RUNNING HEAD: DEVELOPMENT OF THE EBBINGHAUS ILLUSION IN WESTERN AND

REMOTE CULTURES

The ontogeny of visual context effects: Tracing effects of culture and the urban environment on the development of the Ebbinghaus illusion in British and Namibian observers

Andrew J. Bremner[1], Martin Doherty[2], Serge Caparos[3], Jan de Fockert[1], Karina J. Linnell[1], & Jules Davidoff[1]

[1]Department of Psychology, Goldsmiths, University of London

[2]School of Psychology, University of East Anglia

[3]Département de Psychologie, Université du Québec à Trois-Rivières

CORRESPONDENCE TO: Dr Andrew J. Bremner, Department of Psychology, Goldsmiths, University of London, New Cross, London, SE14 6NW, U.K.; Tel: +44 (0) 20 7078 5142; Fax: +44 (0) 20 7919 7873; email: a.bremner@gold.ac.uk.

ABSTRACT

We investigated the development of visual context effects in the Ebbinghaus illusion across UK people and the Himba of Namibia who are remote from Western cultural influence. Traditional Himba showed no illusion up until 9-10 years, whereas UK children show a robust illusion from 7- to 8-years of age. Greater illusion in UK than traditional Himba children was stable from 9-10 years to adulthood. We also examined the Ebbinghaus illusion in Namibian children growing up in the nearest urban conurbation to the traditional Himba villages, finding a sustained influence of the urban environment across childhood and adulthood. We conclude that cross-cultural differences in perceptual biases to process visual context emerge in early childhood and are influenced by the urban environment.

Many cross-cultural studies now show that perceptual phenomena, often assumed to be basic human endowments, vary from culture to culture (e.g., Bremner, Caparos, Davidoff, De Fockert, Linnell & Spence, 2013; Davidoff, 2001; De Fockert, Davidoff, Fagot & Goldstein, 2007; Deregowski, 189; Doherty, Tsuji & Phillips, 2008; Miyamoto, Nisbett & Masuda, 2006; Nisbett, Peng, Choi & Norenzayan, 2001; Rivers, 1905). Such findings do not just challenge the widely-held assumption that research studies involving solely Western educated participants are representative of perceptual (and psychological) processes the world over (see Henrich, Heine & Norenzayan, 2010). They also provide insight into the ontogeny of perceptual functioning. In that sense, cross-cultural comparisons share some of the aims of developmental research.

However, whereas cross-cultural studies illustrate the environmental context which gives rise to particular phenotypes, developmental studies, by delineating the developmental trajectories by which phenotypes unfold, provide clues to the ways in which inheritance, biology, environment and physical constraints interact to give rise to a given phenotype (Mareschal, Johnson, Sirois, Spratling, Thomas & Westermann, 2007). Here we report the findings of three experiments which combine the strengths of cross-cultural and developmental methods to shed light on the emergence of visual context effects in childhood and adolescence (cf. Franklin, Clifford, Williamson & Davies, 2005; Roberson, Davidoff, Davies & Shapiro, 2004). More specifically, we investigated visual size contrast effects using the Ebbinghaus illusion (also known as Titchener's circles) in which the size of contextual visual elements induce illusory distortions of the perceived size of visual target stimuli (see Fig. 1A). This task has the advantage of being easily applied to a range of age-groups and across cultures (e.g., Caparos, Ahmed, Bremner, De Fockert, Linnell & Davidoff, 2012; Doherty et al., 2008; Doherty, Campbell, Tsuji & Phillips, 2010). Our findings reveal how different environmental contexts - in particular rural vs. urban environments - give rise to quite different developmental trajectories for even such "basic" perceptual phenotypes as size contrast effects. Crucially, we show how developmental data can help differentiate between alternative accounts of the perceptual and attentional mechanisms whereby environmental influences impact on perception; in this particular case we focus on accounts of how exposure to urban and rural environments leads to differences in the ways in which we use context to perceive visual size.

Effects of context are often considered to be a fundamental aspect of visual processing and cognitive systems more widely in humans (Phillips & Singer, 1997). Furthermore, certain illusory effects of context have been argued to be universal and informationally encapsulated aspects of visual processing, not susceptible to effects of experience over development and learning (Fodor, 1983; see McCauley & Henrich, 2006). Observations of cross-cultural, individual and developmental differences in the effects of visual context (e.g., Caparos et al., 2012; Doherty et al., 2010; Schwarzkopf, Song & Rees, 2011) are particularly noteworthy in this light. In particular, a large body of findings shows that East Asian observers are more likely than Western observers to give priority to contextual information in a variety of tasks including object categorisation (Norenzayan, Smith, Kim & Nisbett, 2002), change detection (Miyamoto et al., 2006) and size judgements (Doherty et al., 2008; Kitayama, Duffy, Kawamura & Larsen, 2003).

A range of accounts of these kinds of cross-cultural differences have been offered. Nisbett et al. (2001; see also Varnum, Grossman, Kitayama & Nisbett, 2010) have argued that cross-cultural variations in the use of context are due to differences in the social structure in those cultures. More individualistic cultures (e.g., Western cultures) are argued, through their sociocultural inheritance, to promote "analytic" processing of the details in visual patterns, whereas more collectivist cultures (e.g., East Asian cultures) promote "holistic" processing of continuities and relationships. Another class of explanations, not necessarily incompatible with those appealing to social structure, has suggested that the physical environments which different cultures inhabit lead them to prioritise context to different extents. Miyamoto et al. (2006) argue that greater visual clutter in our physical environments (such as that found in urban vs. rural environments, or in Japanese vs. U.S. cities) leads to a greater processing of context. Aside from clutter there are a great many other aspects of the visual environment which could potentially drive differences in processing of visual context. Inhabitants of towns and cities are much more likely to be exposed to pictures and other printed materials (e.g., when looking at picture or when learning to read). Recent research shows that learning to read enhances "holistic" visual processing (Szwed, Ventura, Querido, Cohen & Dehaene (2012). Researchers (e.g., Deregowski, 1989; Doherty et al., 2010) have also argued that the extents to which different cultures are exposed to different kinds of pictures shape perceptual tendencies. More specifically,

Doherty et al. (2010) argue that greater processing of context is required when viewing depictions of objects in depth in order to resolve the conflict between pictorial cues to depth and primary depth cues specifying the real depth of the picture and its markings (see Gregory, 1968). They propose that extended experience of resolving this conflict might lead to differences in use of size contrast in the Ebbinghaus illusion.

