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Preservation of Emmert's Law in a Visual Form Agnosic

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Size constancy was investigated in DF, a patient with visual form agnosia, using a technique based on Emmert's law of visual after-images. DF was first given a task in which she was asked to indicate the distance of a vertical surface and a task where she had to estimate the width of a series of squares (widths ranging from 5 cm to 35 cm) placed at varying distances and having a constant visual angle. In the distance estimation task, DF greatly overestimated the distance of the vertical surface placed in front of her. DF also had great difficulty performing the size estimation task. DF then performed a task in which she stared at a bright 5 cm square for a brief period of time at a distance of 30 cm followed by the presentation of a vertical surface which varied in distance and was asked to indicate the width of the after-image either verbally or manually. DF's after-images conformed to the size-distance relationship predicted by Emmert's law — as the distance of the vertical surface increased her perception of the size of the after-images also increased. These data demonstrate that although DF is rather impaired in tasks that require explicit estimates of size and distance, at some level, DF must have relatively intact size constancy mechanisms given that her estimates of the width of the after-image conform to Emmert's law. Thus, the processes underlying explicit judgements of size and distance appear to differ from those underlying the size and distance scaling of after-images.

Introduction

Work with DF, a patient with visual form agnosia, has demonstrated that in addition to her visual object recognition impairment, she has great difficulty in perceptually estimating the size and distance of objects placed within grasping space (Carey *et al*., 1998). However, in a visuomotor task in which DF was required to reach out and pick up the same objects placed in front of her she showed excellent scaling of the size of her grasp with object size and the velocity of her reach with object distance (Goodale *et al*., 1991; see also Milner and Goodale, 1995). DF's accurate object-directed reaching and grasping movements demonstrated that at some level, accurate size and distance information was available to her at least for distances up to around 50 cm. Thus, even though DF has poor perceptual size constancy, at some level she does retain size constancy given her accurate reaching and grasping movements.

The present study extends these findings by examining DF's size and distance estimates at distances beyond grasping space. Based on the foregoing, it was predicted that DF would show impaired size constancy when standard techniques (i.e., tasks requiring explicit perceptual estimates of size) were used. However, it is possible that size constancy might be revealed in DF at these farther distances if the appropriate 'implicit' test were used. Of course, at distances beyond grasping space DF's object-directed reaching and grasping movements could not be used as an indirect measure of size constancy. In the present study, then, I describe a task which involves implicit estimates of distance in order to compute object size. This technique is based on Emmert's law of visual after-images.

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Method

The Patient

At the time of testing, DF was a 37-year-old woman who suffered irreversible brain damage as a consequence of carbon monoxide poisoning. Magnetic resonance imaging indicated damage ventrally in the parasagittal occipitoparietal region (primarily areas 18 and 19) but with apparent sparing of area 17. Subsequent neuropsychological and psychophysical testing revealed the presence of a profound visual form agnosia. DF was impaired in the perception of shape and orientation regardless of which stimulus parameters were used to define the contours — intensity, color, texture, stereopsis, motion, proximity, continuity, or similarity. Psychophysical testing revealed that her visual form agnosia could not be reduced to a simple sensory deficit (see Milner *et al*., 1991). DF's performance was compared to that of a neurologically-intact subject who matched her in terms of age, sex, and handedness. The control subject performed exactly the same tasks and in the same order as DF.

Emmert's Law

If one stares at a bright image for a few seconds, an after-image of the original image will occur and its size will vary according to its apparent distance (Emmert, 1881). When the after-image appears on a more distant surface it will look larger than when it appears on a closer surface. Note that the size of the retinal image remains constant. What changes is the apparent size of the image and this is influenced by distance judgments of the surface. Emmert's law describes the quantitative relationship between the apparent size of the after-image and its apparent distance. This relationship is virtually identical to the size distance scaling of real images such that for a given constant retinal image size the perceptual size of an object linearly increases with the perceived distance of that object (Dwyer *et al*., 1990). Thus, to accurately estimate the actual size of an object (especially if it is unfamiliar) one needs to combine the object's retinal image size with an estimate of its distance.

