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Visual asymmetries for relative depth judgments in a three-dimensional space

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ABSTRACT

Our ability to process information about an object's location in depth varies along the horizontal and vertical axes. These variations reflect functional specialisation of the cerebral hemispheres as well as the ventral/dorsal visual streams for processing stimuli located in near and far space. Prior research has demonstrated visual field superiorities for processing near space in the lower and right hemispaces and for far space in the upper and left hemispaces. No research, however, has directly tested whether the functional specialisation of the visual fields actually makes objects look closer when presented in the lower or right visual fields. To measure biases in the perception of depth, we employed anaglyph stimuli where participants made closer/further judgments about the relative location of two spheres in a three-dimensional virtual space. We observed clear processing differences in this task where participants perceived the right and lower spheres to be closer and the left and upper spheres to be further away. Furthermore, no relationship between the horizontal and vertical dimensions was observed suggesting separate cognitive/neural mechanisms. Not only does this methodology clearly demonstrate differences in perceived depth across the visual field, it also opens up many possibilities for studying functional asymmetries in three-dimensional space.

1. Introduction

A variety of mechanisms contribute to our ability to perceive our visual world in three dimensions. Monocular cues such as perspective, relative size, shading and occlusion all play a role in the perceived distance of an object (Howard & Rogers, 2012). For animals with binocular vision, such as humans, stereopsis and convergence can provide particularly accurate information about an object's distance from the observer (Howard & Rogers, 2012). Precise depth perception is critical to survival fitness and continues to play a particularly important role for those who work in complex multidimensional spaces – such as pilots, surgeons, and athletes. Given the importance of accurately judging depth in the environment that surrounds us, it is surprising to learn that asymmetries exist in the processing of near and far space along the horizontal and vertical axes.

In relation to the horizontal axis, asymmetries for processing near and far stimuli have been observed by Heilman, Chatterjee, and Doty (1995). Under free-viewing conditions, they presented radial lines to the left and right hemispaces and asked participants to judge which of the two lines appeared longer. Analyses demonstrated that lines presented to the left hemispace were judged to be shorter compared to those presented to the right hemispace. To explain these results, Heilman et al. (1995) referred to a model of functional cerebral asymmetry. They argued that the left hemisphere is specialised for tasks involving local attention (see: Barrett, Beversdorf, Crucian, & Heilman, 1998; Robertson, Lamb, & Knight, 1988) and for peripersonal spatial tasks such as reading and writing. In contrast, the right hemisphere was believed to be specialised for global attention (see: Barrett et al., 1998; Robertson et al., 1988) and for extrapersonal spatial tasks such as face/emotion recognition and navigation. The left hemisphere therefore directs attention towards the body whereas the right hemisphere directs attention away from the body. With this cerebral asymmetry in mind, Heilman et al. (1995) suggested that the ends of the lines retracted towards the middle when they fell to the left hemispace – causing them to appear shorter. Conversely, the endpoints of the lines expanded away from the middle when they fell on the right hemispace – causing them to appear longer.

Neurological research supports a left/right asymmetry for processing near and far space. Weiss et al. (2000) asked participants to bisect lines or point towards dots located in either near or far

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space. Positron Emission Tomography (PET) was used to record activity of the brain as they carried out the tasks. For tasks located in near space, results showed preferential activation of centres located in the left hemisphere, including the dorsal occipital cortex, the intraparietal cortex, the ventral premotor cortex and the thalamus. For tasks located in far space, there was bilateral activation of ventral occipital cortex and the right medial temporal cortex. The PET research complements clinical research showing dissociations in neglect between peripersonal and extrapersonal space for patients with unilateral lesions to the left or right hemispheres (Vuilleumier, Valenza, Mayer, Reverdin, & Landis, 1998; Williamson et al., 2014).

Asymmetries have also been reported for processing near and far space along the vertical axis. Geldmacher and Heilman (1994) presented stimuli above and below fixation and demonstrated that visual attention in the upper portions of a visual scene is biased towards more distant points in space. Previc, Breitmeyer, and Weinstein (1995) presented random dot stereograms in the upper-left, upper-right, lower-left, lower-right quadrants of a display. Participants were asked to detect a shape within the anaglyph image as quickly as possible. Results showed that, while there was no upper/lower difference for near targets, far targets were identified more readily in the upper visual field. There was also an unexpected advantage for detecting far targets in the upper-left quadrant, which is consistent with the left/right asymmetry discussed above.