Recent data from a population which is particularly remote from Western and East Asian cultural influences (the Himba of Northern Namibia) promises to help distinguish between at least some of these accounts. The Himba live in a traditional and distinctly uncluttered rural environment with few if any pictures. However, Himba society promotes interdependent rather than independent behaviours (Gluckman, 1965), due to their villages being comprised of large family compounds. Thus, lesser processing of context in this group relative to Western observers is predicted by the visual clutter and picture exposure accounts, whereas similar, if not greater processing of context is predicted by Nisbett et al.'s (2001) social structure account. De Fockert et al. (2007), and Caparos et al. (2012) have demonstrated that the Himba exhibit less Ebbinghaus illusion and, correspondingly, greater accuracy at discriminating the real sizes of stimuli in this task relative to UK and Japanese participants. This enhanced performance points to a relative neglect of the (task-irrelevant) contextual elements which leads to the illusion in Westerners and Japanese participants. These findings strengthen arguments that the urban environment (either through the visual clutter it presents or through the exposure to pictures and printed materials which go along with urban living) may drive cross-cultural differences in size contrast effects, and weaken arguments based on a role for social structure. Indeed, Caparos et al. (2012) show that, among the Himba themselves, urbanisation is associated with the degree of context processing. Himba who have moved to live in an urban environment show a greater influence of context on visual processing than traditional Himba in the Ebbinghaus illusion and in a hierarchical figure matching task.

As described above, our aim with these studies was to investigate the emergence of cross-cultural differences in visual context effects to gain clues as to the underlying developmental processes which give rise to such variations. We examined the development of size contrast effects in the Ebbinghaus illusion in both UK and traditional Himba children. Before we outline alternative accounts of the development of

crosscultural differences in visual context effects (which the experiments reported here separate between) we first review the literature on the development of the Ebbinghaus illusion. A number of studies have examined the development of this illusion in early life in Western cultures. The majority report an increase in the effect of context with age (Doherty et al., 2010; Duemmler, Franz, Jovanovic & Schwarzer, 2008; Kaldy & Kovacs, 2003; Weintraub, 1979). One study by Hanisch, Konczak, and Dohle (2001) reports no difference in the extent of the illusion between 5 to 12 years of age and adulthood. However, the absence of a finding in Hanisch et al.'s study is explicable through their use of a "same/different" judgement task in which differential response bias can mask differences in the strength of illusion between groups (Doherty et al., 2010; Kaldy & Kovacs, 2003).

The extent of separation between targets and context elements has been shown to lead to local contour interactions which influence processing of the size of the target in the Ebbinghaus illusion, independently of size contrast effects (Haffenden, Schiff & Goodale, 2001). One advantage of Doherty et al.'s (2010) study is that it provides a purer measure of size contrast effects by controlling for the potential effects of such local contour interactions on the strength of the illusion; they did this by keeping the separation between targets and context elements constant across conditions. Like Kaldy and Kovacs (2003) they also employed a two alternative forced choice task (2AFC) to identify the larger of two targets, which, because it does not require "same/different" (or "yes/no" responses), is typically less susceptible to response biases in children. Doherty et al. (2010) found that across 4- to 10-year-old children, it is only from 6 years of age that children begin to demonstrate a significant Ebbinghaus illusion, and that the illusion continues to develop even beyond 10 years of age. Given the above advantages, we decided to employ the same task as Doherty et al. (2010), in the current investigation. In Experiments 1 and 2 we investigate the developmental trajectories of size contrast effects in the Ebbinghaus illusion across children from the UK and Himba children. Our aim was to examine the developmental trajectories of size contrast effects between these groups in order to determine at what point in development cross-cultural divergence arises in effects of visual context. Such information provides clues to the origins of variations in visual context effects. We focussed on two potential ways in which cross-cultural variations in the Ebbinghaus illusion (and context

perception more generally) might arise.

Variations in the Ebbinghaus illusion have traditionally been argued to arise from differences in the extent to which we are perceptually biased (or have a perceptual style) to process context (Doherty et al., 2008; Caparos et al., 2012; Happé, 1999; Phillips, Chapman & Berry, 2004). The cross-cultural variations in the Ebbinghaus illusion observed between Himba and UK participants are certainly explicable in this way. As well as showing less susceptibility to the Ebbinghaus illusion, the Himba also analyse and compare local (featural) rather than global (configural) aspects of hierarchical (Navon) figures, suggesting a perceptual bias away from contextual processing (Caparos et al., 2012; Davidoff, Fonteneau & Fagot, 2008). However, there is at least one other explanation of cross-cultural variations in the Ebbinghaus illusion (and in context processing more widely). In the Ebbinghaus illusion task, participants are asked to judge the sizes of the central circles. The surrounding inducing elements are essentially distracting information to be ignored. Thus, improved performance (and a greater neglect of context) in the Ebbinghaus illusion task can also be explained by a greater ability to focus attention on the relevant information, and filter out irrelevant information (De Fockert & Wu, 2009); what has been referred to as *attentional filtering*. This explanation of variations in context effects is particularly pertinent given that there is now quite some evidence that the Himba demonstrate an advantage compared to Westerners at selectively attending to task-relevant information (Caparos, Linnell, De Fockert, Bremner & Davidoff, 2013; De Fockert, Caparos, Linnell & Davidoff, 2011; Linnell, Caparos, De Fockert & Davidoff, 2013).

