Correspondence

Size constancy following long-term visual deprivation

Elena Andres[1], Ayelet McKyton[1], Itay Ben-Zion[2], and Ehud Zohary[1,*]

We can estimate the veridical size of nearby objects reasonably well irrespective of their viewing distance. This perceptual capability, termed size constancy, is accomplished by combining information about retinal image size together with the viewing distance, or using the relational information available in the scene, via direct perception [1]. A previous study [2] showed that children typically underestimate the size of a distant object. This underestimation is reduced with time, suggesting that years of visual experience may be essential for attaining true size constancy. But what if you have had very limited vision during the early years of life? We studied 23 Ethiopian children suffering from bilateral, early-onset cataract, who were surgically treated only years after birth. Surprisingly, most children were able to estimate object size reasonably well irrespective of distance; in fact, they usually tended to overestimate the far-object size. Closer examination indicated that, although before surgery the patients were diagnosed as having a full, mature bilateral cataract, they nevertheless had some residual form of vision, typically limited to very close range. Gandhi *et al*. [3] earlier reported immediate susceptibility to geometric visual illusions in a similar group of newly-sighted children, concluding that size constancy was probably innate. We suggest that their immediate ability to judge physical size irrespective of distance is more likely to result from their previous visual experience.

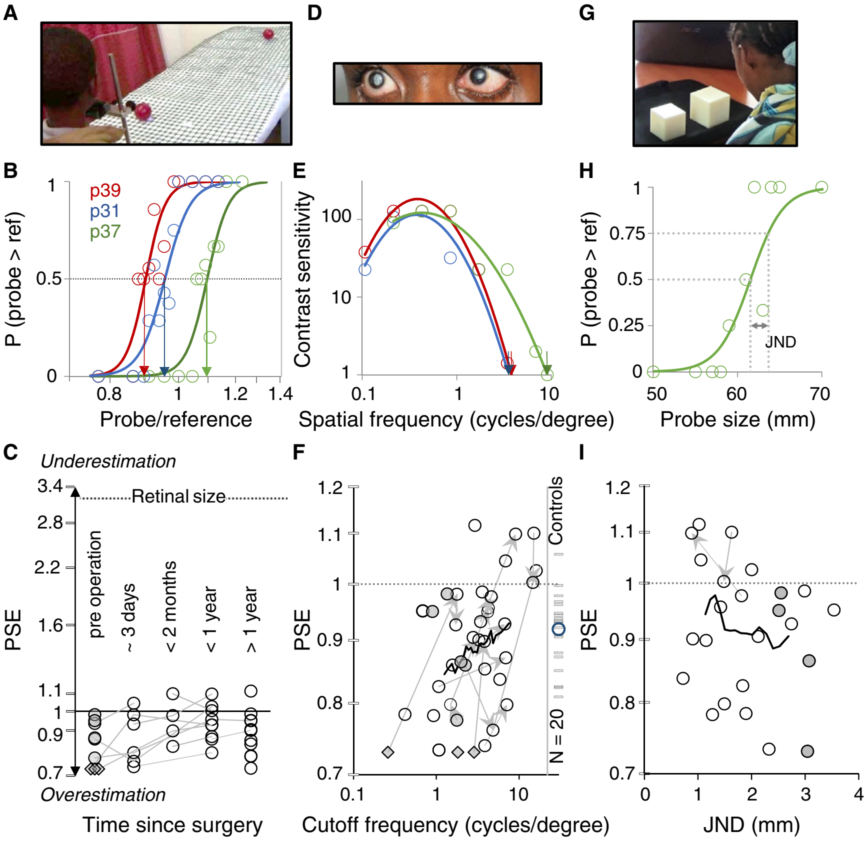

Figure 1. Size constancy in the newly sighted.

(A) Illustration of the experimental setup of the size constancy task. (B) Performance of three exemplary patients a few months after surgery. Their point of subjective equality (PSE) is shown by the arrows. (C) The PSE of all subjects (N = 23) at various times post-surgery. The hatched line indicates assessment based on the probe retinal size. Rhombuses represent the minimum value of probe overestimation of three subjects before surgery (due to a ceiling effect). (D) Picture of the dense cataract of p39 before surgery. (E) The contrast sensitivity function of the same patients from (B). Cutoff frequencies are denoted by arrows. (F) PSE plotted as a function of the cutoff frequency of each subject. The black contour indicates the running average (using 15 data-points). PSE values of controls (N = 20) are depicted on the right side, the open blue circle indicates the group mean value. (G) Illustration of the experimental setup of the visual size discrimination task. (H) An example psychometric function of one subject (p37) depicting the proportion of judgments that the probe cube was larger than the reference, as a function of the probe size. The distance between the two hatched vertical lines is the just noticeable difference (JND). (I) The PSE of the newly sighted patients (N = 22) as a function of their JND in the visual size discrimination task. Both tests were done on the same day. The black contour indicates the running average (using 10 data-points). In all graphs, filled circles mark tests performed pre-surgery. Tasks performend at different times by the same subject are connected by lines. Arrowheads point to the latest test.

