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Visual context integration is not fully developed in 4-year-old children

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Abstract. Long-range horizontal interactions supporting contour integration were found to be weaker in children than in adults (Kovács et al, 1999 *Proceedings of the National Academy of Sciences of the USA* **96** 12204 – 12209). In the present study, integration on a larger scale, between a target and its context was investigated. Contextual modulation of the percept of a local target can be directly measured in the case of geometric illusions. We compared the magnitude of a size contrast illusion (Ebbinghaus illusion or Titchener circles) in children and adults. 4-year-old children and adults performed 2AFC size comparisons between two target disks in the classical Ebbinghaus illusion display and in two other modified versions. We found that the magnitude of the illusion effect was significantly smaller in children than in adults. Our interpretation is that context integration is not fully developed in 4-year-old children. Closer-to-veridical-size estimations by children demonstrate that the perception of the local target is less affected by stimulus context in their case. We suggest that immature cortical connectivity is behind the reduced contextual sensitivity in children.

1 Introduction

Psychophysical studies showed that contour integration ability develops slowly in childhood and it is not adult-like until 14 years of age (Kovács et al 1999; Kovács 2000). Physiologically, integration across space can be mediated either by horizontal connections within each cortical representation of the visual field, by the increasing receptive field sizes at higher-level cortical areas, or by modulatory feedback connections from them. A possible anatomical substrate of the psychophysically defined long-range interactions is the plexus of intrinsic horizontal connections of the primary visual cortex (Gilbert and Wiesel 1983; Rockland and Lund 1983; Stettler et al 2002). The development of horizontal connections in layer 2/3 of the primary visual cortex of humans has been shown to extend well into childhood (Burkhalter et al 1993). Feedback connections that originate in extrastriate cortex and mediate top – down influences might also contribute to contour integration. A delayed postnatal development of feedback connections between V1 and V2 has also been indicated in humans (Burkhalter 1993). In a recent neuropsychological study (Giersch et al 2000), a visual agnosic patient who had an intact V1, but a severe damage in other occipital and temporal areas, has shown entirely normal contour-integration performance. This indicates that V1 is sufficient to mediate in the contour-integration task.

In addition to enhancing the local tuning of neurons, long-range horizontal, and feedback connections might also contribute to visual context integration on a larger scale (see eg Gilbert et al 1996; Gilbert 1998). Here is a quote from a neurophysiologist who was among the first to identify lateral connections in the visual cortex:

> “Attempts by the visual system to integrate information over space is seen in completion illusions such as illusory contours and perceptual fill-in, in grouping operations such as contour saliency and pop-out, in perceptual constancies, and in the segmentation of surfaces and contours into distinct objects. The process intervening between the perception of simple, physical attributes and the recognition of complex objects is referred to as ‘intermediate level vision’. A growing body of evidence now reveals that what may

be considered an intermediate perceptual process actually involves very early events in the cortical processing of visual information, including the primary visual cortex." (Gilbert 1998, page 468)

Questions regarding the perceptual consequences of immature low-level cortical connectivity motivated this research. Does the immaturity of long-range spatial interactions result in less efficient contextual integration in children? Perceptual contextual influences can be estimated by assessing contextual modulation on the percept of a local target. Geometric optical illusions provide an excellent paradigm to answer our question. We used a classic geometric optical illusion, known as the Ebbinghaus illusion (or Titchener circles—figure 1a).

While there is early indication (Weintraub 1979) that the effect of the illusion might be weaker in children than in adults, in a more recent attempt to estimate the illusion in children, there were contradictory comparative findings across different age groups (Hanisch et al 2001). A great disadvantage of the available developmental studies is that they employ simple "yes/no" paradigms; therefore, they are predisposed to criterion changes across trials, conditions, or subjects (as in, eg, Hanisch et al 2001). We have developed a robust psychophysical paradigm employing a 2AFC task that allows us to estimate the illusion reliably, even in the youngest age groups. Our findings show that children are indeed less susceptible to the illusion than adults, indicating their lower sensitivity to contextual influences in the visual field.