These *perceptual bias* and *attentional filtering* accounts make quite different predictions regarding the development of cross-cultural differences in the Ebbinghaus illusion. There is good reason to presume that variations (cross-cultural or otherwise) in perceptual bias to features vs. context (configural shapes) could arise early in life. Biases to process particular kinds of visual patterns are evident early in the first year of life (e.g., Bornstein, Ferdinandsen & Gross, 1981; Ghim & Eimas, 1988; LoBue, 2012). Visual context appears to play a role in visual processing early in the first year (e.g., Bremner, Bryant & Mareschal, 2006; Yamazaki, Otsuka, Kanazawa & Yamaguchi, 2010), and even 3-month-old infants appear to change their processing of visual patterns from global to local aspects depending on duration of exposure (Colombo,

Mitchell, Coldren & Freeseman, 1991; Frick, Colombo & Allen, 2000). Furthermore, there is also evidence that cross-cultural differences in perceptual biases emerge across the first year of life. Yoshida, Iversen, Patel, Mazuka, Nito, Gervain, and Werker (2010), found that differences in grouping of auditory stimuli between infants growing up in English-speaking and Japanese-speaking environments, although not apparent at 5-6 months, were observable at 7-8 months.

In contrast to perceptual biases, an ability to filter out distracting information (attentional filtering) has not been observed in infancy and continues to mature well beyond 10 years of age and into early adulthood (Comalli, Wapner & Werner, 1962; Enns, Brodeur & Trick, 1998; Ridderinkhof & Van der Stelt, 2000; Rueda, Fan, McCandliss, Halperin, Gruber, Lercari & Posner, 2004; Waszak, Li & Hommel, 2010). Thus, if cross-cultural differences in context processing in the Ebbinghaus illusion are driven by variations in attentional filtering, we would predict a much more protracted divergence between Himba and UK groups. Experiments 1 and 2 addressed this issue.

In Experiment 3 we examined in more detail the nature of the environmental factors which mediate the emergence of cross-cultural differences in context effects in the Ebbinghaus illusion. Specifically, we traced the development of the Ebbinghaus illusion in Namibian children who were growing up in an urban environment near the Himba villages where we had tested the traditional Himba. Elements of the urban environment (including, as discussed above, greater perceptual clutter, and increased exposure to pictures and other printed matter) could quite plausibly drive both increases in perceptual bias towards context and/or decreased ability to ignore task-irrelevant context. Many children across a range of ethnic groups including the Himba now grow up in Opuwo, the only permanent town within easy reach of the traditional Himba villages. By comparing the development of the Ebbinghaus illusion in traditional Himba and urban children in Opuwo we can glean a relatively pure measure of the effect of an urban vs. rural environment on the developmental unfolding of context effects in the Ebbinghaus illusion.

Experiment 1

In Experiment 1 we investigated the development of the Ebbinghaus illusion in children between 3 and 10 years of age, who were being brought up traditionally in a remote Himba village in Kaokoland in

Northern Namibia. We used the 2AFC Ebbinghaus task used by Phillips et al. (2004) and Doherty et al. (2010) in their investigation of the development of the illusion in children living in the UK. This task includes a control condition in which participants make size discriminations in the absence of the illusion inducers. We compared the extent of the illusion set against baseline size discrimination performance in traditional Himba children with an age-matched subset of the UK participants tested by Doherty et al. (2010).

Methods

Participants. The Himba are semi-nomadic herders who have very limited contact with Western culture and artifacts. The traditional Himba participants were recruited from two traditional villages in Kaokoland. Fifty traditional Himba children participated (29 female, 21 male). None of the Himba participants had ever been involved in experimental research. The Himba do not usually keep accurate birth records and so we had to estimate the ages of the participants; this was achieved by asking the children's friends and parents how old they were, and by evaluating ages on the basis of physical similarity to children whose ages were known. For the younger children we determined whether they were younger or older than 5 years of age by asking them to touch their ear with their contralateral hand over the top of the head (Roberson et al., 2001). The estimated ages of the children varied from 3 to 10 years. Three participants (whose estimated ages were 4, 5, and 5) were excluded from analyses as two did not complete the test and one demonstrated a complete bias to respond to one side of the display only. The remaining participants were then grouped into the following age-groups: 3-6 years, 7-8 years, 9-10 years (see Table 1 for participant characteristics). To provide as fair a comparison as possible with the UK sample we selected a subset of the participants tested in Doherty et al. (2010) who were matched to the Traditional Himba participants in age (in years) and gender; this yielded groups which were matched as precisely as was possible on the basis of the age information which we had. Where there was more than one potential match among the UK sample per Himba participant, we selected the first participant tested.

--Insert Table 1 about here--

Apparatus, materials and design. The experimental stimuli were presented via a computer running a

custom C++ program (Doherty et al., 2010). The task required participants to select which of two orange circles (presented on either side of a computer screen) was the larger. On experimental ("context") trials the orange "target" circles were surrounded by grey "inducer" circles, yielding two side-by-side 3 x 3 arrays of circles (see Fig. 1A). The orange target circles were present on their own on control ("no context") trials (see Fig. 1B).

--Insert Figure 1 about here--

For both the experimental and control conditions, on each trial the size difference between the target circles was 2, 6, 10, 14, or 18 pixels. One of the targets was always 100 pixels (subtending approximately 3.3° of visual angle at a viewing distance of 45 cm), and so the other target varied in size between 82 and 118 pixels, yielding 10 possible size comparisons. Each size comparison was presented twice, once with the 100 pixel target on the left, and once with it on the right.