Explicit Estimates of Size and Distance

DF was tested on two tasks in which she was required to make separate size and distance estimates. In one of these tasks she was asked to indicate the distance of a blue (CIE values, x = 0.141, y = 0.112; as measured by a *Tektronix* J16 digital photometer) vertical surface (1 m square) placed at eye level at various distances in front of her (30–210 cm in 30 cm increments). In another task she was asked to estimate the width of a series of red (CIE values, x = 0.527, y = 0.378) squares (5–35 cm in 5 cm increments) placed at eye level at varying distances from her (30–210 cm in 30 cm increments). Each of the squares was placed at a particular distance from her such that the visual angle subtended by each was kept constant (9.5^0 X 9.5^0). For example, a 5 cm square would have to be presented at a 30 cm distance to maintain a 9.5^0 X 9.5^0 viewing angle whereas a 30 cm square would need to be presented at a 180 cm distance to maintain this viewing angle.

Estimates of After-image Size

The after-image task required DF to stare at a very bright 5 cm square for approximately 5 seconds at a distance of 30 cm. The inducing stimulus was produced by a *Kodak Ektagraphic* slide projector with an opaque mask containing a 5 cm square opening — luminance 85,000 cd/m^2. Following this, DF's chair was rotated 90° clockwise and she was asked to look at the blue vertical surface used in the distance estimation task that had been placed at a particular distance away from her. In one testing condition she provided verbal estimates of the width of the after-image. In another condition she was asked on each trial to indicate manually the width of the after-image using two wooden pointers (1 cm diameter; 2 m length) by positioning their tips on the blue surface. The distance between the pointer tips was measured with a ruler having mm increments. Following each trial, DF was given a 5–10 minute rest period to ensure that the after-image no longer persisted. A new inducing stimulus would only be presented to DF when she reported that the after-image was no longer present. The distances used in this task were identical to those used in the size estimation task. Thus, if one were able to perfectly perform this after-image task one's estimate of the after-image would vary linearly with the distance of the surface. For example, the width of a square after-image corresponding to a 30 cm distance would be 5 cm whereas at a 60 cm distance it would be 10 cm.

General Procedure

Testing was conducted over two sessions. In the first session DF performed the after-image manual task and then the distance estimation task. In session two, the following day, DF performed the after-image verbal task followed by the size estimation task. In all tasks, presentation order was random (each target distance or target size was presented once). Between each trial DF kept her eyes closed as a stimulus was moved to a particular location for the subsequent trial. At the end of the second testing session, as a means of ensuring that DF was able to perceive the location of the edges of the red squares, DF was asked to indicate with the two wooden pointers the edges of each of the seven red squares presented to her in a random sequence at the same distances used in the size estimation task. DF was able to do this without error.

All testing was conducted in an empty classroom that contained minimal depth cues except for some monocular depth cues such as texture and linear perspective. These cues would have been minimal given the relatively low ambient light level at the observer of 11.5 mW/m^2. Throughout testing, DF sat in a comfortable chair in a fixed location in the center of the room. In making their size and distance estimates, both DF and the control subject were encouraged to use whatever measurement units they were most comfortable with (both used feet, inches) and to use partial units whenever there was a need.

Results

Explicit Estimates of Size and Distance

Figure 1A demonstrates that in the distance estimation task, DF tended to greatly overestimate the distance of the vertical surface placed in front of her. In contrast, the control subject's distance estimates were quite accurate.

As Figure 1B shows, DF also had great difficulty performing the size estimation task producing the same estimate for 4 of the 7 stimuli and another response for 2 of the 3 remaining stimuli. The slope of this line is rather close to zero (0.1) whereas the corresponding slope in the control subject is close to one. Indeed, phenomenologically DF felt that many

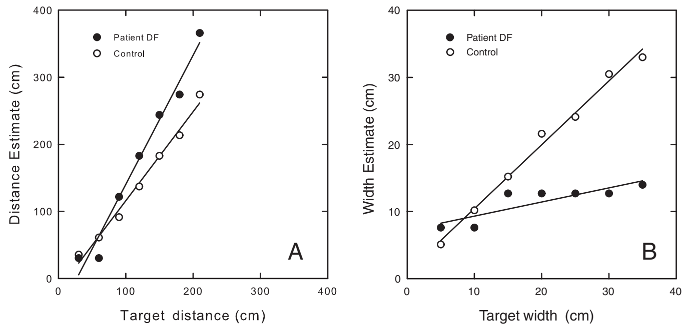

Fig. 1. A. Verbal distance estimates as a function of target distance. Note that patient DF has a tendency of overestimating target distance whereas the control subject's estimates are quite veridical. B. Verbal width estimate as a function of target width. Note that patient DF's estimates bear very little resemblance to actual target width.

of the squares presented to her looked about the same size. In both the size and distance estimation tasks, separate Wilcoxon Matched-Pairs Signed-Ranks tests (Siegel, 1956) revealed that there were significant differences between DF's estimates and the more veridical estimates of the control subject (size estimation task, $P < 0.02$); distance estimation task ($P < 0.02$).

