferroni corrected) of White's illusion effects revealed the opposite pattern: mean PSE was lower in British observers (22.9 cd/m^2) compared with the urban Himba (34.9 cd/m^2), $t(81) = 4.92$, $p < .001$, $d = 1.09$, who in turn had lower PSEs than traditional Himba observers (42.1 cd/m^2), $t(75) = 2.32$, $p = .044$, $d = 0.55$. Thus, the more urban groups showed an enhanced perception of White's illusion, and a less veridical perception of lightness in this context.

If a more local perceptual style causes higher simultaneous lightness contrast and lower White's illusion, as we have hypothesized, we should expect a negative correlation between the extent of simultaneous lightness contrast and White's illusion across individuals. Thus, we investigated the relationship between the mean PSE for simultaneous lightness contrast and the mean PSE for White's illusion across the entire sample and found a strong negative correlation between the two PSEs that we used as measures of the simultaneous contrast effect and White's illusion, $r(105) = -.59$, $p < .001$.

Discussion

Our findings demonstrate substantial cross-cultural differences in lightness perception between groups varying in urban exposure: Compared with the traditional (nonurban) Himba, both the urban Himba and the urban British participants expressed weaker simultaneous lightness contrast but stronger White's illusion. Both effects can be explained by the urban participants adopting a more global perceptual style: the urban reduction of simultaneous lightness contrast is explained by a greater influence of the global boundary between black and white grounds (Gilchrist, 2013) and the urban enhancement of White's illusion is explained by a greater tendency to process circle-parts together and to perceive them contrasted against the background rather than the vertical bars.

The urban Himba showed contrast effects on their lightness perception that sat between those of the traditional Himba and the Western controls. This is predicted by a dose-effect relationship, given the lesser urbanization of a small African town (Opuwo) compared with a large Western city (London) and the fact that the urban Himba had grown up traditionally.

We propose that the effects of varying urban exposure on lightness perception are because of concomitant, and proportionate, changes in perceptual style. Our previous research has shown that local bias is reduced in proportion to the extent of urban experience (Bremner et al., 2016; Caparos et al., 2012; Linnell et al., 2013). Here we show that the magnitude of simultaneous lightness contrast and White's illusion are negatively correlated, with lightness contrast decreasing and White's illusion increasing with urban exposure. The latter is exactly what is predicted if perceptual style becomes proportionately less local with urban exposure and in doing so causes proportionate decreases in simultaneous lightness contrast and increases in White's illusion.

Given the scale of the group differences in lightness perception reported here, it is prudent to consider the possibility that they are underpinned by differences in basic vision. One obvious possibility is that the Himba possess uncorrected refractive errors (although previous tests of visual acuity have not supported this). While White's illusion—like simultaneous lightness contrast—is purely contrast-based at the low spatial frequencies of grating used here (Blakeslee, Padmanabhan, & McCourt, 2016), refractive errors would effectively cause assimilation effects that also affect White's illusion (Blakeslee & McCourt, 2004). Assimilation effects, however, enhance White's illusion, suggesting that refractive differences do not play an important causal role here. In contrast, the scale of the group differences in lightness perception reported here is entirely in keeping with the scale of group differences in perceptual style previously reported to arise from experience (Caparos et al., 2012).

Thus, we argue that our findings are consistent with a role of experience. Though the phenomena measured here have been successfully modeled in Bayesian accounts (Corney & Lotto, 2007), we have no way of knowing whether the history of lightness perception for our populations fits the assumptions of such models. It is, however, known that differential sampling of displays affects lightness perception (Toscani, Valsecchi, & Gegenfurtner, 2013); such research is consistent with our proposal that differences in local-global perceptual style—whether manifesting in differences in covert or overt sampling or both—cause differences in lightness perception.

In summary, we have provided the first empirical evidence that even so fundamental an aspect of perception as lightness is not hard-wired (see also Toscani et al., 2013) and can be altered by perceptual experience over a timescale that remains, as yet, to be clarified. Our findings consolidate mounting evidence that urban experience biases observers to process visual information more globally. Furthermore, they provide evidence that it is the more global perceptual style fostered by urban living that results in substantial effects on lightness perception through a greater influence of contextual information. Accounts of lightness perception need to take into account stimulus configuration but also perceptual style and its effects on stimulus integration and sampling.

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