We studied vision in individuals (ages 5–19) who had bilateral early-onset cataract. Figure 1D shows an example of the cataract extent in both eyes in one such patient (p39) prior to surgery. All subjects had nystagmus: a sign of early-onset blindness. Size constancy was assessed using methods similar to Gori *et al*. [2]. Briefly, on each trial a reference ball (65 mm diameter; 'ref') was always present at 32.5 cm on a grid-marked table, and a test ball ('probe') was placed at 145 cm from the viewer (Figure 1A). Participants had to indicate which of the two balls was bigger. The probe size was adaptively varied according to the subject's report using a staircase procedure (for experimental details, see Supplemental Information). Performance, depicting the proportion of trials in which the probe was judged to be larger than the reference (as a function of the probe to reference ratio), was assessed. The data were fit by a psychometric curve using logistic regression, yielding the point of subjective equality (PSE) — where the probe size was judged to be equal to the reference. A PSE smaller than 1 indicates overestimation of the far object size and *vice versa*. Children were tested at different times: before surgery (N = 9), and a few days up to years after cataract removal. Individual performance examples are shown in Figure 1B.

We also assessed the degree of image blur experienced by each participant by evaluating his/her cutoff frequency in the contrast sensitivity function (for experimental details, see Supplemental Information) at the same date as the size estimation test (Figure 1E). Our expectation was that, immediately after sight onset, patients might initially fail to assess the distance appropriately and rely heavily on the retinal size, thus underestimating the size of the far object. Indeed, previous studies of patients who were blind from early childhood and regained sight years later showed that they had difficulty interpreting depth cues [4–7]. But this clearly was not the case here; rather, an opposite effect (probe overestimation) was seen. The population results are shown in Figure 1C. Note that some of the patients were quite accurate in the task even before the surgery. In general, children with a higher cutoff frequency were better in veridical size comparison than those with poor spatial vision (Figure 1F; see Supplemental Information for statistical analysis). Overestimation of the far object size could possibly result from blurry vision: A Gaussian blur kernel applied to a distant object (having a small retinal size) might increase its perceived size proportionately more than when applied to a close object of the same physical size. However, our results (Supplemental Information) suggest that blur mainly reduces the impact of depth cues, leading to a tendency towards comparison of the retinal sizes of the two objects irrespective of their apparent distance.

We conclude that blur in itself cannot be responsible for the strong overestimation observed in the newly sighted. We also tested the newly-sighted subjects' ability to visually discriminate between two cubes of different sizes (Figure 1G) at close range (for experimental details see Supplemental Information). Their size discrimination performance was assessed by the just noticeable difference (JND) required to tell which of the two cubes was larger. As expected, the JND (in the visual size discrimination) and the PSE (in the size constancy test) were negatively correlated (Figure 1H). Still, the correlation was quite weak (Pearson's r = –0.218). Probably, this is because size constancy performance is largely limited by the estimation of the object's distance and the accuracy of the *mapping function* between the retinal size and physical size of an object, according to its distance from the observer. Alternatively, size constancy may result from *direct perception* using the relational information available in the scene [1].

Our results suggest that children who had dense bilateral cataract for years can estimate physical size despite their poor vision. They also complement the surprising findings of Gandhi *et al*. [3] who reported immediate susceptibility of the visual Ponzo and Müller-Lyer illusions in similar cases of newly-sighted patients. Traditionally, these illusions were seen as a result of a learned association of two-dimensional perspective cues with the distances they represent in the three-dimensional world [8]. Because the newly sighted showed immediate susceptibility to these illusions, Gandhi *et al*. [3] concluded that perception of these geometric illusions does not require extensive visual experience. The patients in that study were reported to have pre-operative vision "limited to the perception of hand movements close to the face". One cannot completely rule out that their sample of patients was drastically different from ours; however, we have learned from our growing experience that the patients' pre-operative vision is often better than expected from basic clinical observation (for example ophthalmoscopy or slit lamp testing) and requires careful testing beyond the division of patients as having vision limited to light perception, hand movement, or finger counting from X meters.

We therefore suggest that limited visual experience may be sufficient for the development of size constancy. Infants are sensitive to various depth cues despite the fact that, below 6 months, visual acuity and contrast sensitivity are much poorer than in adults [9]. A blurred retinal image is still inversely scaled with distance, and object size can be confirmed for objects within hand range. Still, children slowly learn to assess physical size beyond the haptic workspace. They show a clear shift from an underestimation of a distant object size in early childhood to its overestimation in adulthood, possibly reflecting the use of better cognitive strategies with time [10]. Irrespective of the process by which size judgments are derived — a reasoning process or a cognitively impenetrable visual process — they require visual information about object distance. Our results show that such information is available even in the presence of a dense, long-standing cataract. Thus, although we cannot completely exclude an innate mechanism allowing for size constancy, it is more likely that its development depends on visual experience.

SUPPLEMENTAL INFORMATION

Supplemental Information includes supplemental experimental procedures, one figure and one table and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2017.05.071.

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[1]Edmond & Lily Safra Center for Brain Science, The Hebrew University of Jerusalem, 91904, Israel. [2]Sheba Medical Center and Tel Aviv University, 6997801 Israel.
*E-mail: udiz@mail.huji.ac.il