On most trials in the experimental condition, the larger of the two target circles was surrounded by eight larger inducers (each of which was 125 pixels in diameter) and the smaller of the two target circles was surrounded by eight smaller inducers (each of which was 50 pixels in diameter). Size discrimination is typically impaired by inducers presented in this juxtaposition of size contrast to the targets. In the experimental condition, we also presented an additional four trials in which the inducers should, if the size contrast illusion is perceived, enhance size discrimination, that is, trials in which the inducers are smaller than the larger target and larger than the smaller target. These four trials (the helpful context condition) only used the most difficult size discrimination condition (i.e., where the targets were either 100 vs. 102, or 98 vs. 100 pixels in size. These additional trials allowed us to check whether the participants are employing a response strategy in the experimental condition which relies on the size of the inducers rather than the targets. If a participant were to choose the array with larger inducers, which would lead to success on the majority of experimental trials, then they would be incorrect on each of the trials in this subset.In total the participants were presented with 44 trials (24 experimental trials, 20 control trials). The control and experimental conditions were presented in separate blocks (order was counterbalanced across participants). Within each block, the order of trials was fully randomized in a different sequence for each participant.

Procedure. The participants were tested inside a tent placed in a shaded area. The only occupants of the tent were the participant, the experimenter and the translator. The participants were asked to point to the orange (target circle) which "looks bigger". The experimenter recorded the participant's response on each trial via a keyboard. The key-presses also advanced the program to the next trial presentation. No feedback was given throughout the procedure. The procedure lasted between 2 and 5 minutes.

Statistical analyses. Analyses focused on two dependent variables. Firstly, size discrimination accuracy was operationalised as the percentage of trials on which participants selected the larger of the two circles when prompted to do so, pooled across all of the size difference discrimination conditions (excluding the helpful context condition) ("percentage accuracy"). Percentage accuracy across participant groups and conditions was investigated using Analysis of Variance (ANOVA). Secondly, to glean a measure of the extent of the illusion we subtracted participants' overall accuracy in the context condition from their accuracy in the control condition ("percentage illusion"). To determine the age at which cross-cultural differences in the illusion emerge in development, we conducted planned comparison tests of the percentage illusion score between the UK and traditional Himba participants at each age-group. Further planned comparisons were conducted to determine the age-groups in which a significant illusion was observed in both cultures. Statistical analyses were run on IBM SPSS Statistics Version 21.

Results

Figure 2 (Panels A-C) illustrates participants' percentage accuracy at size discrimination either with or without the presence of inducers which would lead to size illusions, and plots corresponding variations in performance across size discrimination conditions. Performance declines as the difference in sizes between the targets decreases, across age-groups. The effect of the Ebbinghaus illusion, seen in poorer size discrimination performance in the "context" condition than to the "no context" condition, is particularly notable in the 9- to 10-year-old UK participants. Their performance in the context (illusion) condition was poorer than the Himba participants' performance in the same condition.

--Insert Figure 2 about here--

Participants' percentage accuracy across all conditions (apart from the helpful context condition) was entered into a 2 x 2 x 3 mixed design ANOVA with the within-participants factor of Condition (Context / No context), and the between-participants factors of Culture (UK / Himba), and Age-group (3- to 6-year-olds / 7- to 8-year-olds / 9- to 10-year-olds) (see Fig. 2). This revealed main effects of Condition, $F(1, 88) = 44.3$, $p < .001$, $\eta_p^2 = .335$, describing poorer performance in the Context condition ($M = 71.2$, $SD = 16.5$) than in the No context condition ($M = 81.8$, $SD = 14.5$) – i.e., an effect of the illusion across groups and conditions, and Culture, $F(1, 88) = 8.6$, $p = .004$, $\eta_p^2 = .089$, describing poorer size discrimination accuracy by the Himba children ($M = 72.9$, $SD = 14.0$) than the UK children ($M = 80.1$, $SD = 9.3$) across conditions, and Age-group, $F(2, 88) = 4.9$, $p = .01$, $\eta_p^2 = .100$, describing an overall trend for improved size discrimination accuracy with age across conditions (3- to 6-year-olds: $M = 72.5$, $SD = 13.5$; 7- to 8-year-olds: $M = 78.0$, $SD = 13.7$; 9- to 10-year-olds: $M = 80.3$, $SD = 7.5$). There were also 1st order interactions of Condition x Culture, $F(1, 88) = 8.4$, $p = .005$, $\eta_p^2 = .087$, Condition x Age-group, $F(2, 88) = 7.6$, $p = .001$, $\eta_p^2 = .147$, and Culture x Age-group, $F(2, 88) = 9.9$, $p < .001$, $\eta_p^2 = .184$. These were all qualified however, by a significant 2nd order interaction of Condition x Culture x Age-group, $F(2, 88) = 5.9$, $p = .004$, $\eta_p^2 = .118$.

Rather than using post-hoc tests to explore the interaction of Condition x Culture x Age-group we proceed to the planned comparisons detailed in the Methods section. Planned comparisons were run on the percentage illusion score (calculated by subtracting participants' overall percentage accuracy in the context condition from their overall percentage accuracy in the control condition) comparing cultures at each age-group. These planned comparisons to function as simple contrasts in an exploration of the 2nd order interaction reported above. Three comparisons were made and so a Bonferroni correction was applied yielding an alpha level of $p = .017$. Cross-cultural comparisons of this illusion score within each of the age-groups revealed a significantly greater illusion in the UK 9- to 10-year-olds than the Himba 9- to 10-year-olds, $t(28) = 3.83$, $p = .001$, $d = 1.28$. No significant differences in illusion between cultures were found for 7- to 8-year-olds, $t(24) = 1.67$, $n.s.$, $d = .71$, or 3- to 6-year-olds, $t(36) = 0.67$, $n.s.$, $d = .21$. Planned comparisons were also run to determine whether each age-group and culture demonstrated a significant

illusion, by comparing the illusion score against zero using one-sample t-tests (see Table 2). The comparisons comprised six tests and so a Bonferroni correction was applied yielding an alpha level of $p = .008$. These tests revealed that only the oldest two UK age-groups demonstrated a significant influence of the inducers on discrimination accuracy (i.e. from 7 to 8 years of age).

