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Chapter

SHORT COMMUNICATION: VIRTUAL ENVIRONMENTS IN VISUAL PERCEPTION: APPLICATIONS AND CHALLENGES.

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ABSTRACT

A 3D virtual environment (a VR cave) is an extremely beneficial tool for the examination of visual perception. So far, very little work on Virtual Reality has been specifically dedicated to human perception. Nevertheless, this technology has a number of advantages over traditional computer- or paper-based experiments. Virtual reality provides precise control over the visual scene, to a degree that is extremely difficult to achieve by manipulating physical objects in a room. More specifically, it allows full control of the luminance and of the spatial arrangement of the surfaces in the environment. In addition, within the immersive system, depth perception can be elicited through a combination of binocular stereopsis, head motion parallax and maintaining constant luminance intensity. This chapter outlines how recent studies in visual perception have employed an immersive 3D environment and discusses directions for future research.

Keywords: Visual perception, lightness, contrast, VR Cave

INTRODUCTION

Visual perception is a central area of cognitive science, where some of the most remarkable advancements have been made in recent years. In fact, we know more about how the visual system works both functionally and biologically, than we know about any other part of the brain (Pylyshyn, 1999). Even so, there are many visual phenomena that still puzzle cognitive scientists and in some cases, the difficulty stems from finding a way to observe the

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phenomenon experimentally. The aim of this chapter is to outline some key phenomena in visual perception that are still not fully understood, such as the perception of colour under different illuminations, the perception of colour under different backgrounds, contrast and the perception of colour under different spatial arrangements. We will begin by describing how each one is traditionally examined in a research setting, discuss some problems that arise in studying visual perception and finally, we look at a recent study of perception that successfully employed virtual reality to overcome these limitations.

Visual perception phenomena and traditional experimental approaches.

The colour constancy phenomenon. The fact that we can recognise the same colour under different illuminations is a problem for visual scientists. Known as the colour constancy phenomenon, the puzzle is derived from the very thing that allows us to perceive the world: light. Visual objects are perceived by means of the light rays reflected from their surfaces to the retina. The amount of light that reaches the retina is the product of the incident light and the pigment of the object's surface. It follows then, that equally pigmented surfaces illuminated by different light sources would project different lights to the retina. Because of this, one might expect that we would perceive their colour differently. Surprisingly however, under many conditions, surfaces sharing the same superficial pigment are perceived as having the same colour, even when they are under different illumination and the light being sent to the retina is different (Katz, 1911). This phenomenon becomes even trickier in the achromatic domain. When achromatic surfaces are illuminated by white light, two equal reflecting surfaces appear to have the same level of greyness even when one is in shadow and the other is brightly illuminated.

Traditionally, these phenomena are examined using an experimental technique known as the light/shadow method (Katz, 1911, 1935; Gilchrist and Annan, 2002). The method involves two discs that are placed on a homogeneous achromatic background with a vertical screen between them. When light is projected from one side of the room, it fully illuminates one disc, while the other is in shadow. The discs used are known as Maxwell discs - after the Scottish physicist James Clerk Maxwell (1831 – 1879) – a black and white wheel mounted on the shaft of a motor. While the colour on the discs is a combination of black and white sectors, measured as a proportion of 360 degrees (e.g. 180° Black/180° White), spinning the disc at high speed (above 60 rounds per second) produces a homogeneous surface that appears as a shade of grey. By changing the proportion of Black and White it is possible to obtain any grey shade, from black to white.

In the study, the observer's task is to adjust the relative proportions of white and black on the illuminated disc to match the lightness of the disc in shadow. Studies have found that the two discs are perceived to have the same greyness when, in fact, the illuminated disc contains a much higher proportion of black than the disc in shadow. In other words, Katz found that colour constancy is not a perfect mechanism and two surfaces which are different in colour may still be perceived to be the same if one is more illuminated than the other.