Estimates of After-image Size

After viewing the inducing stimulus, DF reported seeing a white after-image that was shaped like a square. Figure 2 shows DF's verbal and manual estimates of the width of the after-image. Both DF's pointing and verbal judgments of the size of the after-images conformed to the size-distance relationship predicted by Emmert's law. As the distance of the vertical surface increased her perception of the size of the after-images also increased. Note, however, that DF's size estimates in the after-image task were approximately half as large as those produced by the control subject and that predicted by Emmert's law.

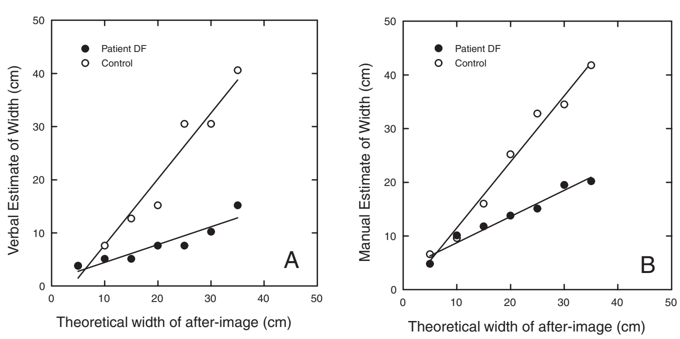

Fig. 2. A. Verbal estimates of the width of the after-image as a function of the theoretical width of the after-image. B. Manual estimates of the width of the after-image as a function of the theoretical width of the after-image. Note that in both cases, patient DF's estimates are linearly related to the theoretical width of the after-images although the corresponding slopes are attenuated relative to the control subject's.

If DF does indeed access distance information more readily in the after-image task than in the explicit size estimation task then her estimates of target size in the after-image task should be more accurate than those produced in the perceptual task. Wilcoxon Matched-Pairs Signed-Ranks tests showed that, indeed, her size estimates were more accurate in the after-image task (manual estimates of after-image more accurate than perceptual estimates, $P < 0.05$; verbal estimates of after-image more accurate than perceptual estimates, $P < 0.02$ — see Figure 1B and Figure 2). In contrast, the control subject's size estimates were comparable in both tasks (manual estimates of after-image equivalent to perceptual estimates, $P > 0.5$; verbal estimates of after-image equivalent to perceptual estimates, $P > 0.5$).

Discussion

The explicit tests assessing DF's distance estimation abilities confirm earlier findings reported on this patient in which she has difficulty estimating the distance of target objects relative to neurologically intact subjects (Carey *et al*., 1998). Like the Carey *et al*. study which presented targets to DF in the 16–40 cm range, DF tended to underestimate target distance for the two nearest targets used in the present study. Interestingly, for targets placed at relatively far distances (90–210 cm) we found that DF greatly overestimated target distance. In addition, DF's explicit estimates of target size were quite impaired — the slope of the line relating her size estimates with target size was close to zero.

In contrast to DF's poor performance explicitly estimating target distance and size, her pointing and verbal judgments of the size of the after-images conformed to the size-distance relationship predicted by Emmert's law. As the distance of the vertical surface increased, her perception of the size of the after-images also increased. Note, however, that DF's size estimates in the after-image task were approximately half as large as those produced by the control subject and that predicted by Emmert's law suggesting that DF's size constancy mechanisms are not fully intact. Nevertheless, DF's performance in the after-image task clearly shows that she retains some degree of size constancy. DF is able to access more veridical versions of distance information and use this to scale the size of the after-images she reports seeing because her estimates of target size in the after-image task were clearly more accurate than those that she made in the explicit size estimation task.

One implication of these findings is that it is possible that the processes underlying explicit judgements of size and distance may be separate from those underlying the size and distance scaling of after-images. If DF were using the same processes to estimate distance in the after-image task as she was in the explicit perceptual task then one would have expected her size judgments in the after-image condition to be exaggerated since she overestimated distances in the explicit perceptual task. This was not the case. In fact, she systematically underestimated the size of the after-images — suggesting that she was underestimating the distance of the surface in the after-image task.

