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PAPER

The Ebbinghaus illusion deceives adults but not young children

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Abstract

The sensitivity of size perception to context has been used to distinguish between 'vision for action' and 'vision for perception', and to study cultural, psychopathological, and developmental differences in perception. The status of that evidence is much debated, however. Here we use a rigorous double dissociation paradigm based on the Ebbinghaus illusion, and find that for children below 7 years of age size discrimination is much less affected by surround size. Young children are less accurate than adults when context is helpful, but more accurate when context is misleading. Even by the age of 10 years context-sensitivity is still not at adult levels. Therefore, size contrast as shown by the Ebbinghaus illusion is not a built-in property of the ventral pathway subserving vision for perception but a late development of it, and low sensitivity to the Ebbinghaus illusion in autism is not primary to the pathology. Our findings also show that, although adults in Western cultures have low context-sensitivity relative to East Asians, they have high context-sensitivity relative to children. Overall, these findings reveal a gradual developmental trend toward ever broader contextual syntheses. Such developments are advantageous, but the price paid for them is that, when context is misleading, adults literally see the world less accurately than they did as children.

Introduction

Sensitivity to context is a hallmark of cognitive systems (Phillips & Singer, 1997). In perception, this helps disambiguate local signals which, if considered independently of the broader context, would be open to alternative interpretations. Well-known examples are provided by visual size perception. Though experienced as being direct, rapid and without conscious effort, this uses context to deal with some major ambiguities. The effects of surrounding context on visual size perception have been used to study an exceptionally wide range of issues, including: the proposed distinction between a dorsal action pathway and a ventral conscious perception pathway (Aglioti, DeSouza & Goodale, 1995; Milner & Goodale, 2008); differences between the sexes (Phillips, Chapman & Berry, 2004); cultural differences in the balance between analytic and holistic cognitive styles (Doherty, Tsuji & Phillips, 2008; Kitayama, Duffy, Kawamura & Larsen, 2003; Nisbett & Miyamoto, 2005); the neural substrates of attentional control (Hedden, Ketay, Aron, Markus & Gabrieli, 2008); and the cognitive styles associated with autism (Happé, 1999) and schizophrenia (Phillips & Silverstein, 2003; Uhlhaas & Silverstein, 2005).

Many previous studies support the view that the ventral and dorsal visual pathways have distinct functional roles (Milner & Goodale, 2008). The ventral pathway receives input mainly from parvocellular streams at lower visual levels, and is concerned predominantly with conscious perception of the distal scene and objects as represented within exocentric coordinates. The dorsal pathway receives input mainly from magnocellular streams at lower visual levels, and is predominantly concerned with guiding attention to and action upon specific objects represented within egocentric coordinates. These specializations occur because the two groups of functions require incompatible computations. Object recognition and scene perception require the ability to recognize things independently of their temporary orientation and location relative to the viewer, whereas those are the variables most crucial to the detailed guidance of action (Johnson, Mareschal & Csibra, 2001). Much remains to be discovered concerning the development of these visual capabilities. There is evidence that, in infant development, some functions attributed to the ventral pathway mature earlier than some attributed to the dorsal pathway (Dannemiller, 2001). In contrast to this, however, Kovács (2000) presents psychophysical, anatomical, and computational grounds for supposing that during later perceptual development several functions attributed to the ventral pathway have a much more protracted developmental course than many putative dorsal functions. Her arguments are of particular

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relevance here as we report developmental studies of aspects of size perception that depend predominantly upon the ventral pathways and show a long developmental time-course.

Unlike most studies of the distinctions between dorsal and ventral pathways, here we do not compare perceptual judgments with actions. However, our findings are relevant to the debate about the functions of the two pathways because sensitivity to context in the Ebbinghaus illusion has played such a major role in that debate.

Studies of the effects of context on size perception have contributed to a wide range of issues. They have also given rise to extensive debates concerning the conditions under which the effects occur and how they are to be interpreted (e.g. Franz, Gegenfurter, Bulthoff & Fahle, 2000; Milner & Goodale, 2008; Ropar & Mitchell, 2001). Resolution of these debates requires distinction between three underlying components of the effects of context on size perception. Two of them are well known: size contrast, which depends on relative size, and size constancy, which depends on pictorial depth cues. However, there is also a third component, which is not. This third component involves local contour interactions, and it depends on the separation between targets and surrounds. Targets are perceived as being enlarged when this separation is small, and as being reduced when it is large (Roberts, Harris & Yates, 2005). Haffenden, Schiff and Goodale (2001) show that the separation between targets and surrounds affects grasp scaling. They present evidence that when that separation is kept constant then grasp scaling is unaffected by the size of surrounds. Therefore, to specifically study effects of the size of surrounds, the separation between targets and surrounds should be controlled, but it rarely is. It is particularly important to distinguish local contour interactions from interactions that depend upon size relations, because it is likely that local interactions operate at lower levels of the visual pathways, and develop earlier than interactions that depend upon relative sizes. Here we show that, when this size-separation confound and other methodological difficulties are overcome, a clear developmental time-course for size illusions is seen, with major implications for our understanding of differences between vision for perception and vision for action, and of normal and pathological differences in perceptual style.

