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Disappearance of afterimages at 'impossible' locations in space

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Abstract. An eccentrically positioned afterimage, viewed in the dark, will disappear if the eye is positioned so that the afterimage now projects to a more extreme location relative to straight ahead. It was found that the afterimage disappeared when it projected to a location which corresponded to the edge of the visual field defined by the brow, cheek, and nose. This suggests that visibility of stimuli from those retinal regions shadowed by the head is influenced by eye-position information.

1 Introduction

When the eyes are directed to extreme locations in the visual field, large regions of the retina are shadowed by the cheek, brow, and nose, substantially reducing the total area of the field of view. For example, if one looks all the way up, nearly half the visual field is occluded by the brow. These shadowed retinal regions cannot provide useful information about the visual scene because it is not possible to stimulate them from the corresponding regions in the external world. This means, of course, that we have never seen objects in these 'impossible' locations in visual space. If we could stimulate these retinal regions when they are shadowed, how would the brain interpret signals from these impossible locations? Do we have a perceptual representation for these locations in egocentric space, or is the representation defined only within the limits set by the cheek, brow, and nose?

Though it is practically impossible to stimulate directly these shadowed regions(1), we can use the retinal persistence that gives rise to afterimages to provide signals from them. Consider the situation illustrated in figure 1. The observer looks straight ahead, and an afterimage is induced by a bright flash falling near the lower edge of the visual field. Now, if the observer looks far enough down, the retinal region containing the afterimage is shadowed by the cheek, and the afterimage lies in an impossible location in visual space. We have found that when we do this the afterimage vanishes.

Could the disappearance of afterimages that lie in shadowed regions mean that there is no perceptual representation for impossible locations? To answer this question, we first need to specify the conditions under which the afterimage vanishes. For example, the disappearance of the afterimage might have been simply a consequence of saccadic suppression (Fiorentini and Mazzantini 1965). This is not a viable explanation in this situation because the disappearance depends on the direction of the eye movement. In the example considered above, if the observer looks up an equal distance, instead of down, the afterimage remains perfectly visible. The opposite is true if the afterimage is in the superior visual field. Then, if the observer looks up, the afterimage disappears, but it remains perfectly visible for eye

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(1)It may be possible to stimulate these regions with lights applied to the sclera. However, it is difficult to stimulate a specific retinal region with the eye in various positions with these diffuse stimuli.

movements in other directions. The disappearance depends not on the eye movement itself, but on the location of the eye. One has the impression that the afterimage disappears when it falls outside the field of view defined by the eyebrows, the cheek, or the nose. The following experiment establishes that this is indeed the case.

2 Experiment

2.1 *Method*

The experiment was conducted in complete darkness. A bright positive afterimage, subtending 3.5 deg, was generated at a chosen eccentricity with a flash gun. The subject then moved to another bite bar in a rather crude perimeter. The position in the visual field at which the afterimage vanished was measured by having the subject slowly move the position of a dim red fixation light along the meridian containing the afterimage. The subject tracked the light until the afterimage disappeared. He then moved the light back toward the initial position and the afterimage reappeared. He continued to make settings until the afterimage permanently faded from view. A tracking procedure was used to avoid saccadic suppression of the afterimage. Because even smooth pursuit movements may cause afterimage suppression (Fiorentini and Mazzantini 1965), the subject moved the tracked spot of light as slowly as possible, generally between $\frac{1}{2}$ and 2 deg s^{-1}. If the afterimage truly vanishes at the edge of the visual field defined by the head, then the eye rotation necessary for disappearance should be that which moves the afterimage to the edge of the visual field. In general, for different afterimage retinal eccentricities, the sum of the original afterimage eccentricity and the eye rotation required for disappearance should equal the extent of the visual field in that direction. That is, as in figure 1, $\epsilon+\rho$ should equal θ, for various values of ϵ.[2]

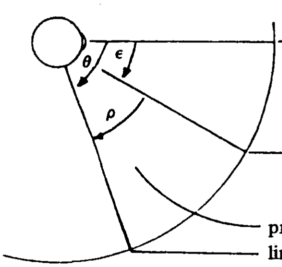

Figure 1. Illustration of the experimental situation: ϵ is the eccentricity of the afterimage, θ is the limit of the visual field defined by the orbit, and ρ is the eye rotation required to bring the afterimage to the edge of the visual field. We predict that ρ is the eye movement required to make the afterimage disappear, ie that for disappearance $\epsilon+\rho = \theta$.

