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Emmert's law in the dark: active and passive proprioceptive effects on positive visual afterimages†

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Abstract. The relationship between apparent size and apparent distance is given by Emmert's law, which states that a retinal image is proportional in size to the distance of the surface it is projected upon. This principle also applies to retinal afterimages in that they, too, will change in apparent size if distance cues suggest that the location of the object projected onto the retinal image has been altered. It has also been known for some time that non-retinal cues can produce quantitative and qualitative effects on an afterimage when it is viewed in the dark. In the present two studies, positive afterimages of an observer's hand, as well as objects held by that hand, were used as targets to investigate the effects on size-constancy scaling of moving the hand to and fro along the line of sight for different distances in the dark. Results show that, when observers focus on a held object, the changes in size predicted by Emmert's law occur in response to both active and passive proprioceptive or haptic cues. The most intriguing result consisted of the finding that, when only the hand is the target, there appears to be a limit to the decrease in apparent hand size. It appears that the visual system 'refuses' to size-scale the hand below a limit it accepts as representative or acceptable of 'its' hand.

1 Introduction

The idea that there exists a close connection between the visual and tactile modalities can be traced back to George Berkeley (1709, 1710; reprinted in 1965), a connection which is central to his arguments that visual space and object perception are derived from our ability to relate to, and manipulate, things manually. Berkeley's ideas on this reappear in modified form between 1850 and 1860 first in Lotze's 'local sign theory' of space perception, and then in Helmholtz's doctrine of 'unconscious inferences' (Boring 1942). Curiously, this fundamental principle of empirical theories of space perception had to wait for another century for a convincing demonstration of dynamic changes in our 'idea' of space, and objects in space, as derived from the reciprocal influence of tactile and visual stimulation.

The interaction of nonretinal cues with the size of retinal afterimages was first reported by Gregory et al (1959), who showed that afterimages can be used to induce changes in the apparent spatial coordinates and size of objects as a function of movement on part of the observers while viewing the positive afterimage. Since then, several researchers have investigated such factors as changes in body parts in afterimages (Davies 1973), the effect of oculomotor cues on the size of afterimages (Heuer and Lüschow 1983; Suzuki 1986), changes resulting from head movements (Duwaer 1982); as well as changes in complex spatial layouts such as the Ames room (Dwyer et al 1990). While a general observation is that positive afterimages of objects follow Emmert's law (specifically, by size scaling the apparent rather than the actual distance, ie a perceived decrease in distance results in the perception of shrinkage of the afterimage) no quantitative data exist to assess how closely such changes in size follow Emmert's law. Moreover, findings of Davies (1973), that an afterimage of the hand can undergo a 'crumble' effect or disappear when proprioceptive feedback not along the

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line of sight is incorporated, suggests that the perceptual system finds it difficult to accommodate changes of body parts when the information available concerning its 'true' representation conflicts with a fixed afterimage. If this is the case, then a comparison of changes in the size of an observer's hand to that of an object held in the hand conceivably could yield differential results. The aim of the present experiments was twofold: (i) to obtain a quantitative assessment of Emmert's law for afterimages in the dark using active as well as passive proprioceptive cues to simulate changes in the distance of the target stimulus; and (ii) to ascertain whether an afterimage of a body part (the observer's hand) and a hand-held object would yield similar results. It was hypothesised, given Davies's (1973) findings, and some preliminary observations, that the hand-held object would conform to Emmert's law, while an afterimage of an observer's hand would do so only within limits.

2 General procedure

2.1 *Subjects*

Eight female and four male volunteers (age 22 to 54 years) with normal or corrected-to-normal vision served as observers in the first experiment.

2.2 *Materials*

The stimuli consisted of either the white face of a commercially obtained Rubik's cube (5.62 cm × 5.62 cm) or the right hand of the observers. The observer stood in front of a blackboard (120 cm × 90 cm) and with the right arm fully extended either held the cube, or placed the hand, so that it touched the blackboard. A small, luminous dial from a wristwatch positioned directly above the target was attached to the blackboard at eye level and served as the fixation point in the dark. A Minolta Auto 25 flashgun which the subject could trigger was held in the observer's left hand beside and ~2 cm behind the left eye. Scaled drawings of a cube and a hand (10% – 140% in 5% steps) were posted on the wall to the left of the observer to obtain magnitude estimates for any changes in the afterimage reported. Figure 1 gives examples of scaled drawings of the cube.