Developmental studies of size perception

Many of the capabilities underlying size perception develop during infancy. At 4 months infants show size constancy by habituating to real object size rather than to retinal image size (Granrud, 2006), and by 7 months they are sensitive to interposition cues (Granrud & Yonas, 1984). This evidence concerns only near space, however. The perception of size in far space continues to develop until at least 9 years of age (Zeigler & Leibowitz, 1957), as it also does in pictured spaces, where there is conflict between cues to depth of the picture surface and to depth within the picture (Wilcox & Teghtsoonian 1971; Yonas & Hagen 1973). The general developmental trend seems to be toward ever broader contextual syntheses, and usually to more veridical perception. The extent to which these later developments involve perceptual rather than higher cognitive enhancements is still debated, however (e.g. Granrud & Schmechel, 2006). Therefore, we focus on context effects in the Ebbinghaus illusion because they are predominantly pre-attentive, with little or no dependence on higher cognition.

Developmental studies of susceptibility to the Ebbinghaus illusion have had inconsistent outcomes. In a study of the development of distinct pathways to action and to conscious perception, Hanisch, Konczak and Dohle (2001) report that children as young as 5 years of age are deceived by the illusion to the same extent as adults. A more recent study of the same issue also reports the classical illusion at 5 years of age, but together with other findings this is interpreted as casting doubt on the hypothesized separation between two visual systems (Duemmler, Franz, Jovanovic & Schwarzer, 2008). Happé (1999) concludes that typically developing 7- to 8-year-olds succumb to the illusion, but adolescents with autism do not. More recent studies found no differences between typically developing and autistic subjects, however (Ropar & Mitchell, 2001). Long-range horizontal collaterals in visual cortex and psychophysically measured spatial integration both continue to develop for many years (Kovács, Kozma, Fehér & Benedek, 1999), and this suggests that contextual modulation may also have a long period of development (Kovács, 2000). To test this, Káldy and Kovács (2003) compared sensitivity to context in the Ebbinghaus illusion using young children and adults, and report that at 4 years of age sensitivity is present, but not fully developed. In the only developmental study designed to distinguish different ways in which context affects size perception, Weintraub (1979) tested 384 subjects ranging in age from 6 to 21 years. He concluded that local contour interactions that depend on the separation between targets and surrounds operate fully at all ages tested, but that size contrast effects do not occur before 7 years of age. He used complex and idiosyncratic methods, however, and others have interpreted his results as showing that children as young as 5 years of age are deceived by the illusion (Hanisch *et al.*, 2001), and even as showing that the effects of the illusion decrease with age (Rival, Olivier, Ceyte & Bard, 2004).

The evidence on development of susceptibility to the Ebbinghaus illusion is therefore far from clear. This is, at least in part, because most prior studies suffer from one or more weaknesses. First, following Aglioti *et al.* (1995), several of the developmental studies used small surrounds arranged as a tight ring close to the target figure, whereas large surrounds were placed further away. Therefore, in such displays surround size is confounded with the separation between targets and surrounds.

Second, same–different judgments were often used, and this confounds discrimination with response bias. Third, in many studies the target circles to be compared were of the same size, which provides no measure of the strength of the contextual effects. Fourth, less accurate performance by young children may be a secondary consequence of the immaturity of more general cognitive capacities, rather than being specifically due to differences in the effects of context on size perception.

To overcome these difficulties, we used a rigorous double dissociation paradigm (Phillips *et al.*, 2004). This can provide clear evidence on these issues, and is analogous to a paradigm more recently developed by Ganel, Tanzer and Goodale (2008). In our paradigm some contextual conditions are designed to enhance discrimination and others to impair it. If younger children are genuinely less context-sensitive than adults then they will be more accurate when context is misleading, but less accurate when it is helpful. To obtain sensitive measures of the strength of context effects, uncontaminated by response bias, we studied two-alternative forced-choice discrimination between comparison circles across a range of different real-sizes. To avoid confounding target–surround separation with size relations we placed all surround stimuli at the centres of a 3×3 array such that the separation between the middle of each central circle and its nearest surround was constant.