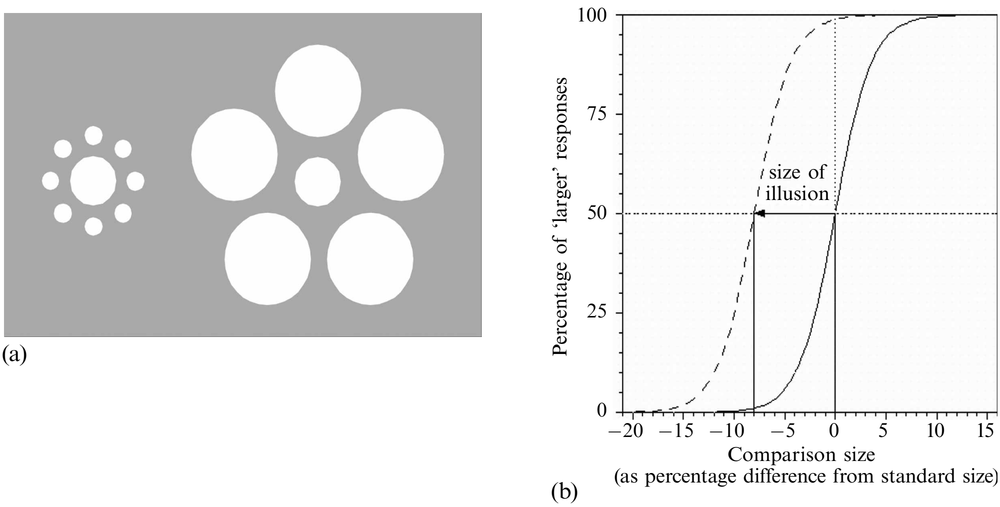


Figure 1. (a) Ebbinghaus illusion stimulus used in experimental condition E. Further stimuli included: large annulus only (L), small annulus only (S), and no-annulus control (C). (b) The amount of illusion was determined as a horizontal shift of the psychometric curve, that is as the difference between the diameters of the standard and comparison disks at $p = 0.5$ 'larger' responses. Two hypothetical psychometric curves are shown, where the percentage of 'larger' responses is plotted as a function of the difference between comparison and standard stimuli. The solid curve indicates the lack of illusion. The dashed curve shows a case where the point of subjective equivalence is shifted to the left, indicating an illusion magnitude of -8%.

2 Methods

2.1 *Subjects*

Subjects were thirteen 4-year-old children (nine males, four females; mean age: 4 years 6 months; range: 4 years 1 month – 4 years 11 months) and fifteen adults (eight males, seven females; mean age: 26 years; range: 23 – 31 years). Children were recruited in daycare centers in the New Brunswick area, New Jersey. Adults were students of Rutgers, the State University of New Jersey. All subjects had normal or corrected-to-normal vision.

We tested an additional seven child subjects who could not finish two blocks in each condition owing to tiredness or external circumstances (missing from school on the days of testing). Their data were not included in the final analysis.

2.2 *Stimuli*
Two white target disks on a gray background were presented on a Dell Inspiron 7000 portable computer. We used three different test conditions and a control condition:
(i) Ebbinghaus illusion display (E): one of the two disks was surrounded by an annulus of small white disks ($d = 8$ mm), the other one was surrounded by an annulus of large white disks ($d = 63$ mm). See figure 1a.
(ii) Large-annulus condition (L): one of the disks was surrounded by the annulus of large white disks ($d = 63$ mm), the other one was presented alone.
(iii) Small-annulus condition (S): one of the disks was surrounded by the annulus of small white disks ($d = 8$ mm), the other one was presented alone.
(iv) Control condition (C): only the two target disks were presented without the surrounding disks.

One of the targets, the standard, was held at a constant size of $d = 38$ mm across all conditions. In conditions L and S, this was always the target circle with the illusion-inducing annulus; in condition E, it was the one surrounded by the small annulus (in condition C naturally a distinction is not possible). In order to minimize the number of trials for the children, comparison stimuli varied in diameter within different ranges for different conditions, with eight different comparison sizes per condition, and 1.33 mm increments. Based on pilot study results, these ranges were determined to be 31.33 mm to 40.66 mm in conditions E and L, 34 mm to 43.33 mm in condition S, and 32.66 mm to 42 mm in condition C. Within one block of trials, each comparison size was presented five times. The order of the $8 \times 5 = 40$ trials, and the side of the presentation of the comparison disk was randomized within each block.