In the present study, given that familiar size cues were not available as a source of distance and hence size information, the two sources of distance information available to DF would have been vergence angle (Gogel, 1961; Foley and Held, 1972; Morrison and Whiteside, 1984) and vertical disparities (Rogers and Bradshaw, 1993). Because the contribution of vertical disparities in distance coding is believed to be relatively small relative to vergence angle (Trotter *et al*., 2004) I will focus on eye vergence. Work by Mon-Williams and colleagues has demonstrated that vergence is the principal distance cue used by DF (Mon-Williams *et al*., 2001).

At present, the neural substrates of distance perception and hence size constancy (i.e., regions that are able to integrate retinal image size with object distance) in humans remain elusive. Given that areas 18 and 19 are damaged in DF it is possible that remaining regions such as area 17 and portions of the inferior parietal lobes might play a role in size constancy.

It is speculated that what could be termed explicit judgements of size and distance may require processing by the ventral stream (which originates in primary visual cortex, projects to extrastriate areas and downstream to the inferotemporal region, and which appears to be damaged in DF) whereas the size and distance scaling of after-images might involve processing in the dorsal stream (which originates in primary visual cortex and projects to the posterior parietal region, and which appears to be spared in DF). Consistent with this notion is work in patient DF and other visual form agnosics suggesting that binocular depth cues such as vergence are preferentially used by the dorsal visual stream whereas the ventral stream is specialized for such monocular depth cues as linear perspective and familiar size (Marotta *et al*., 1997; Mon-Williams *et al*., 2001). Another source of evidence consistent with the role of the ventral stream in explicit judgements of size and distance is the small literature investigating patients reporting size distortions following cortical damage. Although such patients are relatively rare and their perceptual abilities have not been extensively investigated, Kassubek and colleagues do report a patient with hemimicropsia; the patient complained that objects in the affected visual field appeared reduced in size (Kassubek *et al*., 1999). Careful localization work by Kassubek *et al*. suggests that damage in this patient was primarily restricted to the lateral portion of area 19 bordering area 37, making it likely that only his ventral stream was damaged.

In contrast to the relative paucity of information concerning the neural substrates of visual size and distance processing in humans, unit work in non-human primates suggests two broad cortical regions that likely play a critical role in the computations underlying estimates of distance — the posterior parietal lobe and primary visual cortex — both regions which are relatively intact in DF.

Parietal regions such as area 7a and LIP (lateral intraparietal region) contain cells that are selective for fixation distances (Sakata *et al*., 1980; Gnadt and Mays, 1995; Genovesio and Ferraina, 2004). In addition, the responses of a large proportion of the visually-responsive cells in both area 7a and area LIP are modulated by angle of gaze (Sakata *et al*., 1980; Gnadt and Mays, 1995) suggesting that area 7a and area LIP cells may be able to integrate information about the position of an object of interest with extra-retinal signals about eye position such that appropriate fixation of the target can be made.

Cells in area V1 of the monkey have also been shown to modulate their responses as a function of viewing distance (Trotter *et al*., 1992; Dobbins *et al*., 1998; Gonzalez and Perez, 1998). Trotter *et al*. (1992) found that the majority of disparity sensitive cells and a large proportion of non-disparity sensitive cells modulated their responses with respect to viewing distance. The responsiveness of these neurons appears to be modulated by the distance signals produced by eye vergence (Trotter, 1995; Trotter *et al*., 2004).

Recent extensions of the Goodale and Milner conceptualization of the different roles played by the dorsal and ventral cortical processing streams (Goodale and Milner, 1992; Milner and Goodale, 1995) suggest that the neural bases of certain visual illusions might originate along different portions of the cortical visual processing streams. For example, the simultaneous tilt illusion which affects both explicit perceptual judgements and object-directed action presumably occurs relatively early in the visual processing stream before the segregation of the dorsal and ventral processing streams whereas the rod-and-frame illusion only affects perceptual judgments, not the orientation of the grasping hand (Goodale and Westwood, 2004). Likewise, in the present study, implicit computations of distance which are manifested in the after-image task likely occur in primary visual cortex and associated regions before the segregation of the dorsal and ventral cortical visual processing streams whereas explicit estimates of target distance such as those used in the task requiring explicit estimates of target distance and size are likely computed in the ventral processing stream subsequent to the segregation of the two streams.

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