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In the present study I tested the effect of stereoscopic depth on the lightness of two targets equal in size, presented simultaneously so that one target appeared in depth coplanar to the background and the other appeared floating in a frontal plane closer to the observer. When targets were equal in luminance, the target that appeared more distant from the observer appeared also more contrasted to the background: when targets were increments with respect to the luminance of the background the distant target appeared lighter than the closer one; vice versa when targets were decrements the distant target appeared darker. Results are discussed with respect to the Gestalt factor "belongingness", and to more recent finding of the effect of perceived size on lightness in the Delboeuf and the Ebbinghaus Illusions.

Keywords: lightness, belongingness, perceived size

1. Introduction

It has been recently demonstrated that both the Delboeuf and the Ebbinghaus size-contrast illusions have an effect on the lightness (achromatic surface colour) estimation of two targets equal in size and in luminance[1,2]. In both the Delboeuf and the Ebbinghaus illusions, the target that appears bigger appears also more contrasted to the background. In other words, if targets are decrements to the background (targets darker than the background), the target that appears bigger appears also darker than the other one. Vice versa, if targets are increments (targets lighter than the background), the target that appears bigger appears also lighter than the other target.

Effects of perceived size on lightness have already been reported in other studies. Brigner[3] was the first to show the effect of the Delboeuf and the Ebbinghaus illusions on lightness, but he failed to notice the role played by the contrast sign between targets and background in the lightness outcomes. Gilchrist[4,5] reported instead that when a visual scene is comprised of only two surfaces, lightness is positively correlated to the area of surfaces: as a surface is increased in perceived size it tends to appear brighter. If such findings were to be extended in terms of a more general area rule, it would not account for the findings previously reported concerning the effects of lightness caused by the Delboeuf and the Ebbinghaus illusions.

On the other hand, it has been suggested that these size-contrast illusions are triggered by different factors, including implicit depth indexes[6,7]. This hypothesis is indirectly supported by Vicario[8] who reported a density effect in the texture of targets physically equal inserted in Delboeuf contrast rings: the target that appeared bigger appeared also to have a more rarefied texture. This effect, however, is consistent with two opposite depth interpretations of the scene: 1) the target that appears bigger appears actually closer to the observer, hence the texture rarefaction is a case of magnification; 2) the target that appears bigger appears also far away, hence the texture rarefaction is directly related to size.

The following experiment draws inspiration from all these issues, as it is the first of a series of experiments in which I address the hypothetical role of size and distance in the lightness effects observed in both the Delboeuf and the Ebbinghaus illusions. In this experiment, however, I did not use those illusory configurations; I used instead square targets equal in size but that appeared different in size because of their apparent differences in depth caused by stereopsis: the target that appeared far in depth appeared also bigger than the target that appeared floating in the front plane.

2. Experiment

2.1 Participants

Four participants (1 female and 3 male, age 25–55), who were either members or guests of the Psychology Department of Tohoku Gakuin University in Sendai, volunteered to take part to the experiment. All participants had normal or corrected-to-normal vision. One participant is the author of this study (O), another participant was aware of the purpose of the study (D), while other two participants were completely naïve to the purpose of the study (P and T).

2.2 Stimuli

Stimuli were stereograms (**Fig. 1**) with target disparities set to ±0.24°. Targets consisted in two grey squares (sides 0.5 cm) seen against a square background (side 6.5 cm) that was surrounded by a random dot frame (width 2.5 cm). The far target was the standard stimulus (ss) and its luminance was 38.8 cd/m^2. The near target (comparison stimulus, cs) had one of the following luminance values: 34.3, 35.5, 36.6, 37.4, 38.8, 40.0, 41.1, 42.1, and 43.2 cd/m^2. The left-right positions of ss and cs were balanced. Targets were seen either on a dark (8.5 cd/m^2) or on a bright background (98.4 cd/m^2). From here on, light targets on the dark background will be denoted as *increments*, and dark targets on the bright background will be denoted as *decrements*. A small red fixation cross was present at the centre of each configuration and it appeared to be floating in a middle plane, coplanar to the random dot frame.

The combination of cs luminance × background luminance determined 18 ss+cs configurations, each of which was presented 20 times in random order on a CRT Sony™ MultiScan G 520® controlled by an Apple™ MacBook Intel Core Duo 2®. Configurations were viewed through a mirror stereoscope at a distance of 61 cm.