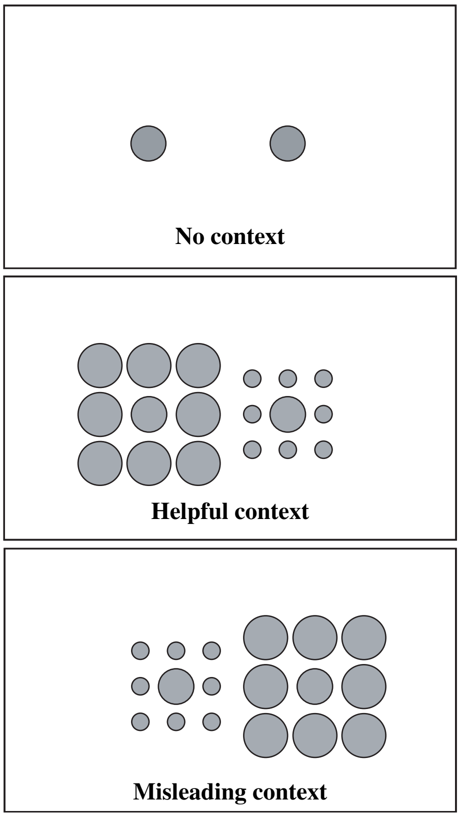

Figure 1 *Examples of the stimuli shown in each of the three contextual conditions (the text was not present in the displays, only the circles). The central circles were coloured orange, the surround circles grey. On each trial participants were presented with one of the displays, and were asked to point to the biggest orange circle. In each case shown here the orange circle on the right is 2% larger than that on the left.*

Method

The two-alternative forced-choice paradigm that we used has been described in detail elsewhere (Phillips *et al.*, 2004; Doherty *et al.*, 2008). The task was to point to the larger of two circles. The two circles to be compared always differed in actual size, and this difference varied in magnitude across trials. In the experimental condition they were presented with surrounding circles arranged so that this context would either support or oppose accurate discrimination (Figure 1). In the control condition they were presented without surrounds.

Participants

Children were recruited from a single primary school with an attached nursery school in a predominantly working-class neighbourhood. All available children were included, in order to have a representative sample. All had normal or corrected to normal vision. Twenty-four young adults were also recruited at the University of Stirling. Participant details are presented in Table 1.

Stimuli, experimental design and apparatus

The circles whose size was to be compared were orange and surrounds were grey, which makes it easier for children to understand the task. On each of the experimental trials two 3×3 arrays of circles were presented, side by side, on a computer screen. The centre circle of one array was 100 pixels in diameter, which subtended approximately 3.3 degrees at the viewing distance of 18 inches. The centre circle of the other was 2, 6, 10, 14, or 18 pixels larger or smaller. Each of these 10 size differences was presented twice, with the larger central circle surrounded by larger circles (125 pixels diameter) and the smaller central circle surrounded by smaller circles (50 pixels diameter). In these conditions size contrast impairs discrimination. Additionally, the 98 and 102 pixel circles

Table 1 *Details of participant numbers, gender and age for each age group*

Group	*N*	male:female	mean age	range	*SD* (mo.)
4 years	29	14:15	4;4	3;9–4;11	4.1
5 years	21	9:12	5;6	5;1–5;11	3.2
6 years	20	10:10	6;5	6;1–6;11	3.5
7 years	20	10:10	7;6	7;1–7;11	3.3
8 years	21	12:9	8;7	8;1–8;11	3.2
9 years	19	10:9	9;5	9;1–9;11	3.2
10 years	21	12:8	10;5	10;1–10;11	2.7
Adult	24	12:12	19;11	18;3–25;6	19.8

were presented twice each with the smaller centre circle surrounded by larger surround circles and the larger central circle surrounded by smaller surround circles. Size contrast then increases accuracy if participants compare the apparent sizes of the centre circles. However, if they simply choose the array with larger surrounds then they will be wrong on every trial in this condition. The 24 trials [$(10 \times 2) + (2 \times 2)$] were presented in random order. In the no-context control condition each of the 10 size differences was presented twice for each child.

A C++ program was developed to present stimuli and record and analyse responses. Stimuli were presented on an Acer 4050 laptop computer with a 15-inch monitor.

Procedure

Participants were tested individually in a quiet familiar area of their classroom. They were shown an example of the stimulus arrays to be used and the task was explained. They were asked to point to the central orange circle that 'looks bigger'. The experimenter pressed the left or right cursor key to record the answer and present the next stimulus. Each participant performed one block of 24 trials with context, and one block of 20 trials without context. Block-order was counterbalanced across participants. No feedback was given during the procedure, which took about 2 minutes. To estimate nonverbal IQ, Raven's Coloured Progressive Matrices were then administered according to the manual.

Results

Here we report our analysis of the accuracy of the two-alternative forced-choice responses. This is simpler and more direct than fitting psychometric functions, and leads to similar conclusions.