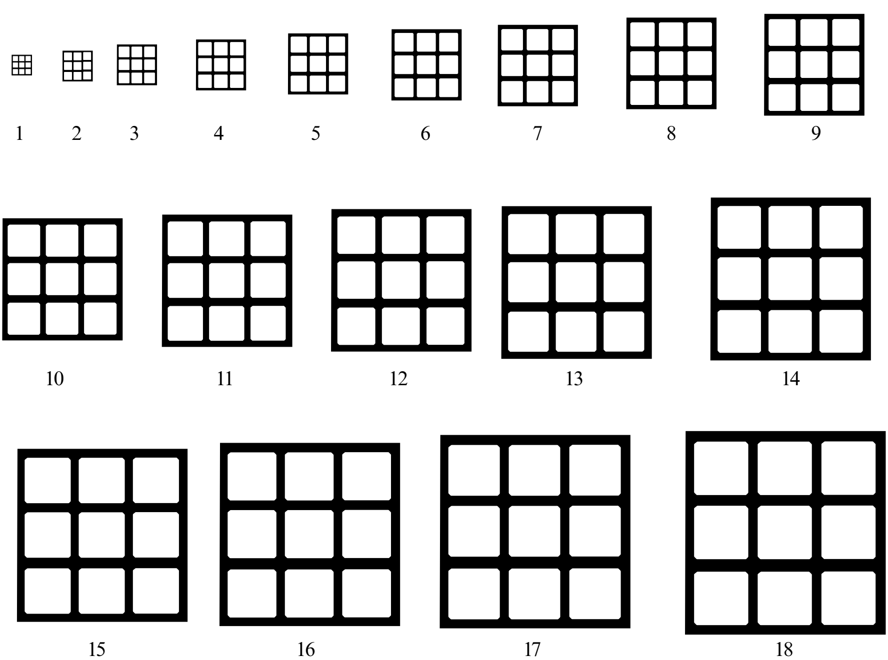

Figure 1. Example (not to scale) of magnitude judgment sheet for the cube.

3 Experiment 1

3.1 *Method*

All the experiments were performed in a totally dark room. Preliminary trials had established that a 3 min period of dark adaptation was sufficient to generate a positive afterimage that would last approximately 5 s to 10 s; and that a short exposure (5 s – 10 s) to a 25-watt light would require 30 s of dark adaptation between trials to generate a new positive afterimage. For each trial, the subjects were asked to start triggering the flashgun until they saw a clear, positive afterimage. The number of flashes varied for the subjects between 1 and 4 flashes, and all subjects reported clear positive afterimages when using this procedure. In the first experiment, for the first 3 trials observers were instructed to start moving either the cube or their hand towards their nose, and to signal the experimenter when the nose was touched by saying "now". Half of the participants started the trials with the cube, the other half with their hand. After each trial the cube was moved out of the observer's field of view, the 25-watt light was turned on, and the observers made magnitude estimates of the size of the cube or hand as it appeared the last time they 'saw' it in the dark. For the second set of 3 trials, a metal rod barrier was placed at half the distance between the blackboard and the observer's nose. Here the subjects signaled "now" when the barrier was touched. For the third set of 3 trials, the subjects started at the metal rod and moved their hands in the opposite direction until it touched the blackboard. Prior to the experiment, the observers were shown the scaled drawings to be used in the magnitude estimates. After completion of all trials, they were asked to indicate on the drawings the closest match to real size of the cube and their hand; these estimates were used as baseline data.

3.2 *Results*

For all analyses, the mean of the 3 trials per observer condition was employed for purposes of statistical analyses. The lengths of each subject's hand, arm, and fingertips to elbow in the second study, were taken to measure the distances needed to calculate visual angles.

For each direction of arm movements, a separate ANOVA was carried out on the respective magnitude estimates. In the case of movement towards the nose, a 3 (distance) × 2 (object type) within-subjects ANOVA yielded a highly significant main effect for both distance ($F_{2,22} = 47.78$, $p < 0.001$) and object type ($F_{1,11} = 50.65$, $p < 0.001$). In addition, it also showed a highly significant interaction effect ($F_{2,22} = 12.91$, $p < 0.001$). Figure 2 shows that the magnitude estimates for the Rubik's cube follow a linear trend, whereas those for the hand at first decrease and then increase; and it is the latter reversal which brings about the significant interaction.