The effect of position along the vertical axis are in line with an evolutionary model of upper/lower visual field specialisation developed by Previc (1998). Previc proposed that human spatial behaviours, such as grasping objects or searching, have evolved in relation to the expected location of these objects in space. For the upper visual field, Previc suggested there was an advantage for visual search behaviours for objects typically found in far space. Conversely, Previc suggested that we have an advantage for visuomotor manipulatory behaviours (such as grasping) in the lower visual field because these objects are typically found in near space (see: Chewning, Adair, Heilman, & Heilman, 1998; Costantini, Ambrosini, Tieri, Sinigaglia, & Committeri, 2010). The specialisation of the upper and lower visual fields is thought to reflect asymmetries in the activation of ventral and dorsal visual streams, respectively (Previc, 1998). Specialisation of the ventral and dorsal visual streams for processing stimuli in near and far space is borne out by fMRI research. Chen, Weidner, Weiss, Marshall, and Fink (2012) asked participants to perform allocentric/egocentric judgements on objects located in near or far space within a virtual 3D environment. Results demonstrated two dissociable streams of processing within the brain. Processing in far space loaded on the ventral stream whereas near processing loaded on the dorsal stream.

From the research reviewed thus far, it appears that asymmetries exist within the horizontal and vertical axes in the way near and far space are processed. The right and lower dimensions are specialised for processing near space, whereas the left and upper dimensions are specialised for far space. While research has investigated the comparative specialisation of the visual fields, to our knowledge, no research has directly tested whether this specialisation actually affects the perception of depth in both the horizontal and vertical dimensions. That is, does the specialisation of the left hemisphere/right hemispace for 'near' processing make objects appear closer on the right compared to the left? Similarly, does the specialisation of the dorsal stream/lower hemispace for processing near objects make objects appear closer in the lower hemispace compared to the upper hemispace? Besides being interesting from a theoretical viewpoint, systematic biases in the perceived depth of an object could be important from an applied perspective when making fine judgements of relative depth. For example, relative depth precision is essential for everyday tasks such as driving and specialised tasks such as surgery.

To investigate asymmetries in the perceived distance of an object, we used anaglyph images to induce a perception of an object located at different depths. Anaglyph images contain pictures taken from slightly different viewpoints encoded in either red or cyan. When offset slightly in relation to one another and viewed through a pair of anaglyph glasses, the binocular disparity gives rise to an impression of an object located in three-dimensional space. Stereoscopic 3D are an ideal means of exploring asymmetries in depth perception along the horizontal and vertical axes – but have not been used before. We presented spheres along the horizontal and vertical axes offset slightly from one another in perceived 3D space. Participants made forced-choice discriminations of 'nearer' or 'further'. If the right and lower hemispaces are predisposed for processing objects in near space, we predicted that participants would be biased towards reporting that these spheres were closer compared to similar spheres presented in the left and upper hemispaces. Because eye dominance could affect the left/right asymmetry for anaglyph images, this was used as a between groups variable in the horizontal analysis. Finally, to investigate whether the horizontal and vertical asymmetries are the result of separate cognitive/neurological mechanisms, a correlational analysis was performed.

2. Method

2.1. Participants

Fifty-eight ($m = 15$; $f = 43$) university students participated in the experiment in exchange for $10AUD. Ages ranged between 18–62 years of age ($M = 24.862$, $SD = 7.321$) and every participant was right-handed according to the FLANDERS handedness test (Nicholls, Thomas, Loetscher, & Grimshaw, 2013). All participants had normal or corrected-to-normal vision acuity, and out of the fifty-eight participants thirty-one were right-eye dominant (Coren, Porac, & Duncan, 1979). Participants gave informed consent prior to the start of the experiment. This study was approved by the Human Research Ethics Committee at Flinders University and adhered to the principles outlined in the Declaration of Helsinki.

2.2. Apparatus

Stimulus presentations were displayed on a LCD screen (500 mm diagonally). Stimuli were created using OpenGL, and red-cyan anaglyph glasses were used to view the 3D stimuli. E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA) was used to run the experiment and an E-Prime Serial response box was used to record participants' responses. Participants' heads were kept still using a chin-rest (Richmond Products; model # 6100R) placed centrally 600 mm in front of the computer screen. Closed-circuit audio/visual surveillance was used to monitor participants when the experimenter was outside of the testing room.

2.3. Stimuli and viewing conditions

Rendering stereo images involves defining a collection of surfaces with reflectance properties, light sources and camera to model the projection of the surfaces onto the virtual imaging plane. The projection is controlled by the camera's focal length and optical centre which collectively define the convergence of the virtual optical rays onto the imaging plane. We generated a set of stereo images by defining cameras in a virtual scene that represent the participant's eyes in the real world. Essentially, we modelled the computer screen in the virtual space as the imaging plane with the