Discrimination accuracy over all real-size differences combined

In the control condition, the ability to discriminate the sizes of two circles presented with no context was already good at 4 years, at 79% correct, and increased to between 87% and 95% for the older age groups. In striking contrast, in the experimental condition, discrimination with misleading context remained high for the 4- and 5-year-olds, at 76% and 80% correct respectively, but *declined* with increasing age, being 62% for the 10-year-olds, and only 46% for the adults. The difference between these two contextual conditions was confirmed by an ANOVA, showing a main effect of task (misleading context vs. no-context: $F(1, 167) = 232.1$, $p < .001$, $\eta p^2 = 0.582$), a main effect of age group [$F(7, 167) = 5.06$, $p < .001$, $\eta p^2 = 0.175$], and an interaction [$F(7, 167 = 17.8$, $p < .001$, $\eta p^2 = 0.427$]. Planned *t*-tests indicate that performance in the no-context condition was superior to performance on the misleading context condition for each age group from 6 years onwards (all p values ≥ 0.006, d values between 1.08 and 2.62 for child participants, $d = 6.02$ for the adult group), but not for the 4- or 5-year-olds [$t(28) = 1.25$, $p = .227$, $d = 0.47$; $t(20) = 1.82$, $p = .084$, $d = 0.81$, respectively]. Thus, the younger children were not deceived by the misleading context.

The difference in discrimination accuracy between adults and 10-year-olds was significant [$t(42) = 3.34$, $p = .002$, $d = 1.01$], but they did not differ on the no-context condition. Thus, sensitivity of size perception to context continues to develop beyond 10 years of age, but size discrimination without context does not.

Accuracy as a function of real-size difference, age and context

We now analyse discrimination accuracy as a function of real-size difference to show in more detail how the effects of context change with age (Figure 2). For

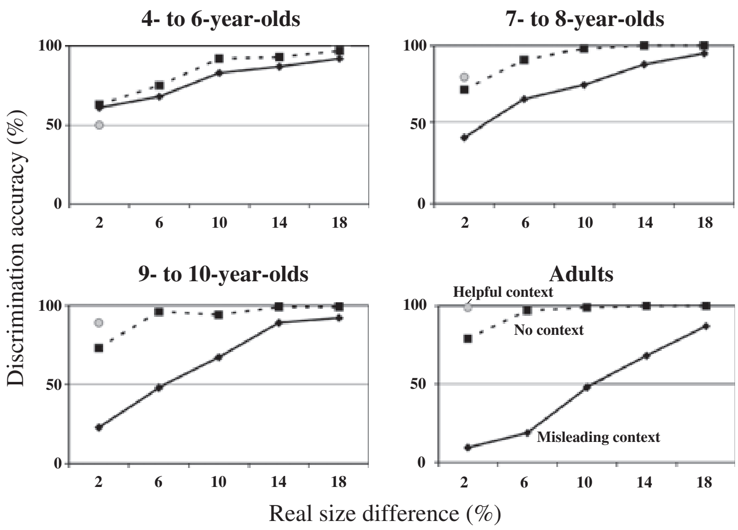

Figure 2 *Discrimination accuracy as a function of real-size difference and context for four age groups. Chance level is 50%. Helpful context was tested at 2% real difference only. For adults it was then already at ceiling, but for 4- to 6-year-olds it was near chance. At 6% real difference with misleading context accuracy was far below chance for adults, but was significantly greater than chance for 4- to 6-year-olds.*

adults, the effects of context and real-size difference were as reported in earlier studies (Phillips *et al.*, 2004; Doherty *et al.*, 2008), i.e. at 2% real-size difference, discrimination accuracy was near to 100% with helpful context, but near to 0% with misleading context. More than 10% real-size difference was needed to overcome the effects of misleading context. For 4- to 6-year-old children, accuracy was little affected by context, however, being similar at 2% real-size difference for all three contextual conditions, and at all other real-size differences in the misleading context and no-context conditions. The decline in accuracy with increasing age in the misleading context condition was particularly strong for the smaller real-size differences. Thus, Figure 2 shows clearly that, for older children and adults, misleading and helpful context have the large effects expected, but for younger children they have little or no effect. This produces worse discrimination by the younger children when context is helpful, but better discrimination when it is misleading.

To assess these differences we carried out an ANOVA on accuracy at 2% real-size difference with the helpful and misleading context conditions as a within-subjects factor and age group as a between-subjects factor. There was a large effect of context [$F(1, 167) = 93.8$, $p < .001$, $\eta p^2 = 0.36$]. There was no overall effect of age group [$F(7, 167) = 0.97$, $\eta p^2 = 0.039$], but a large interaction between condition and age group [$F(7, 167) = 18.18$, $p < .001$, $\eta p^2 = 0.433$]. Improving accuracy with age on the helpful trials was inversely proportional to accuracy on the misleading context trials; these two conditions being highly negatively correlated, $r = -0.65$, $p < .001$. For 2% size difference misleading context trials, 4-year-olds' performance was significantly better than chance [$t(28) = 3.66$, $p = .001$, $d = 1.38$]; 9-year-olds, 10-year-olds' and adults' performances were significantly lower than chance [$t(18) = -4.73$, $p < .001$, $d = 2.23$; $t(19) = -4.82$, $p < .001$, $d = 2.21$; $t(23) = -12.31$, $p < .001$, $d = 5.13$, respectively]; 5- to 8- year-olds' performances did not differ from chance.