For the case of movement away from the body, a 2 (distances) × 2 (object type) within subjects ANOVA yielded significant main effects for both distance ($F_{1,11} = 18.72$, $p < 0.001$), and object type ($F_{1,11} = 101.52$, $p < 0.001$), but no interaction effect.

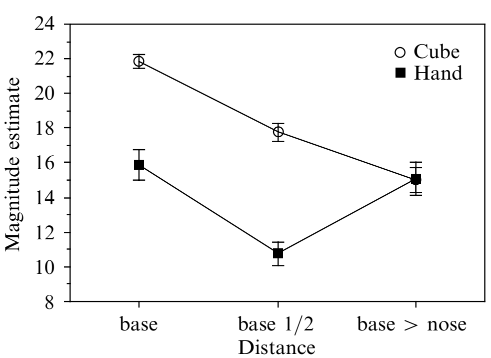

Figure 2. Changes in magnitude estimates as a function of arm/hand movement toward the body (base = hand at blackboard).

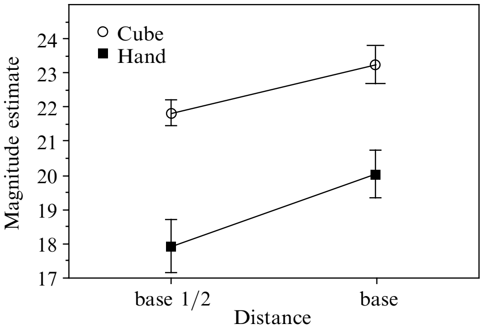

Figure 3. Changes in magnitude estimates as a function of arm/hand movement away from the body (base = hand at blackboard).

As can be seen in figure 3, here the magnitude estimates for both the Rubik's cube and the hand follow a similar trend.

4 Experiment 2

4.1 *Subjects*

Nine females and five males (age 21 to 33 years), all with normal or corrected-to-normal vision, participated in the second experiment.

4.2 *Method*

For the second study, which assessed the effect of passive, haptic feedback, the general procedure was identical except for the following points: (i) observers extended their right arm along the line of sight and placed their fingertips, palm down, against the blackboard and the experimenter placed the cube on their hand; (ii) again the flashes were triggered by the subjects, but now the observers were instructed to say "now" when they saw a clear positive afterimage; (iii) at that point the experimenter moved the cube in a sliding motion on the arm to the elbow where a cardboard cuff stopped the motion. Then the 25-watt light was turned on and the magnitude estimate obtained. Two sets of 3 trials per subject were given: in the first set the subjects were asked to keep their eyes open in the dark and in the second set to close them once the after-image appeared. Half the subjects started with their eyes open, the other half with their eyes closed. As in the first study, after completing all trials the observers were asked to indicate which scale drawing represented the closest match to the real size of the cube and these estimates were used as baseline data.

4.3 *Results*

For this experiment a 2 (distance) $\times$ 2 (eyes open/closed) within-subjects ANOVA yielded significant main effects for distance ($F_{1,13} = 86.95$, $p < 0.001$), but no significant difference for the eyes open versus shut, or an interaction effect. As can be seen in figure 4, here also the magnitude estimates of the cube show a trend conforming to Emmert's law for both the eyes-open and the eyes-closed conditions.

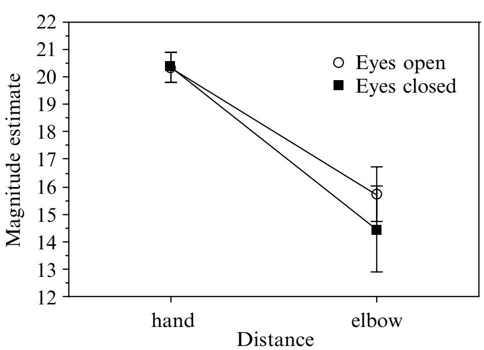

Figure 4. Changes in magnitude estimates as a function of passive movement along the arm for the eyes-open and eyes-closed conditions.

5 Discussion

The results of the present studies are of interest in two respects; first they show in the case of the Rubik cube that the perceptual system can use proprioceptive and/or haptic information for size–distance scaling in a manner that conforms closely to Emmert's law. Second, as evident from the first experiment, there can be exceptions to this mechanism when the object to be scaled has well-established representations which can impose limits on the degree and accuracy of size–distance scaling. These two points will be addressed separately.