2.3 Procedure

The method of constant stimuli was used with a forced-choice task: participants were asked to indicate which of two targets appeared darker, the left one or the right one, by pressing a yellow key for the left target or a red key for the right target. The yellow key and the red key were positioned at opposite ends of a keyboard. Participants were first presented with a training task to verify whether they perceived stereo depth correctly. All participants carried out the

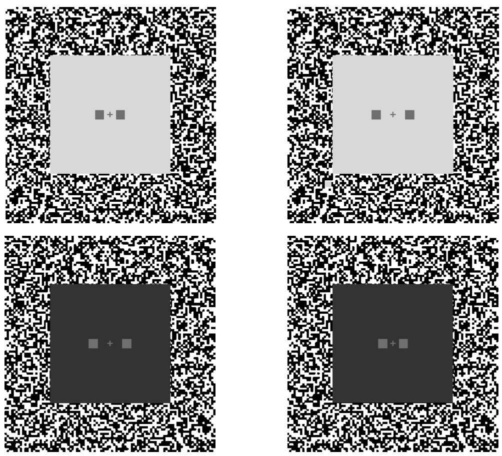

Fig. 1. Example of the stereograms used in the experiment: decrement targets (top) and increment targets (bottom).

task easily and quickly without errors. After the training trials, instructions appeared for the actual task; if there were no questions, the participant was instructed to press either one of the two response keys to start the experiment. A pause was set after 5 blocks of trials. Participants were invited to press either one of the response keys when they were ready to resume the experiment. The entire experiment lasted for about 30–40 minutes, depending on participants' response times. At the end of the experiment, subjects were asked whether the targets appeared equal in size. All subjects saw the targets in the far plane as bigger than the targets in the near plane.

2.4 Results

Fig. 2 displays the results for increments and decrements for each participant. As one can readily see, all four participants responded practically in the same way when the comparison stimulus (near target) and standard stimulus (far target) had the same luminance (38.8 cd/m^2): with increments, the ss appeared lighter; with decrements it appeared darker than the cs. Furthermore with increment configurations, for participant *D* ss appeared lighter with all cs>38.8 cd/m^2; for participants *O* and *P* the PSE corresponded to cs=43.2 cd/m^2; for participant *T*, PSE corresponded to 42.1 cd/m^2. With decrement configurations, for participants *D* and *O* the PSE corresponded to cs=34.3 cd/m^2; for participant *P* the PSE corresponded to cs=36.6 cd/m^2; for participant *T* the PSE corresponded to cs=35.5 cd/m^2. PSEs are confirmed statistically by binomial tests in which the theoretical proportion of the ss appearing darker in both increment and decrement configurations was set respectively to 0.6 and 0.4, given that the ss was physically either more or less intense than the cs.

2.5 Discussion

In this experiment two targets equal in size were seen at different depths by means of stereoscopic presentation: the target that appeared in the front plane appeared smaller and less contrasted with the background, independently from whether the targets were luminance increments or decrements with respect to the background. This experiment supports the hypothesis that the lightness effects in the Delboeuf and the Ebbinghaus illusions are related to a combination of perceived size and perceived depth. The "magnification" hypothesis, instead, according to which the target that appears closer should appear also more contrasted to the background, is not supported by the data. Opposite results are actually found: it is the target that appears more far away that appears more contrasted to the background.

2.5.1 Lightness, depth, and belongingness

The results presented here are interesting also because they relate to another issue: the role played by the Gestalt factor *belongingness* in surface colour contrast. Wolff[9] showed that in simultaneous lightness contrast, the lightness difference between two targets of equal physical intensity is greatly reduced when the targets are coplanar to each other but separated in depth from their backgrounds. Yet, while this effect was observed with an actual depth separation, it was not found when targets and background were seen in different depth planes by means of stereopsis[10,11].

The data from the experiment reported above, however, clearly supports the role of belongingness in lightness perception: in incremental displays, for instance, not only does the target seen adjacent to the background appear lighter than a target of equal luminance floating in a front plane, but it appears also