The decline in accuracy with age in the misleading context condition continues for many years as the 10-year-olds discriminated significantly better than adults at each of the size differences from 2 to 14% (all probabilities < .05, d values between 0.61 and 0.91).

Relation of context-sensitivity to sex and Raven's Matrix score

There were no significant differences between males and females at any age. Overall, boys were correct on 71% and girls on 75% of misleading context trials [$t(149) = 1.25$, $p = .215$, $d = 0.20$]. The largest difference in performance for any age group was between the 9-year-olds: girls were correct on 71% and boys on 60% of trials [$t(17) = 1.216$, $p = .241$, $d = 0.57$]. The male adult participants were correct on 47.5% of trials, female participants on 44.6% of trials [$t(22) = 0.421$, $p = .678$, $d = 0.18$].

Performance of individual children on Raven's Matrices varied from 10 out of 36 correct to 35 out of 36 correct (chance performance = 6 out of 36). Mean performance improved with age from 14/36 for the 4-year-olds to 29/36 for the 10-year-olds. The overall correlation between matrices score and overall accuracy on the size discrimination task was $r = -0.34$, $p < .001$. Thus, accuracy of size perception is negatively correlated to non-verbal intelligence over this age range as a whole. This relationship remained significant when age and performance on the no-context condition were partialled out: $r = -0.19$, $p < .05$. Moreover, the correlation varied with age in a very clear way, as shown in Figure 3. For the youngest group, the relationship was significantly positive, indicating that, for them, accurate size discrimination was associated with high scores on the Raven's Matrices. With increasing age the correlation becomes increasingly negative. The negative correlation approaches significance for each of the 7- and 8-year-old groups, and for the 2% size difference trials is significant at these ages: for 7-year-olds, $r = -0.48$, $p < .05$; for 8-year-olds, $r = -0.45$, $p < .05$. Thereafter the correlation declines towards zero at around 10 years of age. As context-sensitivity impairs size discrimination in this paradigm, these results imply that between 6 and 9 years of age context-sensitivity is positively correlated with Raven's Matrices score.

Discussion

These findings show that young children discriminate sizes more accurately than adults when context is misleading. More accurate performance by young children in experimental tasks is uncommon because while many

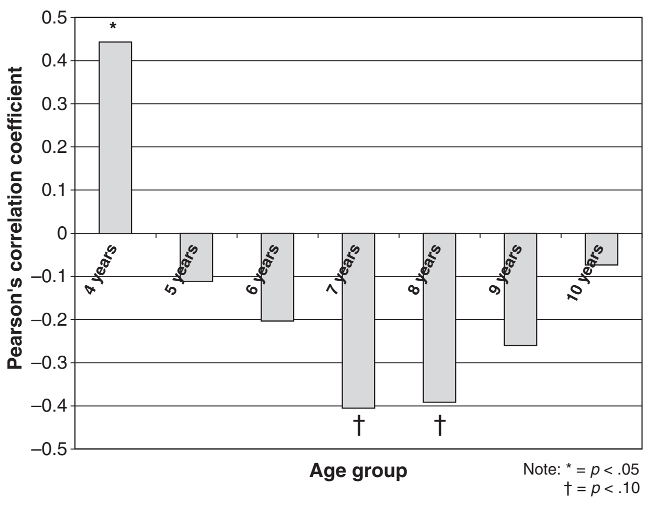

Figure 3 *Correlations between accuracy over the 20 trials with misleading context and score on the Raven's Matrices for each age group from 4 to 10 years.*

factors can produce worse performance, such as failure to understand instructions or lower attention span, few can produce genuinely better performance. The double-dissociation in our data shows that the differences observed here are specific to the effects of context because young children discriminated better than adults when context was misleading, but discriminated less well than adults when it was helpful. Note that our findings are specific to sensitivity to context in the Ebbinghaus illusion. The development of other forms of context sensitivity may well be different.

Our results clearly show that size contrast effects as found in adults are not found in children younger than 7 years of age. Because we controlled the separation between targets and surrounds, the present findings cannot be attributed to the effects of local contour interactions. As discussed in the Introduction, most previous studies of the development of the Ebbinghaus illusion have not controlled for this factor. Thus studies finding evidence for size contrast in young children may do so because they reflect local contour interactions, rather than size constancy or size contrast. This hypothesis awaits empirical test.