It was also important to examine whether the participants in each Age-group x Culture sub-group who showed an illusion were responding on the basis of the sizes of the target circles rather than the sizes of the surround circles. The "helpful context" condition was included to check whether this strategy was being used; if participants responded on the basis of the sizes of the inducer circles this would yield poorer performance in the helpful context condition than the control condition. However, an inspection of Figure 2 (Panels A-C) reveals that, for all of the groups who demonstrated a significant illusion, discrimination performance was better in the "helpful context" condition than in the remainder of the context conditions, ruling out an explanation on the basis of the response strategy described above.

Discussion

The data reported here showed that by 7- to 8-years of age the UK children began to show a significant effect of size contrast on their size comparisons, whereas the Traditional Himba children remained unaffected by context up to 9-10 years. A significant difference in the influence of the illusion between cultures is observable by 9 to 10 years of age. This divergence between Traditional Himba and UK children before 10 years of age suggests that cross-cultural variations in the Ebbinghaus illusion are mediated by processes which are mature in early to middle childhood. This trajectory of developmental divergence between traditional Himba and UK children is consistent with cross-cultural variation being mediated by perceptual bias. Perceptual biases to process particular kinds of visual patterns are evident early in the first year of life (e.g., Bornstein et al., 1981; Colombo et al., 1991; Frick et al., 2000; Ghim & Eimas, 1988; LoBue, 2012), and cross-cultural differences in perceptual biases have been observed to emerge as early as within the first year of life (Yoshida et al., 2010). Indeed, given that perceptual biases can emerge so early it might at first sight appear surprising that crosscultural differences in visual context processing did not emerge until 9-10 years of age. However, one possible explanation of this kind of delay is that the

cultural environmental factors which give rise to these differences may not be present or salient until later in childhood (see the General discussion).

Another potential contributor to differences in the extent of the illusion between cultures (and one which is not mutually exclusive with a contribution from perceptual bias) is a greater tendency to prioritise task relevant information and ignore task-irrelevant distractors (often referred to as attentional filtering). However, this aspect of visual attention develops beyond 10 years of age and into adulthood (Goldberg et al., 2001; Waszak et al., 2010). Thus, in Experiment 2 we examined whether the developmental divergence between Himba and UK children continues into later childhood; this would implicate a role for attentional filtering. Furthermore, we have not yet observed a significant illusion in any of the traditional Himba age-groups tested. Given that recent investigations of Himba adults have demonstrated a significant, albeit reduced Ebbinghaus illusion (De Fockert et al., 2007; Caparos et al., 2012) we predict the emergence of an influence of context on size perception in Himba children later in development.

Experiment 2

We conducted a second experiment with older age-groups (11-12 years, 13-14 years, 15-17 years, Adults), otherwise identical to Experiment 1 except that, because Doherty et al. (2010) did not report data in UK children older than 10 years of age, we report newly gathered data from across both Himba and UK participants. The apparatus and materials were exactly the same as used in Experiment 1. The procedure was exactly the same as in Experiment 1 except that the UK children were tested in a quiet room in the school rather than in a tent pitched outside a Himba village. For the UK adults, testing took place at the university. The approach to statistical analysis adopted in Experiment 1 was also taken in Experiment 2.

Methods

Participants. The Himba participants were recruited from the two traditional villages visited for Experiment 1. Forty-six Himba children participated (23 female, 23 male). The estimated ages of the Himba children varied from 11 to 17 years. One participant (whose estimated age was 16) was excluded from analyses as he did not complete the test. The remaining participants were then grouped into the following age-groups: 11-12 years, 13-14 years, 15-17 years (see Table 2 for participant characteristics). In addition, a

group of Himba adults was tested (n = 35, 25 female, 20 male). One of these adults was excluded due to evidence of impaired vision. None of the Himba participants had ever been involved in experimental research. The UK participants were recruited from a comprehensive school in Sheffield. Table 3 presents the participant characteristics.

Results

Figure 3 (Panels A-D) illustrates participants' percentage accuracy at size discrimination either with or without the presence of inducers which would lead to size illusion, and plots corresponding variations in performance across size discrimination conditions. The effect of the Ebbinghaus illusion is observable in all age-groups across both cultures, but to a greater extent in the UK participants.

--Insert Figure 3 about here--

Participants' percentage accuracy across all conditions (apart from the helpful context condition) was entered into a 2 x 2 x 4 mixed design ANOVA with the within-participants factor of Condition (Context / No context), and the between-participants factors of Culture (UK / Himba), and Age-group (11- to 12-year-olds / 13- to 14-year-olds / 15- to 17-year-olds / Adults) (see Fig. 3). This showed main effects of Condition, $F(1, 144) = 418.5$, $p < .001$, $\eta_p^2 = .744$, describing poorer accuracy in the Context condition ($M = 79.6$, $SD = 13.9$) than in the No context condition ($M = 92.1$, $SD = 7.1$) – i.e., an effect of the illusion across groups and conditions, and Culture, $F(1, 144) = 89.9$, $p < .001$, $\eta_p^2 = .384$, describing greater accuracy across age-groups and conditions in the Himba participants ($M = 85.8$, $SD = 8.6$) compared to the UK participants ($M = 70.2$, $SD = 10.3$). There was also a 1st order interaction of Condition x Culture, $F(1, 144) = 132.94$, $p < .001$, $\eta_p^2 = .480$. No other interactions were significant (all Fs < 2).

The interaction of Condition x Culture was explored with four Bonferroni-corrected t-tests. Two paired-samples tests revealed differences in accuracy between Context and No context conditions in both Himba (Context: $M = 79.6$, $SD = 13.9$; No context: $M = 92.1$, $SD = 7.1$), $t(78) = 8.2$, $p < .001$, $d = .90$, and UK (Context: $M = 47.1$, $SD = 18.2$; No context: $M = 93.4$, $SD = 7.2$), $t(72) = 21.2$, $p < .001$, $d = 2.5$, participants, with both groups performing with greater accuracy in the no context condition. Two

independent-samples tests revealed a difference in accuracy between Himba and UK participants within the Context condition, $t(150) = 12.4$, $p < .001$, $d = 2.3$, where the Himba performed more accurately, but not the No context condition, $t(150) = 1.1$, *n.s.*, $d = .18$. This suggests that the Himba outperformed the UK participants under conditions of the Ebbinghaus illusion.