The colour contrast phenomenon. Color contrast is the condition whereby two surfaces with the same spectral composition are perceived to have a different color when they are placed against different chromatic backgrounds (see Figure 1). This phenomenon is particularly important as it relates to a wider perceptual concept known as belongingness, which refers to the grouping of a set of apparent elements into a perceived whole

(Wertheimer 1923/1939). The traditional method of examining the relationship between perceptual grouping and contrast uses two identical square targets surrounded by a darker and lighter area (Benary,1924). The targets are perceived by the viewer to differ in colour according to their specific belongingness relationships (see figure 1a). The square target belonging to the darker area is perceived as being lighter than that belonging to the lighter area.

Colour perception under different (perceived) distances. Leonardo da Vinci noticed that bright objects tend to appear darker when moved away from the point of view, whilst dark objects tend to appear brighter with distance. Da Vinci attributed this phenomenon to the "colour of the air": with distance, bright objects tend to absorb the colour of the (darker) air and therefore they become darker; whilst dark objects tend to gain the colour of the (lighter) air and they become lighter. More recent research (e.g. Gilchrist, 1977) confirmed this observation and showed that the same colour can dramatically change by changing the perceived distance, by leaving the same physical distance.

The experimental apparatus ideated by Gilchrist used a black piece of paper, folded in a way that only half of it was under bright illumination. Two trapezoids, a bright grey and a dark grey were glued to the border of the black paper (as shown in figure 2). Observers could see the apparatus through a pinhole which limited their view of the entire scene. Illumination was adjusted so that from the observer’s point of view, the trapezoids share the same luminance. There were two experimental conditions: in the first one, observers had to judge the colour of the two trapezoids in monocular vision, whilst in the second condition the stimulus was seen in binocular vision. In binocular vision, the trapezoids depth was perceived effectively and so the darker trapezoid appeared darker when compared to the other. However, in the monocular vision condition, because of its shape, the darker trapezoid appeared at the same depth of the more illuminated area of the larger paper. The other trapezoid, instead, was perceived as if it was in the shadowed area. The combination of these effects led to the brighter trapezoid was perceived as being black, whilst the darker one was perceived as being white.

Limitations of traditional apparatus.

Each of the experiments mentioned above required the use of complex apparatus which had to be custom-built in order to examine the respective visual effect. Naturally, the examination of perceptual phenomena requires very specific manipulation of elements within the visual scene such as the amount of light/shade, distance of stimuli, location of stimuli in the visual field and controlling the participant’s view of the scene. One potential drawback of creating this controlled environment is the emergence of certain idiosyncratic events that might occur specifically because the scene is so contrived.

Indeed, the colour constancy phenomenon is an example of one such effect. Although it can be demonstrated in a laboratory setting, it is not in line with our everyday perceptual experience. Usually, surfaces that are the same colour appear the same colour to us even under different illuminations. On the other hand, the colour contrast phenomenon is an important element of everyday perception because it controls how we perceive relationships between objects in the visual scene. However, this is also what makes it difficult to demonstrate using conventional methods. Indeed, Gilchrist (2006) pointed out that “When the [SLC] display is presented in a textbook, it is perceived to belong to the page of the book and to the table on which the book is lying. Thus, [. . .] the illusion should be quite weak'' (p. 814). Finally, the demonstration of colour perception under different perceived distances requires the precise control over the illumination of a room in order to examine the effect. Gaining precise control over any one element of the visual scene without disturbing another is difficult in a natural setting because all of the individual elements interact and contribute to our overall perceptual interpretation. So changing the arrangement of a stimulus, for example, is likely to affect the amount of illumination the stimulus is under, which will require further adjustment, and do on.

It was imperative therefore, to develop techniques that allow us to accurately control and manipulate the visual scene. In subsequent decades, the need for hand-build experimental apparatus was obviated somewhat by the Cathode Ray Tube (CRT) monitor, which became a staple piece of equipment in visual perception research because of the ability to create, accurately control, and manipulate visual stimuli (e.g. Johansson, 1964).