Furthermore, development toward the adult form of context-sensitivity in the Ebbinghaus illusion is gradual, and continues until at least 10 years of age. This fits our assumption that a trend toward ever broader contextual syntheses is common to cognitive development in general. Nevertheless, it was a surprise to us to find that such an apparently low-level pre-attentive process takes longer to develop than many higher-level cognitive capabilities. We were also surprised because over the past 10 years we have tested hundreds of adults using this paradigm, and all have shown size contrast to some extent. Adults tested include people with disorganized schizophrenia and people with autism as well as their first-degree relatives, and, though we have usually found the normal adult form of context-sensitivity to be reduced in those cases, we have never yet found it to be absent.

Why does the sensitivity to context in the Ebbinghaus illusion studied here have such a late onset and such a long developmental time-course? One plausible hypothesis concerns the use of pictorial cues to depth and size in pre-attentive vision. Given adequate exposure to pictures, the mature visual system can compute the depth and size of objects in pictured scenes, while at the same time computing the depth and size of the markings on the picture surface. Acquisition of this ability may require much time spent looking at, and correctly interpreting, pictured spaces, because pictorial cues to depth and size within a pictured scene conflict with primary cues to the depth and size of the picture surface itself. These primary depth cues, which include motion parallax and stereo, are so strong that learning to use the full range of pictorial depth cues may take a long time. There is evidence that this is so (e.g. Wilcox & Teghtsoonian, 1971; Yonas & Hagen, 1973). This hypothesis involves three assumptions. The first is that pictorial depth cues affect the perception of the size of markings on the picture surface. This is easily shown to be so, as in Figure 4(a), for example. The second is that the Ebbinghaus illusion is in part due to effects of pictorial cues to depth. As far as we know this is a novel hypothesis, but some support for it may be seen in the demonstrations of Figures 4(b) and 4(c). Finally, as there is little or no conscious experience of differential depths in the Ebbinghaus displays we must also assume that surround size cues alone are not strong enough to evoke the explicit experience of depth, but are strong enough to exert some influence on size perception. This hypothesis suggests that the perception of 3D scenes in 2D displays is a ventral pathway function, because we can act on the surface markings but not within the pictured space. Another advantage of this hypothesis is that it provides a simple explanation for the observation of a weaker Ebbinghaus illusion in a remote sub-Saharan culture (de Fockert, Davidoff, Fagot, Parron & Goldstein, 2007); i.e. they spend less time looking at pictures. Clearly, further tests of this hypothesis are needed.

Better performance at any task by children with lower mental age scores is rare. Its occurrence here between the ages of 6 and 9 years when context is misleading implies

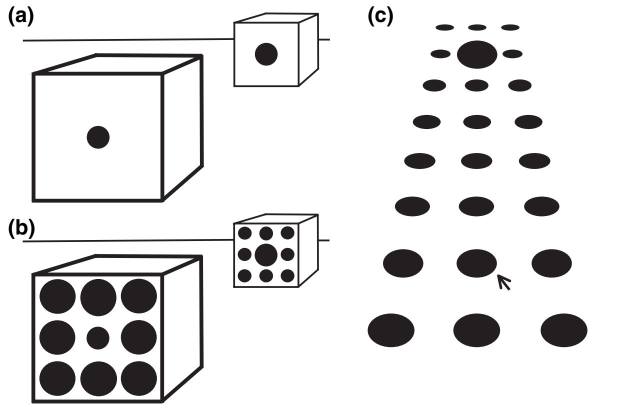

Figure 4 *(a) Most people see the further circle as being larger than the nearer one, though they are equal. They would also judge the 'real' size of the further circle within the pictured space to be much larger than the nearer circle. This shows that pictorial cues to depth and size influence perception of the markings on the picture surface. (b) Adding surrounds, as in the Ebbinghaus illusion, increases the perceived size difference between the two circles. This suggests that surround size adds to the other pictorial depth cues. (c) In texture gradients the mean size and separation of elements decreases with depth. The size of the elements on the picture surface is seen as decreasing with depth, but their 'real' size within the pictured space would be judged to be approximately constant. The large element in the centre of the second row from the top may be seen as being larger than that arrowed below, but they are equal. Its 'real' size within the pictured space would be judged to be much larger. The bottom and top three rows are versions of the Ebbinghaus illusion. Therefore, this suggests that the illusion may in part be due to the visual system learning to use such pictorial cues.*

that the age at which context-sensitivity in the Ebbinghaus illusion is acquired is positively correlated with mental age. One possible reason for this is that either intellectual functions in general or fluid intelligence in particular require sensitivity to context. An additional possibility is that the time spent looking at pictorial spaces is positively correlated with intellectual capabilities reflected in the Raven's Matrices score.

