Virtual Reality Technology for the Visual Perception Study

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Abstract

Visual illusions have provided researchers with important insights into the rules of how the visual system interprets environmental information. In current models of lightness perception it has been suggested that 2D visual cues in a scene play a crucial role in lightness estimations. The role of depth cues was investigated in some studies, but the results were contradictory. Lately, the virtual reality (VR) techniques were applied successfully to investigate 3D visual perception. Using the CAVE system, we studied the strength of 3D visual illusions. We investigated the role of 3D articulated backgrounds in the perception of the simultaneous lightness contrast (SLC) illusion. The results showed that the illusion strength decreased for all 3D displays relative to the 2D articulated version. There were no significant differences between different types of 3D displays.

Keywords and Phrases: *3D visual illusions, lightness perception, simultaneous lightness contrast Virtual Reality, VR, CAVE.*

1. INTRODUCTION

The problem of lightness perception is tightly connected with the perception of lightness illusions. They were often used as demonstrations of theoretical assumptions by different approaches to lightness perception. Recently the anchoring theory of lightness perception was frequently debated [4]. It assumed that the ratios of the test surface luminance to the luminance of other surfaces determined this process. Using these ratios it was possible to estimate the relative reflectance of all surfaces, which were equally illuminated. Since objects lying in the same surfaces were illuminated uniformly in natural scenes, it was assumed, that it was the luminance ratio of coplanar surfaces that was a basic stimulus for lightness perception. It allowed the relative reflectance of all surfaces to be computed. To estimate the absolute reflectance the anchoring rule was applied: one of relative reflectance values anchored to some absolute value, for example, to the most luminous object which supposed to be white [8; 4]. In complex scenes the lightness estimation was accomplished into two stages. At first the groups of coplanar surfaces were picked out, and then the lightness was estimated in accordance with the anchoring rule for each group. The anchoring rules "worked" in the range of local and global frameworks. Local frameworks were used to estimate the luminance ratio of the test and adjacent background patches of a surface. Global frameworks were used for estimating the luminance ratio of test and distant patches of a surface. These theoretical hypotheses were used to explain some of lightness illusions, for example the simultaneous lightness contrast (SLC) illusion [4; 3]. It was found that the SLC illusion formed mainly on the anchoring rules of local frameworks. In our study we investigated the influences of 1) depth cues and 2) articulation cues on lightness perception to test the anchoring theory.

The role of depth cue was tested in a number of works, but the results were contradictory. The main idea of these studies consisted in manipulating of 3D positions of test surfaces relative to background surfaces. In accordance with the coplanar ratio hypothesis it would result in a shift of lightness estimations. Some works [9; 1] confirmed these predictions. These results showed that the relationship between test and background surfaces occurred only when they were coplanar to each other. Other studies did not reveal or determined the very weak influence of coplanar ratios on lightness estimations [2; 11]. So, the question of depth cue influence remained unclear. In our study the strength of the SLC illusion was investigated as a function of 3D configurations of test and background squares. In line with the coplanar ratio hypothesis lightness estimations were determined by the anchoring rules which had the relative strengths within the local and global frameworks. When the test squares were moved out of the background squares it would result in weakening local anchoring and, in their turn, in reducing the illusion strength.

The influence of the articulation cues on lightness perception was proposed and investigated by D. Katz [6]. Articulation effects were determined as the influence of the background. complexity on lightness estimations. The term "complexity" referred to the number of colored patches of the background. The rule of articulation was formulated as following: the more colored patches were located around the test patch the better lightness estimations. This rule has been co-determined in the anchoring theory to accommodate the modern approaches and studies on lightness perception [5]. We proposed that "complexity" may be considered not only as the number of colored patches of the background, but also as 3D content of the background. Then the rule of articulation may be formulated as following: the more complex 3D scene would surround the test patch the better lightness estimations and, in turn, the high the illusion strength.

The last decades have seen a rise in usage of a new Virtual Reality (VR) technology in psychological research. By now its effectiveness has been proven by medicine, neuropsychology, cognitive and social psychology data. The virtual reality technology equips experimental psychology with methods that have certain differences from traditional laboratory instruments. A heated dispute of the advantages and disadvantages of the use of virtual reality systems in psychology has been held in all experimental and review works carried out within this new methodology [7; 10; 12]. As for the studies in lightness perception VR technology provides 1) active 3D viewing enable to construct visual illusions in depth and 2) complex 3D scenes with controlled parameters enable to reproduce articulated effects.

Using the the VR technology, we studied the strength of 3D SLC illusion to find out the role of 1) the depth cues and 2) the articulation cues in lightness perception.