2.3 *Procedure*
Subjects performed a 2AFC discrimination task, comparing the size of the target and comparison disks. The question we asked the children was: "Which one of these two disks (pointing toward the two target disks) is bigger?" Children gave their responses verbally, and occasionally by pointing to the target.(1) The experimenter pressed one of the buttons corresponding to the two possible answers. Adult subjects coded their own answers using the same buttons.

All subjects were tested individually in a well-lit, quiet room. Viewing distance was approximately 40 cm.

Subjects ran a minimum of two blocks of 40 trials in each condition, where the order of the blocks was randomized. Children run one or two blocks of trials per testing session (10 – 20 min). Data collection was completed in approximately one month with child subjects. Six of the thirteen children finished only three conditions out of the four: their data were nevertheless included. Adults completed all eight blocks in one session (30 min). Two of the adult subjects completed an additional eight blocks a month later in order to act as comparison for possible long-term effects.

2.4 *Data analysis*
We present the size of the illusion as a percentage difference from the standard size (38 mm). With this transformation, the step size between the different comparison disks was 3.5%.

Our method of measuring the size of the illusion is illustrated in figure 1b. Psychometric curves were obtained by fitting the data with the standard cumulative

(1) There is currently a debate surrounding a dichotomy between perceptual and motor aspects of this illusion. The fact that some of our child subjects pointed to the target circle does not affect our perceptual results, since grasping and pointing rely on different neural structures (Grafton et al 1996).

normal function. The amount of illusion was determined as a horizontal shift of the psychometric curve, that is as the difference between the diameters of the standard and comparison disks at $p = 0.5$ 'larger' responses. Figure 1b shows two hypothetical psychometric curves where the percentage of 'larger' responses is plotted as a function of the difference between comparison and standard stimuli. For the curve at the center of the graph, the point of subjective equivalence ($p = 0.5$ 'larger' responses) is at 0% difference between comparison and standard, indicating the lack of illusion. For the hypothetical curve to the left from the center, the point of subjective equivalence is shifted to the right, indicating -8% illusion.

3 Results

Individual psychometric curves together with group mean curves for each condition and age group are shown in figure 2. These graphs illustrate the extent of individual differences in the two age groups and allow the comparison of the slopes and the distribution of psychometric curves for children and adults. The mean group functions