Absence or weakness of surround size effects in the Ebbinghaus illusion has been related to the distinction between vision for action and vision for perception, to cultural differences in perceptual style, and to autistic and schizophrenic psychopathology. These issues now need to be related to the new evidence presented here. First, the presence of surround size effects in perceptual judgment but not in manual action has been taken as primary evidence for the distinction between vision for action and vision for perception (e.g. Milner & Goodale, 2008). However, as we show here, children younger than 7 years of age do not show the adult effects of surround size in their perceptual judgments. Most of the arguments for distinguishing between the two pathways apply to young children as well as to adults. As the two pathways are functionally distinct before sensitivity to surround size in the Ebbinghaus illusion has been acquired, differences in that form of context-sensitivity cannot be necessary to the distinction between the two pathways.

Our results do not imply that vision is insensitive to context in general before 7 years of age, and we do not believe that it is. Our hypothesis is that sensitivity to surround size in the Ebbinghaus illusion matures slowly because it depends upon much time spent looking at, and correctly interpreting, 2-D representations of 3-D scenes. We assume that this learning predominantly affects the ventral stream.

This clearly implies that different ventral and dorsal pathway functions develop at different rates. Some ventral pathway functions develop early in infancy (Dannemiller, 2001), but, like those concerned with face and place processing (Grill-Spector, Golarai & Gabrieli, 2008), those studied here continue to develop well into adolescence. Therefore, although some ventral pathway functions develop earlier than some dorsal pathway functions (e.g. Dilks, Hoffman & Landau, 2008), it cannot be the case that in general ventral pathway functions mature either earlier or later than dorsal pathway functions. Both pathways have a long and complex developmental trajectory, with different aspects emerging at different ages within each pathway (Johnson *et al*., 2001).

Second, in relation to the evidence for cultural differences in context-sensitivity in the Ebbinghaus illusion (e.g. Doherty *et al*., 2008), our findings show that there is plenty of time for them to develop as a result of differences in the cultural environment. The paradigm used here has also been used to study children and adults in Japan. The results of that work will be reported elsewhere, but they clearly show that the findings reported here for children and adults living in Scotland apply equally well to Japanese participants, with little or no difference in absolute levels of performance between children of the two cultures. There are cultural differences in context-sensitivity, but descriptions of some cultures as being field or context independent must be moderated (e.g. Kitayama *et al*., 2003). Adults cannot choose to ignore misleading perceptual context, even those in individualistic Western cultures.

Finally, there is evidence that children with autism do not succumb to visual size illusions, and this has been interpreted as supporting the view that they have a detail focused cognitive style, or one with weak central coherence (e.g. Happé, 1999). Our findings clearly show that, for young children, low sensitivity to context in the Ebbinghaus illusion cannot be interpreted as implying that they have an autistic perceptual style. Instead, our findings suggest that the abnormally low sensitivity to context in the Ebbinghaus illusion that has been observed in children with autism (Happé, 1999) is not a fundamental component of their pathology.

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References

Aglioti, S., DeSouza, J.F.X., & Goodale, M.A. (1995). Size-contrast illusions deceive the eye but not the hand. *Current Biology*, **5**, 679–685.

Dannemiller, J.L. (2001). Brain–behavior relationships in early visual development. In C.A. Nelson & M. Luciana (Eds.), *Handbook of developmental cognitive neuroscience* (pp. 221–235). Cambridge, MA: MIT Press.

de Fockert, J., Davidoff, J., Fagot, J., Parron, C., & Goldstein, J. (2007). More accurate size contrast judgements in the Ebbinghaus illusion by a remote culture. *Journal of Experimental Psychology: Human Perception and Performance*, **33**, 738–742.

Dilks, D.D., Hoffman, J.E., & Landau, B. (2008). Vision for perception and vision for action: normal and unusual development. *Developmental Science*, **11**, 474–486.

Doherty, M.J., Tsuji, H., & Phillips, W.A. (2008). The context-sensitivity of visual size perception varies across cultures. *Perception*, **37**, 1426–1433.

Duemmler, T., Franz, V.H., Jovanovic, B., & Schwarzer, G. (2008). Effects of the Ebbinghaus illusion on children's perception and grasping. *Experimental Brain Research*, **186**, 249–260.

Franz, V.H., Gegenfurter, K.R., Bulthoff, H.H., & Fahle, M. (2000). Grasping visual illusions: no evidence for a dissociation between perception and action. *Psychological Science*, **11**, 20–25.

Ganel, T., Tanzer, M., & Goodale, M.A. (2008). A double dissociation between action and perception in the context of visual illusions. *Psychological Science*, **19**, 221–225.

Granrud, C.E. (2006). Size constancy in infants: 4-month-olds' responses to physical versus retinal image size. *Journal of Experimental Psychology: Human Perception and Performance*, **32**, 1398–1404.