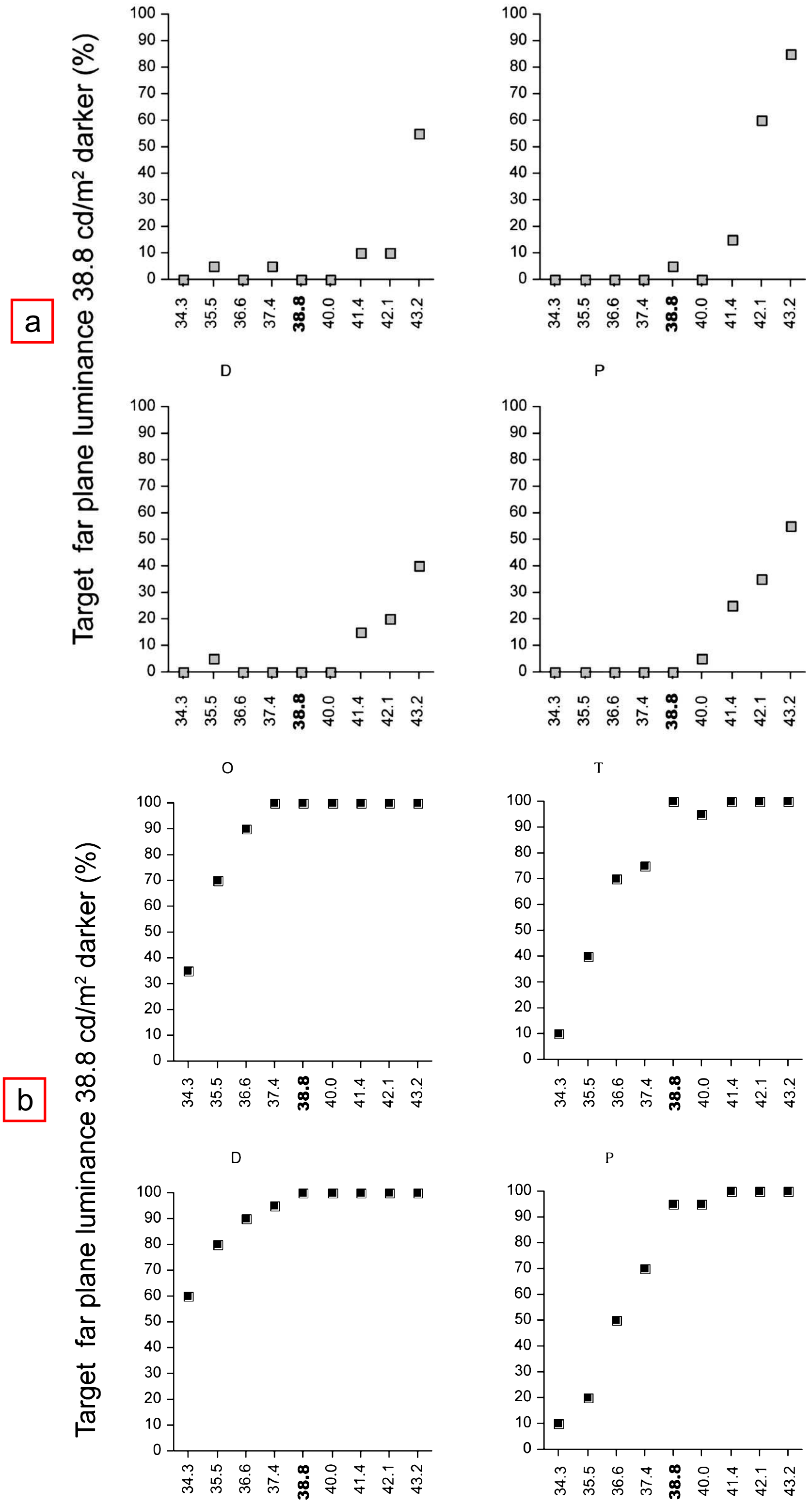

Fig. 2. Results for increment targets (a) and decrement targets (b): x-axis indicates the proportion (%) of ss (38.8 cd/m^2) indicated as the target that appears darker; y-axis indicates the corresponding luminance of cs.

lighter with respect to targets physically lighter. The luminance difference between targets might be small, but the effect is robust. These findings are also in line with those reported by Coren[12], who studied the Benary cross configuration in stereoscopic presentations: when the targets were seen floating in front of the cross, the lightness effect virtually disappeared. Finally, they are also consistent with findings reported by Kardos[13]: in his experiments a middle grey disk appeared lighter when it was adjacent to a dark background in the far plane than when it was floating in a near plane detached from the same background.

3. Conclusions

The results from the experiment reported above support two hypotheses: 1) lightness is affected by perceived size (the target that appears bigger appears also more contrasted to the background), and 2) lightness is affected by belongingness (the target that is seen adjacent to the background appears more contrasted. Only the first hypothesis applies directly to the lightness effects observed in both the Delboeuf and the Ebbinghaus illusions[1,2]. Nevertheless, the two hypotheses are not mutually exclusive; in fact, the effects of size and belongingness may be combined in this experiment. Hence, to test the role of such effects new experiments are being carried out in which perceived size and perceived belongingness are contrasting factors within the same visual scene.

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