2.2 *Results*

Figure 2 shows the results. The results for the inferior visual field are plotted in panel (a). The abscissa, ϵ, shows the eccentricity of the afterimage and the ordinate, ρ, shows the eye rotation required to make the afterimage disappear. Data for three observers are shown, each with different symbols. The results for NH fall close to the solid line which represents the equation $\epsilon+\rho = \theta$, where θ is the extent of the visual field measured separately in the same apparatus. Afterimages further away

[2] Because the center of rotation of the eye lies behind the nodal point, this equation is not exactly true. Large eye rotations move the afterimage closer to the edge of the field defined by the orbit than the equation would predict. However, the error is never more than about 4 deg, at the most extreme eye rotations. We have therefore not corrected for this factor. The correction would have the effect of bringing the data points closer to the predicted values.

from the fovea require a smaller eye movement to make them disappear and in each case the eye movement required is that which brings the afterimage to the edge of the visual field, limited in this case by the cheek. The data of JW conform less well to the hypothesis. However, agreement between data and predictions is more compelling when we consider that, in the absence of the disappearance phenomenon, the afterimage would have remained visible for an additional 20 deg of eye rotation. (The maximum eye rotation possible in this case was about 50 deg.)

Figure 2b shows the results for observer NH in the superior visual field. There is evidence for tradeoff between eye rotation and afterimage eccentricity for all but the most extreme afterimage eccentricities. These measurements are complicated by the difficulty in defining a precise value for the extent of the visual field, since the visual field changes depending on the position of the eyebrows. The dotted line shows the visual field measured with the eyebrows raised. Figure 2c shows measurements in the nasal field, and good tradeoff is observed. Here the region over which the most eccentric afterimage is rendered invisible is nearly 40 deg.

What happens in the temporal field (figure 2d) is of some interest because in this case the visual field is not in general occluded by the head, except when one is looking all the way around in the temporal direction. If the disappearance of the afterimage is indeed related to the visual field, then we would expect the phenomenon

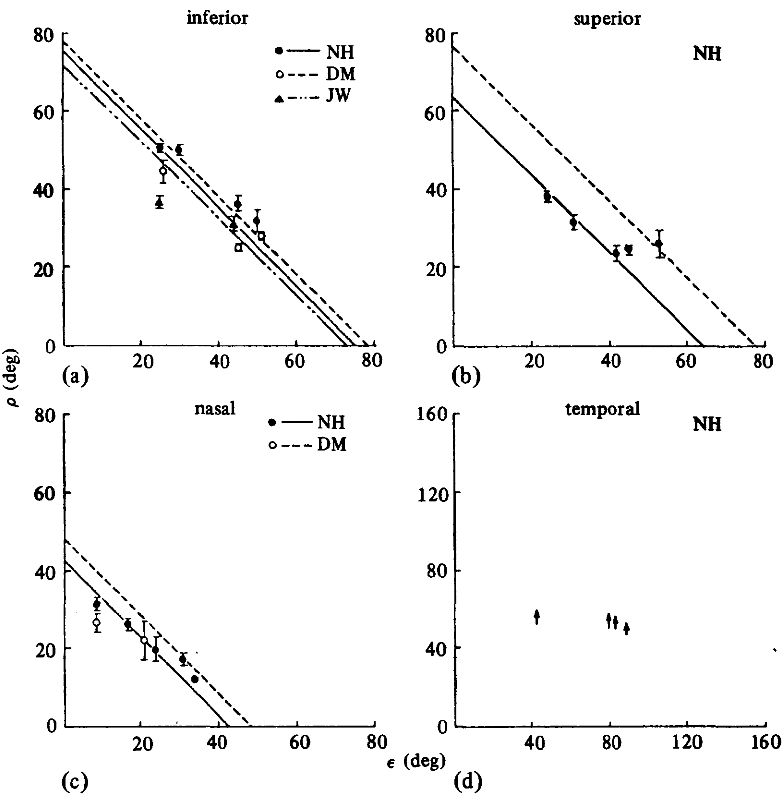

Figure 2. Eye rotation, ρ, required for afterimage disappearance as a function of afterimage eccentricity, ϵ, for each of four directions from straight ahead (a) inferior, (b) superior, (c) nasal, and (d) temporal. The symbols are the data points, and the straight lines represent the equation: $\epsilon + \rho = \theta$, where θ is the measured value of the extent of the visual field (a constant). The dotted line in (b) is the extent of the superior visual field for observer NH with eyebrows raised. Data are based on two or three sessions for each observer and each direction, with two afterimage locations measured in one session, and two runs, each containing five judgments, for each location. Error bars are ± 1 SEM, between sessions in most cases. Note the different scale on the axes of (d).

to be absent or at least less easily observed in the temporal field, and this is indeed what happens. The arrowheads indicate for one observer that the afterimage failed to disappear for the maximum eye rotation possible at any of the four afterimage eccentricities. Occlusion by the head occurs at a location of about 127 deg from the median plane. When the eye was rotated to its extreme position, the projected location of the most eccentric afterimage was 142 deg, so there was a region of 15 deg where this afterimage was located in a shadowed position where we might have expected disappearance.