Granrud, C.E., & Schmechel, T.T.N. (2006). Development of size constancy in children: a test of the proximal mode sensitivity hypothesis. *Perception and Psychophysics*, **68**, 1372–1381.

Granrud, C.E., & Yonas, A. (1984). Infants' perception of pictorially specified interposition. *Journal of Experimental Child Psychology*, **37**, 500–511.

Grill-Spector, K., Golarai, G., & Gabrieli, J. (2008). Developmental neuroimaging of the human ventral visual cortex. *Trends in Cognitive Sciences*, **12**, 152–162.

Haffenden, A.M., Schiff, K.C., & Goodale, M.A. (2001). The dissociation between perception and action in the Ebbinghaus illusion: nonillusory effects of pictorial cues on grasp. *Current Biology*, **11**, 177–181.

Hanisch, C., Konczak, J., & Dohle, C. (2001). The effect of the Ebbinghaus illusion on grasping behaviour of children. *Experimental Brain Research*, **137**, 237–245.

Happé, F. (1999). Autism: cognitive deficit or cognitive style? *Trends in Cognitive Sciences*, **3**, 248–254.

Hedden, T., Ketay, S., Aron, A., Markus, H.R., & Gabrieli, J.D.E. (2008). Cultural influences on neural substrates of attentional control. *Psychological Science*, **19**, 12–17.

Johnson, M.H., Mareschal, D., & Csibra, G. (2001). The functional development and integration of the dorsal and ventral visual pathways: a neurocomputational approach. In C.A. Nelson & M. Luciana (Eds.), *Handbook of developmental cognitive neuroscience* (pp. 339–351). Cambridge, MA: MIT Press.

Káldy, Z., & Kovács, I. (2003). Visual context integration is not fully developed in 4-year-old children. *Perception*, **32**, 657–666.

Kitayama, T., Duffy, S., Kawamura, T., & Larsen, J.T. (2003). Perceiving an object and its context in different cultures. *Psychological Science*, **14**, 201–206.

Kovács, I. (2000). Human development of perceptual organization. *Vision Research*, **40**, 1301–1310.

Kovács, I., Kozma, P., Fehér, A., & Benedek, G. (1999). Late maturation of visual spatial integration in humans. *Proceedings of the National Academy of Sciences*, **96**, 12204–12209.

Milner, A.D., & Goodale, M.A. (2008). Two visual systems reviewed. *Neuropsychologia*, **46**, 774–785.

Nisbett, R.E., & Miyamoto, Y. (2005). The influence of culture: holistic versus analytic perception. *Trends in Cognitive Sciences*, **9**, 467–473.

Phillips, W.A., Chapman, K.L.S., & Berry, P.D. (2004). Size perception is less context-sensitive in males. *Perception*, **33**, 79–86.

Phillips, W.A., & Silverstein, S.M. (2003). Convergence of biological and psychological perspectives on cognitive coordination in schizophrenia. *Behavioral and Brain Sciences*, **26**, 65–137.

Phillips, W.A., & Singer, W. (1997). In search of common foundations for cortical computation. *Behavioral and Brain Sciences*, **20**, 657–722.

Rival, C., Olivier, I., Ceyte, H., & Bard, C. (2004). Age-related differences in the visual processes implied in perception and action: distance and location parameters. *Journal of Experimental Child Psychology*, **87**, 107–124.

Roberts, B., Harris, M.G., & Yates, T.A. (2005). The roles of inducer size and distance in the Ebbinghaus illusion (Titchener circles). *Perception*, **34**, 847–856.

Ropar, D., & Mitchell, P. (2001). Susceptibility to illusions and performance on visuospatial tasks in individuals with autism. *Journal of Child Psychology and Psychiatry*, **42**, 539–549.

Uhlhaas, P.J., & Silverstein, S.M. (2005). Perceptual organization in schizophrenia spectrum disorders: empirical research and theoretical implications. *Psychological Bulletin*, **131**, 618–632.

Weintraub, D.J. (1979). Ebbinghaus illusion: context, contour, and age influence the judged size of a circle amidst circles. *Journal of Experimental Psychology: Human Perception and Performance*, **5**, 353–364.

Wilcox, B.L., & Teghtsoonian, M. (1971). The control of relative size by pictorial depth cues in children and adults. *Journal of Experimental Child Psychology*, **11**, 413–429.

Yonas, A., & Hagen, M. (1973). Effects of static and motion parallax depth information on perception of size in children and adults. *Journal of Experimental Child Psychology*, **15**, 254–265.

Zeigler, H.P., & Leibowitz, H. (1957). Apparent visual size as a function of distance for children and adults. *American Journal of Psychology*, **70**, 106–109.

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