The use of the CRT monitor in visual perception studies brought much needed flexibility in allowing researcher to control the spatial distribution of the light. The CRT monitor has been used successfully for years and even has an advantage over modern Liquid Crystal Display (LCD) Screens in its ability to reproduce true blacks. However, these monitors are limited by the short luminance range that is available (Menozzi Näpflin & Krueger, 1999). In addition, in order to maintain control over the visual stimuli being presented, most experiments with a monitor take place in dark, windowless rooms. This helps the control of the spatial distribution of the light, but isolates the visual scene even more, and may not comparable with everyday life perception. In other words, it creates the same isolated conditions that give rise to the colour constancy phenomenon discussed earlier.

The use of virtual reality to examine visual perception.

To date, a number of studies have examined perceptual phenomena using virtual environments (Wolff & Zettegren, 2002; Wolff, 2003, 2007; Ware et al., 1999; O' Sullivan & Dingliana, 2001; O'Sullivan & Lee, 2004; O'Sullivan et al., 2003; Reitsma & O'Sullivan, 2008). The primary aim of these studies has been to investigate how we perceive causal relationships when objects interact. Wolff & Zettegren (2002) for example, built a 3d model of an environment containing a moving object – in this case, a boat that moved in water – which would collide with another object in the environment. The aim of the study was to build a model that could predict what causal language participants would use when describing the collision, based on the relationship between a force vector, a target vector and the movement of the object. However, these studies were more focused on language and meaning of physical interactions and did not examine visual perception per se. In addition, the 3d environment and the objects contained therein were usually displayed on a normal computer monitor.

One of the first studies to use immersive virtual reality to examine visual perception was carried out by Soranzo, Lugrin and Wilson (2013). This study examined the simultaneous lightness contrast (SLC) phenomenon, related to the contrast effects discussed earlier, by employing a 3d, immersive virtual environment. The aim of this study was to examine whether perception of contrast was affected by articulated backgrounds and by distance between stimuli. Participants were positioned in a room with three surrounding walls made up of large stereoscopic screens. The 3D visualisation was developed using the Unreal™ game engine version 2.0, and by combining stereoscopic visualization and head motion tracking (see figure 3).

A virtual reality "cave" was used in an attempt to overcome a lot of the limitations of traditional experimental methods by enabling precise control of the spatial distribution of the light in the visual scene as well as distance and position of stimuli. In a real room, it is not possible to manipulate these elements completely indpependently. However, with virtual reality it was possible to manipulate the geometrical relationships between the surfaces whilst at the same time maintaining the same photometric relationships (i.e. the amount of light reaching the observers' eyes remained constant). Furthermore, by manipulating objects in three-dimensional space, the researchers were able to examine the effects of positive and negative parallax on contrast perception (see figure 4). Manipulation of the parallax effects would not be possible using a two-dimensional screen.

The results the Soranzo et al., (2013) study provided a new understanding of contrast perception by showing that our perception of the SLC phenomenon is not fully explained by either mid- or high-level theories of cognition; that it in fact relies on elements of both. A major contributor to this finding was the ability to investigate both theoretical explanations at the same time by manipulating parallax. As such, this investigation would have been practically impossible without the use of the virtual reality.

Conclusions

The use of virtual reality provides exciting opportunities for the field of visual perception. By allowing precise and indpependent manipulation of the geometric and photmetirc relationships between stimuli in the visual scene, we can examine phenomena in ways that were not previously possible and significantly enhance our understanding of perception. One potential explanation for the lack of perception studies employing virtual reality to date is the prohibitive nature of the apparatus. The virtual reality cave employed by Soranzo et al., (2013) is not only costly, it also required a large amount of space to install, totalling 3.0×3.0×2.25 metres in size. However, recent advances in virtual reality technology such as the Oculus Rift™ promise to over many of the benefits of the larger installation in a much smaller, more affordable package (Firth, 2013; Oculus, 2012). In the future therefore, we may see many more studies using virtual reality to enhance our understanding of visual perception.

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