As had been expected, in the case of the cube, the data clearly indicate that the changes in perceived size follow closely the pattern predicted by Emmert's law. Evidently both active and passive proprioceptive or tactile signals produced by moving an object along the line of sight are sufficient to produce these changes—a relationship that holds for movement towards and for movement away from the body. Figure 5, in which the magnitude estimates have been converted into the corresponding metric units to calculate visual angles, shows a tight fit between the quantitative predictions and the observed data points for the corresponding active and passive movement towards the body.

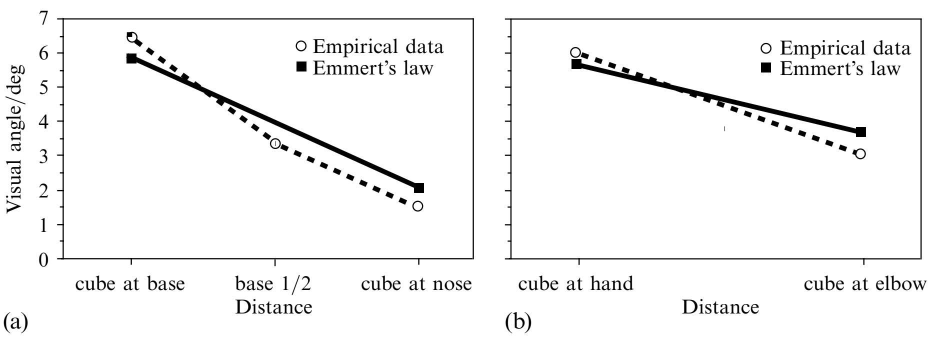

Figure 5. A comparison of the obtained and predicted judgments of the cube for (a) experiment 1 and (b) experiment 2 with the data collapsed for the two conditions.

Also, the second study showed no differences between the eyes-open and eyes-closed conditions, indicating that oculomotor cues appear to contribute very little to these effects. While Suzuki (1986) had shown that oculomotor cues (using convergence to simulate changes in projected distance) can produce alterations in the apparent size of afterimages, the present data indicate that these do not seem to provide any significant additions to proprioceptive and/or haptic cues—a finding in accordance with those of Heuer and Lüschow (1983) that other cues can dominate over eye-movement cues.

The observed changes in size provide corroboration for the essentially amodal nature of the spatial coordinates used by the perceptual system to size-scale objects in space. Additional support for the argument that the proprioceptive cues are indeed changing the visual representation of the size of objects in 'visual' space is born out by the permanence of the change: The alterations in the size of the afterimage are retained after the arm movement stops, and remain so as the positive afterimage turns negative and freezes. That proprioceptive and/or haptic stimulation is sufficient, and that changes in perceived location are not restricted to visual proprioceptive interactions has been shown by Lackner (1988), who reported that blindfolded subjects experience changes in the position of their arms in response to vibratory stimulation to muscle stretch receptors.

The first study also revealed a difference as to how the afterimages of the hand versus a hand-held object conform to Emmert's law. This, however, was not a uniform effect for all observers. While for all participants there was some shrinkage in the apparent size of the hand at half-distance, only three experienced any further shrinkage when the hand was brought to the nose; and nine of the twelve participants experienced a reversal in apparent hand size. That the hand 'refuses' to size-scale below a certain limit is not surprising if one considers that the smallest visual angle observers have ever seen of their hand is when the arm is fully extended, a circumstance which suggests that this phenomenon is specific to the hand of the observer (they have, however, seen quite large visual angles of their hand). The cube, on the other hand, has been seen at very small visual angles and thus follows Emmert's law rather closely. A common report by the subjects in this study was that the decrease in their hand size produced a rather startling and curious feeling. Clearly the size of body parts, especially those which are frequently in the field of vision, has well established perceptual representations and violations of these in visual space are tolerated only to a certain degree. This agrees with the finding of Davies (1973) who reported that lateral hand movement resulted in a 'crumble' effect or disappearance of the hand while the checkerboard background pattern remained visible in the afterimage. Similarly, afterimages of the cube or hand not along the line of sight usually disappear, and a 'fixed' afterimage will reappear at the original location. These observations are similar to those of Hayhoe and Williams (1984) who found that afterimages projected at impossible locations vanish.