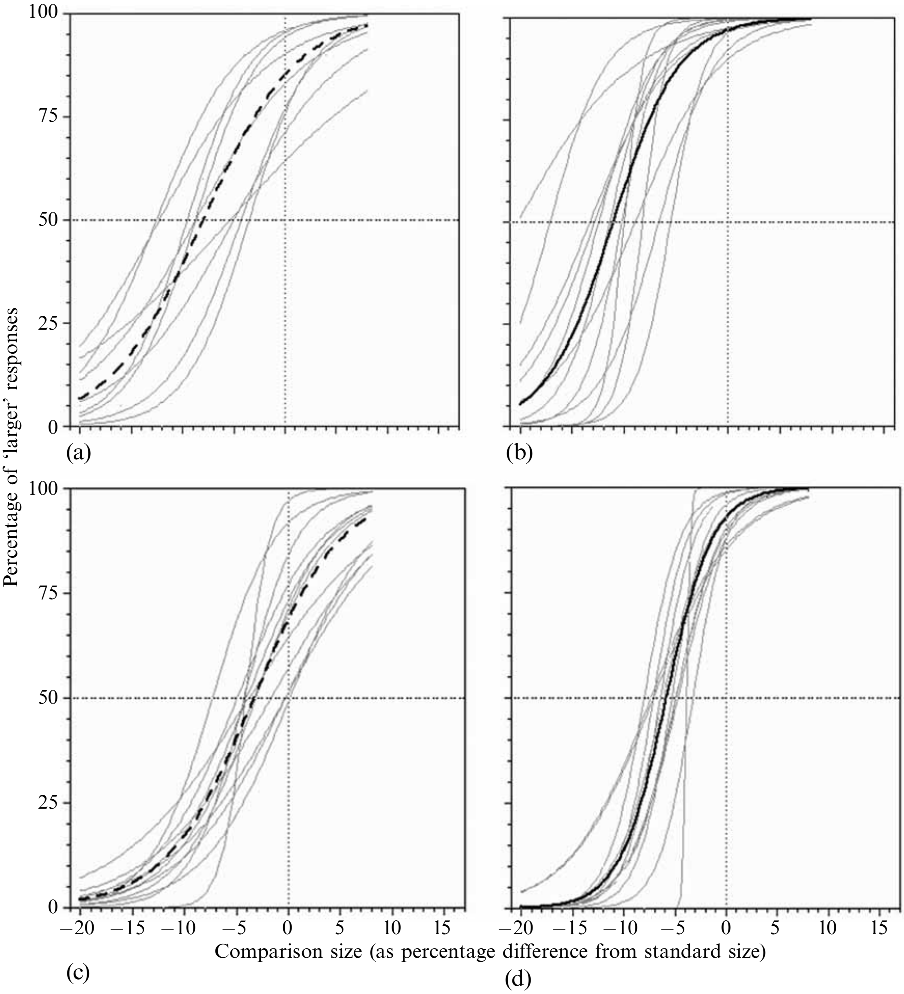


Figure 2. Individual and mean psychometric functions for each age group and condition. Gray lines represent individual functions, black lines represent the mean; solid lines indicate adults' functions, while dashed lines indicate children's functions. (a) Ebbinghaus illusion, children; (b) Ebbinghaus

by condition can be directly compared in figure 3. Individual illusion magnitude values were obtained from these functions and their group averages are shown in table 1.

The results show that children performed reliably in the simple size discrimination test (see figure 3, control condition C). With the given step size we used (3.5%), children could discriminate between different sized disks at the adult level.