In summary, the data are roughly consistent with the hypothesis that the afterimage disappears at the edge of the visual field defined by the orbit, that is, in a fixed location in egocentric space. The lack of precision in the data is not surprising in light of the fact that the edge of the field defined by the orbit is substantially blurred. Calculations show that the retinal image of the edge of the orbit is smeared over about 5 deg.[(3)] Therefore, any central representation of this edge seems likely to be poorly defined.

3 Discussion

One hypothesis that might be suggested to account for afterimage disappearance is that the intensity gradient at the edge of the visual field in normal viewing acts as a mask, suppressing the afterimage. This cannot be the explanation in this experiment because afterimage disappearance can occur in total darkness. The only light present in most of our experiments was a dim fixation light. This also indicates that the source of the information used by observers in making observations is an extraretinal one.[(4)]

Although we are confident of the generality of the effect (which has been independently reported by Piggins 1965, 1978), it should be emphasized that the phenomenon is rather labile. Of the eighteen observers we tested (five of whom were naive), two failed to observe the afterimage disappearance at all. On occasion, the afterimage failed to move with the eye, and did not disappear. Sometimes it would move part of the way with the eye until it reached what seemed to be the edge of the visual field, and then would stay in that position despite any further change in the direction of gaze away from the primary position. Just as the movement of afterimages with the eye is a corollary of the stability of the visual world, this failure of an afterimage to keep up with eye movements implies a failure of eye-movement compensation mechanisms. This, along with the variability in the data, implies that the extraretinal eye-position information required for disappearance is quite inaccurate.

Afterimages that have disappeared beyond the edge of the visual field may be perceived in these locations if they are revived by a diffuse flash of light. This suggests that one can in some circumstances see objects in these impossible locations. We cannot say, therefore, that the representation of the egocentric visual world is completely blind to locations blocked by the head. In experiments by Skavenski et al (1972), where loads were applied to the fixating eye, the observer reported that

[(3)] This calculation assumes Le Grand's simplified unaccommodated eye (Wyszecki and Stiles 1982), with a pupil size of 3 mm, and a distance of the edge of the visual field (determined by, say, the nose) from the nodal point of 3 cm. Other sources of blur are not taken into account.

[(4)] We have made preliminary observations on the nature of the signal responsible for the suppression. Is it an outflow signal arising from the eye-movement command center? In cooperation with Bob Steinman, observations were made where a force was applied to the eye by means of a contact lens and stalk, while the observer attempted to maintain fixation. In this way the outflow signal required to maintain fixation straight ahead was manipulated by the force applied. This led not only to a shift in the perceived direction of the fixation point, but also to the disappearance of the afterimage at the appropriate apparent location, even though the eye did not deviate from its straight-ahead position. This suggests that the signal controlling the visibility of the afterimage is an outflow one (although inflow is still a viable alternative, cf Matin 1972; Shebilske 1977).

the fixation light appeared to lie "behind the head", which also suggests that there is *some* representation for impossible locations in space.

Whatever the mechanism responsible for afterimage disappearance, it must be able to discriminate between the two eyes. This is because the afterimage disappears in the nasal direction, when an afterimage in the corresponding location in the other eye (in the temporal field for that eye, and well within the field of view) does not disappear. This would suggest a mechanism akin to binocular rivalry, but that cannot account for the disappearance in the superior and inferior fields.

The disappearance of the afterimage may result from the action of a system which monitors the relation between visual and kinaesthetic information. Davies (1973) has demonstrated quite specific suppression of parts of an afterimage when there is a discordance between visual and kinaesthetic information (eg when the afterimage of an observer's hand is in one location, and the hand itself is in another). The appearance of an object in a location always occupied by some feature of the face surrounding the eye may be just such a discordance. Since there is no obvious retinally-based masking for those retinal regions shadowed by the head, it may be necessary for a centrally generated signal to suppress messages from these regions and to wipe them clean of lingering images.

The substantial changes in the size and shape of the visual field as the eyes move is not subjectively apparent, which suggests that the visual system tends to ignore the facial features that largely define the extent of the visual field. The disappearance of afterimages at the edge of the visual field may be a consequence of this. In this regard, the phenomenon reported here is similar to the visual suppression that occurs during eyeblinks (Volkmann et al 1980). Just as visual signals are suppressed when the retina is occluded by the eyelid during an eyeblink, so they are suppressed in peripheral retinal areas occluded by the head following an eye movement. The disappearance of afterimages under these circumstances may reflect a general property: that the visual system acts to reduce the visual disruptions that are a consequence of the individual's own motor responses.

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