It is of some importance to note that the shrinkage effect in hand size appears to be subject to habituation and/or learning. All subjects in experiment 1 were naïve with respect to this effect. A follow-up of two observers, who had reported the reversal in apparent hand size, over a 3-month period with weekly tests has shown that the reversal 'disappears' and the hand will size-scale in accordance with Emmert's law. This indicates that experience with this effect can bring about changes in the representation of body parts in afterimages. A suggestive analogy exists here to the remapping hypothesis advanced to explain changes in the perception of body parts (Ramachandran et al 1992), the mechanisms for changes in the topography of the body image proposed by Damasio and Damasio (1996), and the neurological principles of learning and cortical plasticity of Merzenich and deCharms (1996).

Some questions for future research on this topic relate to whether spatial changes signaled by other than proprioceptive signals (eg auditory cues) will also lead to changes in visual afterimages. Also the problem of manipulating more than one afterimage simultaneously remains unexplored. By having observers hold an object in each hand and moving the hands in opposite directions should, in principle, produce divergent changes in the size of the afterimages. Some preliminary pilot work so far indicates that there might be attentional limitations: subjects find it exceedingly difficult to keep track of more than one afterimage.

Finally, it seems appropriate to point out that, in the case of the cube, Berkeley anticipated the general findings presented here. As the following brief quotations show, his prediction would have been that the changes in the apparent size of afterimages would be informed in this case by tactile judgments: "So that in strict truth the ideas of sight, when we apprehend by them distance, and things placed at a distance, do not suggest or mark out to us things actually existing at a distance, but admonish us what ideas of touch will be imprinted in our minds at such and such distances ..." (*The Principles of Human Knowledge*, article 44). And, as with distance, so with the perceived size of objects: "Whenever therefore we speak of the magnitude of any thing ... we must mean the tangible magnitude, otherwise there can be nothing steady and free from ambiguity spoken of it" (*A New Theory of Vision*, article 55). Berkeley goes on to explain at great length the moon illusion using his principles, and it is clear that he argues that we judge the apparent magnitude of things by cues in addition to, and other than, the image cast on the back of the eye, and thereby Berkeley anticipated the present results by almost three centuries.

References

Berkeley G, 1965 *Berkeley's Philosophical Writings* Ed. D M Armstrong (London: Collier MacMillan)

Boring E, 1942 *Sensation and Perception in the History of Experimental Psychology* (New York: Appleton-Century-Crofts)

Damasio A R, Damasio H, 1996 "Making images and creating subjectivity", in *The Mind – Brain Continuum* Eds R Llinas, P S Churchland (Cambridge, MA: MIT Press) pp 19 – 27

Davies P, 1973 "Effects of movements on the appearance and duration of a prolonged visual afterimage: 1. Changes arising from the movement of a portion of the body incorporated in the afterimaged scene" *Perception* **2** 147 – 153

Duwaer A L, 1982 "Assessment of retinal image displacement during head movement using an afterimage method" *Vision Research* **22** 1379 – 1388

Dwyer J, Ashton R, Broerse J, 1990 "Emmert's law in the Ames room" *Perception* **19** 35 – 41

Gregory R L, Wallace J G, Campbell F W, 1959 "Changes in the size and shape of visual after-images observed in complete darkness during changes of position in space" *Quarterly Journal of Experimental Psychology* **11** 54 – 55

Hayhoe M M, Williams D R, 1984 "Disappearance of afterimages at 'impossible' locations in space" *Perception* **13** 455 – 459

Heuer H, Lüschow U, 1983 "Aftereffects of sustained convergence: Some implications of the eye muscle potentiation hypothesis" *Perception* **12** 337 – 346

Lackner J R, 1988 "Some proprioceptive influences on perceptual representations" *Brain* **111** 281 – 297

Merzenich M M, deCharms R C, 1996 "Neural representations, experience, and change", in *The Mind – Brain Continuum* Eds R Llinas, P S Churchland (Cambridge, MA: MIT Press) pp 61 – 81

Ramachandran V S, Rogers-Ramachandran D, Stewart M, 1992 "Perceptual correlates of massive cortical reorganization" *Science* **258** 1159 – 1160

Suzuki K, 1986 "Effects of oculomotor cues on the apparent size of afterimages" *Japanese Psychological Research* **28** 168 – 175