A repeated-measures 4×2 ANOVA was conducted with illusion condition (4) as a within-subject variable and age group (2) as a between-subjects variable. (Values for the six missing blocks in the children data set—see above—were filled in by using the group means for this analysis.) The main effect of age group was highly significant ($F_{2,27} = 10.87$, $p < 0.0001$). The interaction between age group and illusion was not significant ($F_{2,27} < 1$).

Planned comparisons with two-sample t-tests showed significant difference in the magnitude of the illusion between children and adults in conditions E ($t_{21} = 2.40$, $p = 0.026$) and L ($t_{24} = 3.85$, $p = 0.001$). Differences between the two age groups did not approach significance in test condition S ($t_{23} = 1.68$, $p = 0.106$) or in control

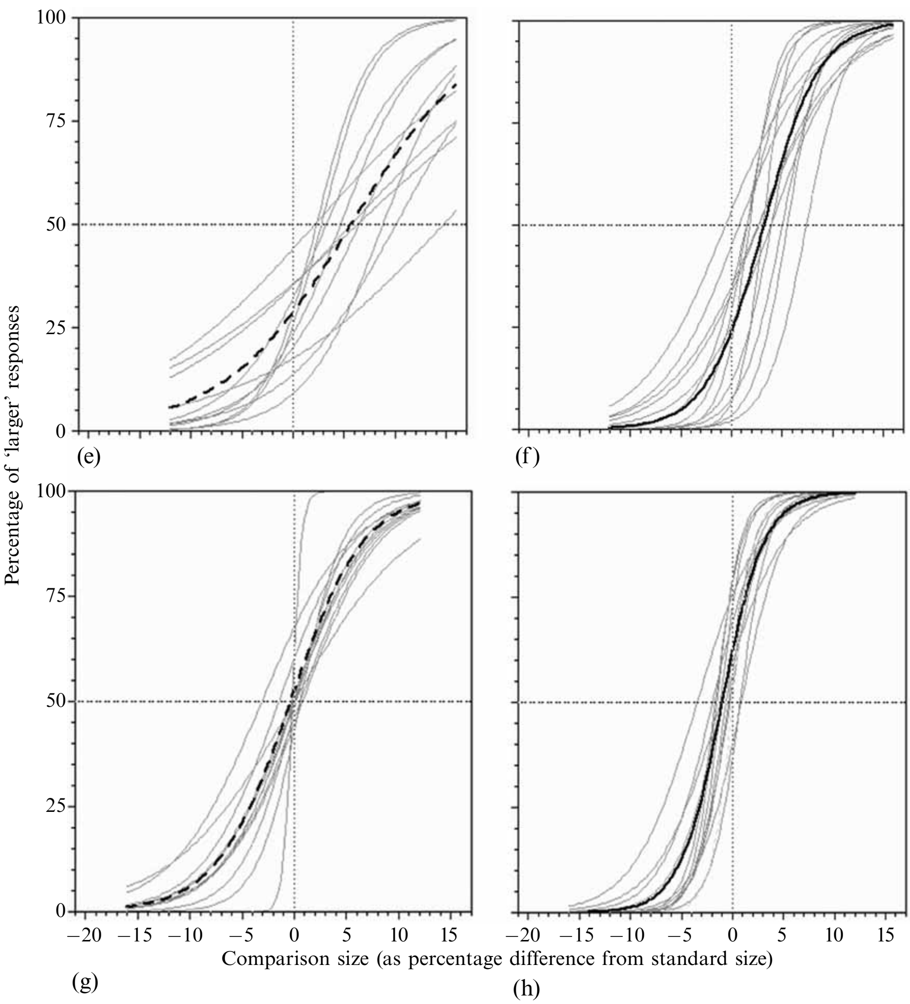
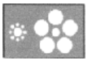
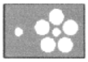
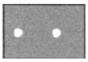