Planned comparisons were run on the percentage illusion score comparing cultures at each age-group. Four comparisons were made and so a Bonferroni correction was applied yielding an alpha level of $p = .013$. Cross-cultural comparisons of this illusion score within each of the age-groups revealed a significantly greater illusion in the UK participants across all age-groups: i) 11- to 12-year-olds, $t(34) = 5.30$, $p < .001$, $d = 1.84$, ii) 13- to 14-year-olds, $t(32) = 4.66$, $p < .001$, $d = 1.88$, iii) 15- to 17-year-olds, $t(18) = 4.26$, $p < .001$, $d = 1.47$, and iv) Adults, $t(60) = 10.95$, $p < .001$, $d = 2.30$. Planned comparisons were also run to determine whether each age-group in each culture demonstrated a significant illusion. We compared the illusion score against zero using one-sample t-tests (see Table 2). The comparisons comprised eight tests and so a Bonferroni correction yielded an alpha level of $p = .006$. All age-groups in both cultures demonstrated a significant influence of the inducers on discrimination accuracy, bar the 13- to 14-year-old Traditional Himba group who nonetheless showed a trend towards illusion, $t(16) = 2.53$, $p = .022$, $d = .61$.

We confirmed that the participants in each age-group (both cultures) who showed an illusion were responding on the basis of the sizes of the target circles rather than the sizes of the surround circles; performance was better in the helpful context condition than in the unhelpful context condition across all of the groups who showed an illusion; indeed, performance in the helpful context condition was virtually at ceiling in all apart from the 11- to 12-year-old Himba children (see Fig. 3, Panels A-D).

Finally, because there were no effects or interactions of Age-group in this experiment we decided to conduct a further analysis to determine whether there were any Age-group related changes in the illusion across cultures between the oldest age-group tested in Experiment 1 (9- to 10-year-olds), and the youngest age-group tested in Experiment 2 (11- to 12-year-olds). Thus, participants' percentage illusion scores across all conditions (apart from the helpful context condition) were entered into a 2 x 2 between-participants ANOVA with the factors of Culture (UK / Himba), and Age-group (9- to 10-year-olds / 11- to 12-year-olds)

(see Figs. 2 & 3). This revealed main effects of Culture (Himba: $M = 12.7$, $SD = 17.6$; UK: $M = 39.4$, $SD = 18.0$), $F(1, 62) = 40.9$, $p < .001$, $\eta_p^2 = .398$, and Age-group (9- to 10-year-olds: $M = 18.8$, $SD = 20.5$; 11- to 12-year-olds: $M = 32.1$, $SD = 22.0$), $F(1, 62) = 10.3$, $p = .002$, $\eta_p^2 = .142$. There was no interaction of Age-group x Culture ($F < 1$). This indicates an increase in the illusion from 9-10 to 11-12 years across both Cultures, but with that illusion being significantly greater in the UK children at both ages.

Discussion

Across 11- to 12-year-olds, 13- to 14-year-olds, 15- to 17-year-olds, and adults we found significant (or, in the case of the Himba 13- to 14-year-olds, trending to significant) illusions in both the traditional Himba and UK participant groups. Consistent with previous findings (Caparos et al., 2012; De Fockert et al., 2007) the illusion was substantially greater in the UK group than in the traditional Himba. This resulted in higher levels of accuracy in the traditional Himba compared to the UK participants. Interestingly, and in contrast to the findings from younger children in Experiment 1, there were no changes between 11-12 years and adulthood in the effect of culture across age-groups. The extent of the illusion increases between 9-10 years and 11-12 years across both cultures, without any further divergence between cultures in the extent of the illusion. This indicates that cross-cultural variations in the Ebbinghaus illusion have emerged fully at around 9-10 years of age, in spite of culture-general increases in the illusion up until 11-12 years.

In combination with the data from Experiment 1 the data presented here show that cross-cultural differences in the influence of size context in the Ebbinghaus illusion develop in early to middle childhood (Experiment 1), but remain stable from 10 years of age (Experiment 2). Given that changes in perceptual bias occur early in development, and attentional filtering develops beyond 10 years of age (see earlier) our data indicate that cross-cultural differences in size context effect emerge due to differences in perceptual bias between cultures, rather than differences in the ability to selectively attend to task-relevant information, and filter out task-irrelevant information (see Caparos et al., 2013; De Fockert et al., 2011; Linnell et al., 2013).

A crucial question concerns how cross-cultural differences in perceptual biases might emerge. There exist a great many differences between the environments which traditional Himba children grow up in and those of British school-children, within both their physical and sociocultural environments. In the next

experiment we tested a hypothesis concerning the environmental source of cross-cultural differences in size contrast in the Ebbinghaus illusion; namely that size contrast effects are driven by exposure to an urban environment. Recent findings suggest that this is the case for cross-cultural differences in perception of size contrasts in adults (Caparos et al., 2012). The next experiment extends this work to examine the effects of urbanisation on context effects across development. By comparing traditional Himba children with urban Namibian children in their development of size context effects in the Ebbinghaus illusion we have a unique opportunity to trace the developing influence of the urban environment on emerging visual perceptual skills, independently of more general sociocultural variations between Namibians and British participants which are unrelated to degree of urbanisation.

Experiment 3

Here we examined the emergence of the Ebbinghaus illusion from 4 years of age to adulthood in a sample of Namibian children growing up in an urban environment. The apparatus and materials were exactly the same as used in Experiments 1 and 2. The procedure was also exactly the same as in Experiments 1 and 2, except that for the urban Namibian children, testing took place in a quiet room within their school. For the urban Namiban adults, testing took place in a quiet room inside the translator's house.