Two hypotheses were offered:

1. Locating the test and background surfaces in different space positions would result in weakening local anchoring and, in their turn, in reducing the illusion strength. So, the strength of 3D SLC illusions would decrease relative to its classical 2D configuration.
2. The more complex 3D scenes of the background would result in better lightness estimations and, in turn, in high values of the illusion strength.

2. METHOD

2.1 Observers

Twenty five observers (age range 17–30) with normal or corrected to normal vision were tested. All observers were unaware of the purpose of the experiment.

2.2 Stimuli

The 2D articulated version of the SLC illusion (Fig. 1.1) was used as a basic display. Three different 3D configurations of the SLC illusion were constructed. They consisted of test squares which were moved out of the backgrounds and different types of 3D backgrounds. The first type was 2D articulated patches (Fig. 1.2), the second – 3D cubes (Fig. 1.3) and the third – 3D balls (Fig. 1.4). 3D backgrounds varied from simple (the first type) to complex (the third type) variant of articulation.

The average luminance of backgrounds was constant for all types of stimuli.

The method of constant stimuli was used to estimate the strength of the SLC illusion. The gray squares on the light backgrounds were standard. Its lightness was 30% of white shade in Grayscale units and was not changed during the experiment. Seven variable stimuli were created for every 2D-3D configuration, for which the value of lightness for the test squares lying on the dark backgrounds decreased from 30% to 12,5% of white shade with a step of 2,5%. So, 28 stimuli were created: four 2D-3D configurations, each having seven variable stimuli.

2.3 Apparatus

The 2D articulated version of the SLC illusion and three types of 3D displays were presented using the CAVE system (Fig. 2).

The CAVE system has four large flat screens (Barco ISpace 4), which are connected into one cube consisting of three walls and a floor. The length of each screen side is about 2.5 meters. Shutter eye glasses are made by CrystalEyes 3 Stereographics. Projection system is based on BarcoReality 909. The projector's matrix resolution is 1400x1050 with 100 Hz update frequency. Tracking system produced by ArtTrack2. VirTools 4.0 is used for software developing. It supports DX9/GL2, HAVOK, particle systems and shaders.

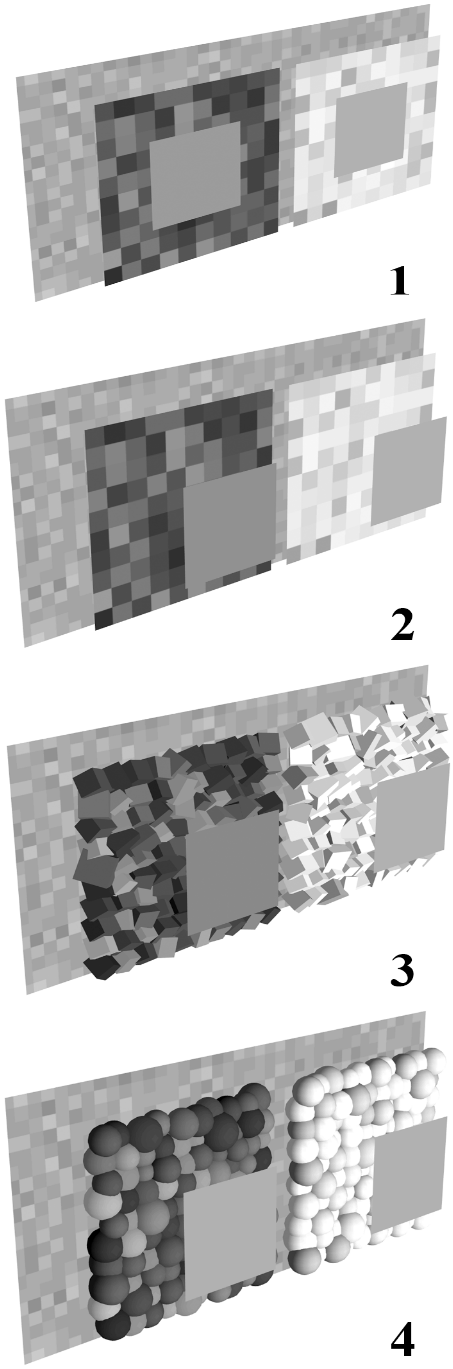

Figure 1: Different types of 2D-3D configurations of the SLC illusion: 1 – 2D classic articulated configuration; 2 – 3D configuration with 2D articulated background; 3 - 3D configuration with 3D articulated background (cubes); 4 -3D configuration with 3D articulated background (balls).