Figure 2 (continued)
illusion, adults; (c) large annulus only condition, children; (d) large annulus only condition, adults; (e) small annulus only condition, children; (f) small annulus only condition, adults; (g) no-annulus (control) condition, children; (h) no-annulus (control) condition, adults.

Table 1. The size of illusion in percentages in the four conditions and the two age groups is shown. The last column indicates the level of significance of the difference between the groups as shown by two-tailed t-tests.

Conditions		Group	Mean illusion/%	SE	Mean difference/%	p (two-tailed)
Ebbinghaus (E)		adults	10.00	0.97	3.30	0.026
		children	6.70	0.91		
Large annulus (L)		adults	5.08	0.35	2.39	0.001
		children	2.69	0.51		
Small annulus (S)		adults	−2.66	0.52	1.92	0.106
		children	−4.58	1.04		
Control (C)		adults	0.78	0.28	0.58	0.169
		children	0.20	0.30		

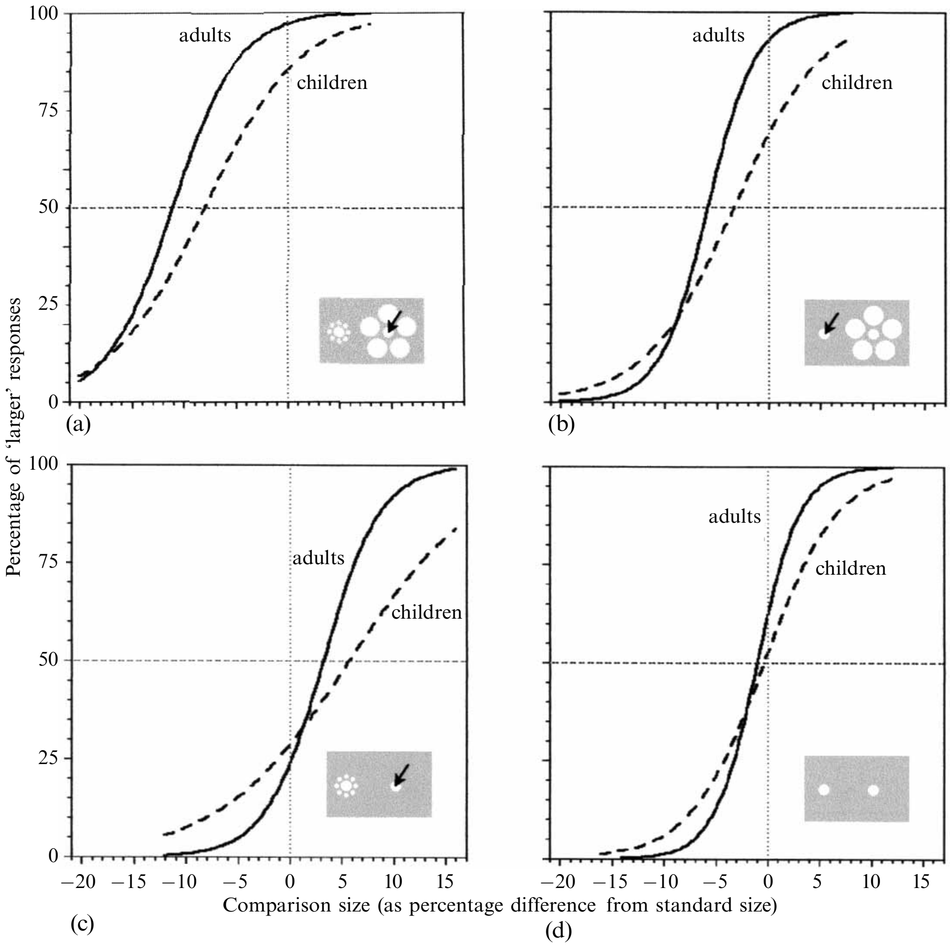


Figure 3. Mean psychometric functions for each condition. Solid lines indicate adults' functions; dashed lines indicate children's functions. Arrows indicate comparison disk. (a) Ebbinghaus illusion; (b) large annulus only condition; (c) small annulus only condition; (d) no-annulus (control) condition.

condition C ($t_{22} = 1.42$, $p = 0.169$). A summary of these results is shown in figure 4 and table 1.

To evaluate the possible long-term effects of extended testing, we tested two adult subjects in two sessions one month apart. As their results did not show any notable differences between the two testing dates, these additional data were included without distinction in the analysis.

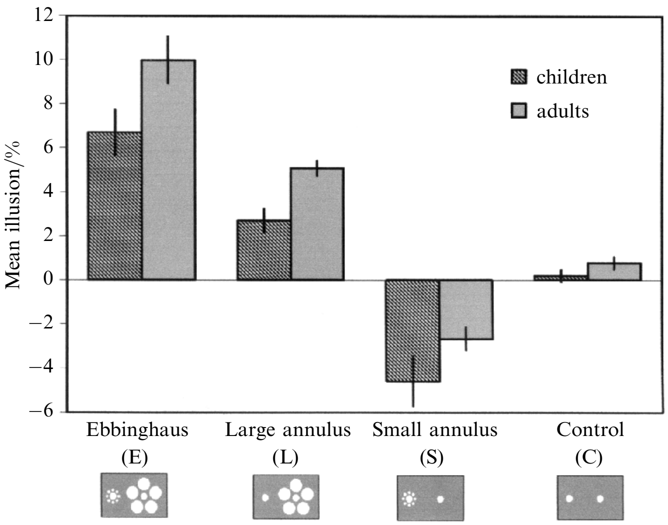


Figure 4. Bars show the magnitude of size estimate differences in percentages. Error bars indicate ±1 SE of the mean. * indicates $p < 0.05$ level of significance, ** indicates $p < 0.01$ level of significance in the age group differences.

4 Summary of results

We have two major findings regarding the performance of 4-year-old children with the 2AFC version of the Ebbinghaus illusion task. First, children showed *highly reliable performance* in condition C, that is they were able to carry out size comparisons at the adult level. Second, children were significantly different from adults in terms of the *amount of the illusion* in conditions E and L. We found that the magnitude of the Ebbinghaus illusion was significantly smaller in 4-year-old children ($p = 0.026$ in condition E), and the illusion effect was significantly smaller ($p = 0.001$) when it was induced by surrounding *only* one of the target disks by an annulus of larger disks (condition L).

The results in condition S, however, are not straightforward. While adults in this condition had psychometric curves that had similar slopes to the ones obtained in the other three conditions, five out of the eleven child subjects had psychometric curves with slopes that are notably shallower (under 45°) than the rest of the group or their own results in any of the other three conditions (see figure 3e). If children found the task with the small annulus only display somewhat precarious, they could follow a certain response strategy: "always tell that the circle with the small annulus is larger, unless the difference is really big". This strategy undoubtedly leads to shallow functions and high illusion threshold values in this condition; however, we cannot prove that this strategy was behind these results. Further studies are needed to explore and explain the observed outcome of this condition.