Methods

Participants. The urban Namibian child participants were recruited in Opuwo (in primary and secondary schools and in the neighborhood of our translator). 115 children participated (59 female, 56 male). We had accurate ages for the urban Namibian children in years. The children were grouped into the following age-groups: 3-6 years, 7-8 years, 9-10 years, 11-12 years, 13-14 years, 15-17 years. In addition, a group of urban Namibian adults was tested (n = 18; 11 female, 7 male). Participants were sampled from across a wide range of Namibian ethnic groups living in Opuwo (including Himba, Herero, Ovambo, Banderu, Zemba, Gambue peoples). It is important to note that many of the urban participants (especially across the older age-groups) had not lived in an urban environment since birth. Table 4 gives full details of the participant characteristics for Experiment 3, including the mean number of years in which each age-group had lived in an urban environment.

Statistical analyses. In addition to the same analyses applied in Experiments 1 and 2 we also conducted further analyses across experiments to examine the effects of culture and urban environment on the illusion across age-groups. An ANOVA was applied to the percentage illusion scores including all age-groups from all of the participants tested in Experiments 1 to 3. Significant interactions between culture and age-group were explored by running further one-way ANOVAs comparing the strength of the illusion across age-groups within each of the different culture groups (urban UK, traditional Himba, urban Namibian).

Results

We report two tests designed to rule out potential alternative interpretations of the data collected. Firstly, we examined whether the number of years of exposure to an urban environment could play a role in masking effects of age on size contrast effects in the Ebbinghaus illusion. We found no correlation between years of exposure to an urban environment and the percentage illusion score across the sample, $r(137) = .06$, n.s.[1] Secondly, as we had included a wide range of ethnic groups in this experiment (see the Participants section above) we also sought to determine whether ethnic factors could be driving any potential differences between traditional Himba participants and the urban Namibian participants. A comparison of the percentage illusion score in the urban Himba participants ($M = 21.5\%$, $N = 27$, $SD = 17.3$) and those from other ethnic groups ($M = 16.6\%$, $N = 110$, $SD = 13.7$) demonstrated no significant difference, $t(135) = 1.6$, n.s., $d = .28$.

Figure 4 (Panels A-G) illustrates participants' performance at size discrimination either with or without the presence of inducers which would lead to a size illusion, and plots corresponding variations in performance across size difference conditions. The effect of the Ebbinghaus illusion can be observed to gradually increase with age, plateauing from 11-12 years.

--Insert Figure 4 about here--

Participants' accuracy across all conditions (apart from the helpful context condition) was entered into a 2 x 7 mixed design ANOVA with the within-participants factor of Condition (Context / No context), and the between-participants factor of Age-group (4- to 6-year-olds / 7- to 8-year-olds / 9- to 10-year-olds / 11- to 12-year-olds / 13- to 14-year-olds / 15- to 17-year-olds / Adults) (see Fig. 4). This showed a main effect of Condition, $F(1, 130) = 209.1$, $p < .001$, $\eta_p^2 = .617$, describing poorer accuracy in the Context ($M =$

75.7, *SD* = 12.8) than in the No context (*M* = 93.3, *SD* = 6.5) condition – i.e., an effect of the illusion across groups and conditions. There was also a marginally significant 1st order interaction of Condition x Age-group, $F(6, 130) = 2.1$, $p = .057$, $\eta_p^2 = .089$. There was no main effect of Age-group ($F < 2$).

We proceed to the planned comparisons detailed in the Methods section, in which the percentage illusion score was compared against zero at each age-group (see Table 2). All of these comparisons comprised seven tests and so a Bonferroni correction was applied yielding an alpha level of $p = .007$. These tests, reported in Table 2, revealed that all age-groups of urban Namibian participants (even the youngest 4- to 6-year-olds) demonstrated a significant influence of the inducers on discrimination accuracy; that is, a significant illusion.

The participants in each age-group who showed an illusion were responding on the basis of the sizes of the target circles rather than the sizes of the surround circles. Performance was better in the helpful context condition than in the unhelpful context condition across all of the groups who showed a significant illusion. The helpful context condition was virtually at ceiling from 9-10 years of age (see Fig. 4).

To examine the developmental unfolding of the influence of the urban environment on size contrast effects, we ran further analyses comparing the UK participants, and the traditional and urban Namibian participants across all age-groups. To this purpose, we took the percentage illusion score and entered it into a 3 x 7 between participants ANOVA with the factors of Culture (UK / Traditional Himba / Urban Namibian), and Age-group (3- to 6-year-olds / 7- to 8-year-olds / 9- to 10-year-olds / 11- to 12-year-olds / 13- to 14-year-olds / 15- to 17-year-olds / Adults) (see Fig. 5). This showed a main effect of Culture, $F(2, 362) = 63.8$, $p < .001$, $\eta_p^2 = .261$. Tukey HSD showed that all three cultures differed on the percentage illusion score, with the traditional Himba demonstrating the lowest percentage illusion (*M* = 10.2, *SD* = 15.0, *N* = 126), the urban Namibian demonstrating an intermediate level of illusion (*M* = 17.6, *SD* = 14.5, *N* = 137), and the UK participants demonstrating the greatest percentage illusion (*M* = 34.0, *SD* = 24.4, *N* = 120) (all paired comparisons were significant, p < .001). There was also a main effect of Age-group, $F(6, 362) = 16.6$, $p < .001$, $\eta_p^2 = .216$, describing a trend to increasing illusion with age (3- to 6-year-olds: *M* = 76.1, *SD* = 13.1; 7-

to 8-year-olds: $M = 81.4$, $SD = 12.2$; 9- to 10-year-olds: $M = 81.5$, $SD = 7.7$; 11- to 12-year-olds: $M = 79.3$, $SD = 11.1$; 13- to 14-year-olds: $M = 79.7$, $SD = 10.1$; 15- to 17-year-olds: $M = 81.2$, $SD = 10.3$; Adults: $M = 80.1$, $SD = 11.2$) and a significant 1st order interaction of Culture x Age-group, $F(12, 362) = 5.4$, $p < .001$, $\eta_p^2 = .151$. To explore this interaction we conducted three one-way ANOVAs, one for each Culture group comparing the illusion score across Age-groups. To correct for these multiple analyses, the alpha value was corrected to $p = .017$. These revealed significant effects of age-group in only the UK participants, $F(6, 113) = 18.5$, $p < .001$, $\eta_p^2 = .496$. No effects of age-group were observed in the traditional Himba participants, $F(6, 119) = 1.3$, n.s., $\eta_p^2 = .063$, or the urban Namibian participants, $F(6, 130) = 2.1$, $p = .057$, $\eta_p^2 = .089$.