The observer stood motionless in front of the central screen at a distance of 2.5 m. Virtual stimulus configuration was located before him with the background placed on the screen plane. It subtended 30^{o} of visual angle horizontally and 15^{o} vertically.

The visual angle of the test squares in 3D configurations (2, 3 and 4) was the same as those in the 2D display (1). Thus, when projected on the retina, 3D and 2D displays produced practically the same pattern.

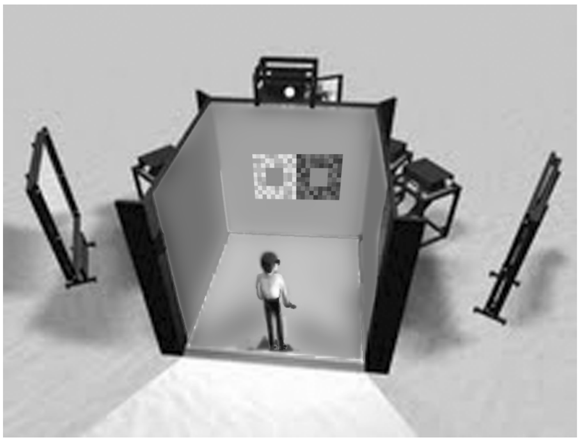

Figure 2: The CAVE system.

The laboratory room was darkened; there were no any light sources, except CAVE systems projectors. The luminance range in stimulus scene was 1:230. The maximum luminance was 5.5 cd/m^2, the minimum – 0.02 cd/m^2.

2.4 Procedure

The observer was given the following instructions: "Each trial you will see two gray test squares on the different backgrounds. Please, choose the lightest of two central squares, using a special joystick. Try to stand motionless during the experiment."

The experiment included four series: 1 – 2D articulated version of the SLC illusion; 2 – 3D articulated version of the SLC illusion with backgrounds consisted of 2D patches; 3 – 3D articulated version of the SLC illusion with backgrounds consisted of cubes; 4 – 3D articulated version of the SLC illusion with backgrounds consisted of balls.

Each series lasted about 5 minutes. The stimuli sequence was completely randomized. Every series consisted of 70 trials: each of seven variable stimuli was repeated 10 times. The left/right position of light and dark backgrounds was changed randomly.

3. RESULTS

Psychometric functions for 2D and three different 3D configurations were obtained and used to evaluate the strength of the SLC illusion for each participant and each 2D-3D configuration. The illusion strength was calculated as IS = (LSt – LT) / LSt * 100%, where LSt– was luminance of standard square; LT – PSE (Point of Subject Equality) - luminance of test square with 50% probability of answers "lighter".

The results averaged across 25 observers are shown in Figure 3. The horizontal axis plots the different 2D-3D configurations. The vertical axis plots the average strength of the SLC illusion (%).

The significant differences were revealed between the type 1 (2D articulated configuration) and the other different 3D configurations ($p<.001$). The strength of 2D classic display was twice more than the strength of any 3D display of the SLC illusion. As to articulation effects, there were no significant differences between the values of SLC strength calculated for three types of 3D backgrounds ($p<.01$).

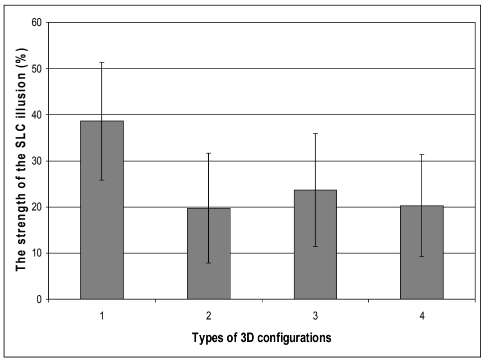

Figure 3: The strength of the SLC illusion for 4 types of stimulus configurations: 1 – 2D articulated configuration; 2 – 3D configuration with backgrounds consisted of 2D patches; 3 – 3D configuration with backgrounds consisted of cubes; 4 – 3D configuration with backgrounds consisted of balls.

4. CONCLUSION

The results showed that the illusion strength decreased for all 3D displays relative to the 2D articulated classic display. This result was in good agreement with the anchoring theory, predicting the reduction of the illusion strength in the conditions of different depth positions of the test and background surfaces. So, our first hypothesis was successfully confirmed.

There were no significant differences in illusion strength for different types of 3D backgrounds. It seems that articulation effects weakly depend on the type of 3D backgrounds. So, our hypothesis of the influence of 3D backgrounds on lightness estimations was not proved.

Virtual reality technologies may be effectively used in studies of lightness perception. It enables to reproduce visual illusions in depth and to construct complex 3D scenes with controlled parameters to create articulated effects.

5. AKNOLEDGMENTS

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