5 Discussion

On the basis of our earlier results (Kovács et al 1999) we predicted that poor spatial integration might result in reduced susceptibility for visual contextual influences. Since children presented significantly smaller illusions than adults did, we conclude that contextual influences might indeed be less efficient in their case. Our overall interpretation of the results is that context integration is not fully developed in 4-year-old children. We suggested earlier that those circuits that process local visual features mature earlier during visual development, while circuits integrating the local features into coherent scenes come about later (Kovács et al 1999; Kovács 2000). We propose now that the reduced susceptibility for contextual influences in children might be a consequence of immature cortical connectivity.

Contextual integration might also involve higher cortical areas. Recently, Melvyn Goodale and David Milner developed a theory about the functional division of labor between higher-level cortical areas, where the dorsal (occipitoparietal) stream specializes in the visual control of action, and the ventral (occipitotemporal) stream specializes in the perception of the permanent properties of objects (Milner and Goodale 1995). Besides the neuroanatomical and neuropsychological evidence, Goodale and his colleagues (eg Haffenden and Goodale 2000) employed psychophysical studies of the Ebbinghaus illusion. They demonstrated functional dissociation between the two streams, where the dorsal stream appeared to be less susceptible to the illusion. Although these findings have been debated (see eg Franz et al 2000), the interesting possibility of a more significant ventral contribution to the perceptual illusion remains. In the latter case, our findings might indicate a slow maturation of illusion-mediating (and context-mediating) circuits within the ventral stream. This proposal is not in agreement with the conclusions of a recent study by Hanisch et al (2001), who also employed the Ebbinghaus illusion, and found mixed results about the developmental trend of the perceptual aspect of this illusion. However, we would like to emphasize that the Hanisch et al study, such as all previous developmental studies of this illusion (including studies of abnormal development—eg Happé 1996), employ "yes/no" or simple adjustment methods, where a change in the observers' criterion level might lead to too many uncertainties in the data. Our 2AFC paradigm avoids these problems, and provides us with reliable estimates of the illusion both in adults and in children.

It is interesting to note that contrary to the well known "as children grow, they get better at doing things" axiom, 4-year-old children showed evidence for seeing a more *veridical* image of the world than what adults see. Thomas Bower, a leading developmental psychologist of the nineteen seventies, suspected[(2)] that children need a long period to acquire the 'usual size' of objects, and before this process ends they are able to see the veridical size more reliably than adults are:

> "Adults are quite susceptible to illusions produced by presenting odd-sized versions of familiar objects. An oversized chair will be as normal-sized and at a closer distance than it really is. A miniature Rolls-Royce is seen as normal-sized but at a greater distance than it really is. But children of up to five or six years of age will give a reasonable estimate of the true size and distance of the aberrant objects presented. Beyond this age they become as susceptible to the illusion as adults are." (Bower 1977, page 51)

Size constancy is a related phenomenon to context integration, since they both involve perceiving relations between a target object and its surroundings. Studies on neuropsychological patients who have the rare disorder called hemimicropsia (isolated misperception of the size of objects in one hemifield) showed damaged in BA 19 and the occipitotemporal cortex (Kassubek et al 1999). Information about distance is the basic component in perceiving size constancy. The dorsal pathway is known to be

(2) Bower unfortunately does not refer to published results here.

involved in forming spatial representations, but parietal lesions do not lead to size-constancy problems in monkeys (Humphrey and Weiskrantz 1969). Distance-dependent changes in neural responses were found recently in neurons in the ventral pathway leading to inferotemporal cortex (mainly in V4) of monkeys (Dobbins et al 1998; Ashbridge et al 2000), confirming the clinical evidence that size-constancy mechanisms rely on processing in the ventral visual stream.

To date, there is no sufficient information to determine the extra contribution of V1 versus higher-level cortical areas, or the contribution of the dorsal versus ventral visual streams to perceptual context integration, as exemplified by size contrast (Ebbinghaus illusion) or size constancy. We would like to suggest, however, that immature cortical connectivity in V1 on the one hand, and a delayed maturation of the ventral stream on the other hand, might be behind the more 'veridical' percepts in children than in adults.

Acknowledgments. Partial results from this study were presented at the Annual Meeting of the Association for Research in Vision and Ophthalmology, April 30 – May 5, 2000 (Káldy and Kovács 2000). We are grateful to Erik Blaser for his help with data analysis and Shital Shah with data collection.

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