--Insert Figure 5 about here--

Discussion

Across all age-groups the urban Namibian children showed a greater illusion than the traditional Himba children tested in Experiments 1 and 2, and this was constant across childhood and into adulthood. Indeed, it is striking to note that even the youngest age-group of urban Namibian children (3- to 6-year-olds) demonstrated a small but significant illusion. These observations provide further evidence that the urban environment has a significant impact on the ways in which children and adults process visual context. They also show that the effect of urbanisation on the Ebbinghaus illusion is manifested early in development, providing further support for our proposal that cross-cultural variation in the illusion is mediated by differences in perceptual bias rather than attentional filtering. The significant illusion in the urban Namibian 3- to 6-year-olds is somewhat surprising given the lack of illusion in UK children at this age (see Experiment 1). This could potentially be explained by the fact that the average age of the urban Namibian children in this age-group is a little older than that of the UK children (see Tables 1 and 4).

In contrast to the findings of Caparos et al. (2012), the urban Namibians in our study did not demonstrate a similar level of Ebbinghaus illusion to UK participants in adulthood. One possible explanation of this discrepancy is that, whereas in Caparos et al.'s (2012) task both target and context elements were black, here (as in Doherty et al., 2010) we coloured the targets circles orange and the context elements grey

to make it easier for the younger participants in our study to comprehend the task instructions. It is possible that this contrast of colour facilitated a perceptual separation between the target and context elements leading to a reduced influence of context. Nonetheless, it is important to note that to explain the difference between UK and urban Namibian participants we would still have to appeal to differences in the extent to which UK and Urban Namibian participants use such colour differences to perceptually separate elements of display. We have no reason to hypothesise such differences.

Our preferred explanation of this discrepancy is that our study (in contrast to Caparos et al., and many others) makes use of a paradigm (developed by Phillips et al., 2008, and Doherty et al., 2010), which controls for the potential influence of the proximity of the context elements to the target circles on the perceived size of the target circles. The extent of separation between targets and context elements has been shown to influence processing of the size of the target in the Ebbinghaus illusion, independently of size contrast effects (Haffenden et al., 2001). It may be that both size context effects and the local contour interactions mediated by the distance between the context elements and the targets contributed to the illusions demonstrated by the urban Himba participants in Caparos et al.'s (2012) study, making them somewhat greater than those observed in the urban Namibian participants tested in the current study. A greater bias to analyse the local features of stimuli (as Caparos et al. also observed in their urban Himba sample in the context of a Navon matching task, see also Davidoff et al., 2008), might thus lead to a strong influence of context in this particular task.

Despite the significant effects of urbanisation observed in this experiment, there was no correlation between the extent of the illusion and years of exposure to an urban environment across our child and adult samples. However, given that our findings and those of others (Doherty et al., 2010; Duemmler et al., 2008; Weintraub, 1979) show that the Ebbinghaus illusion emerges during childhood it is not surprising that there is not a strong relation correlation across the whole age range, and particularly in the older age-groups, many of whom were not exposed to an urban environment earlier in life (see Table 4).

Across age-groups, we found a greater a level of illusion in urban Namibian children than in the traditional Himba children tested in Experiments 1 and 2. The strength of the illusion in the urban Namibian

children was mid-way between traditional Himba and UK participants. Thus it appears that the urban environment of Opuwo has an influence on its inhabitants' encoding of visual context such that they do this to a greater extent than Himba participants living in traditional villages in the bush. Nonetheless, the urban Namibian children's processing of context in the Ebbinghaus illusion is not to the extent observed in Western participants. Why might this be? One straightforward possibility is that there is simply a greater dose of urban factors in the UK urban environments (Stirling, Sheffield), than in Opuwo. These might lead to greater perceptual biases to process visual context. Another possibility is that the less developed illusion in older urbanised Namibian participants is due to the fact, as discussed above, that a larger proportion of the older age-groups were not exposed to an urban environment during childhood. Interestingly, this raises the possibility of a sensitive period in childhood during which exposure to the urban environment is particularly likely to give rise to a perceptual bias to process contextual information.

General discussion

The findings reported in this paper add to the mounting body of evidence that exposure to an urban environment has a significant impact on our processing of visual context (see Caparos et al., 2012; De Fockert et al., 2007). Across the age-groups that we tested, UK participants showed the greatest influence of visual context on their size judgements as evidenced by a sizable Ebbinghaus illusion. However, traditional Himba participants who live in a rural environment with little if any exposure to urban or Western artefacts, showed very little Ebbinghaus illusion and, correspondingly, a greater level of accuracy in their size judgements in the illusion condition. Evidence that this cross-cultural difference is mediated by exposure to an urban environment comes from our third experiment with urban Namibian participants who live in the nearest urban conurbation to the traditional Himba villages. Urban Namibians showed a level of illusion which was intermediate between those of the UK and traditional Himba participants.

However, the most important contribution of the studies reported here is to examine the developmental emergence of cross-cultural differences in size contrast effects. There was a marked difference between cultures in early to middle childhood. Whereas UK children show a robust illusion from 7- to 8-years of age, we observed no significant illusion in the traditional Himba children until 11-12 years

of age. No changes in cross-cultural differences were seen after 9-10 years of age. Namibian children who were growing up in an urban environment demonstrated a greater illusion than traditional Himba children which was sustained across childhood and adulthood giving a clear indication that the urban environment influences the emergence of contextual visual processing. The divergence between traditional Himba and Western children in early childhood sheds important light on the perceptual processes which mediate cross-cultural differences in the ways in which context perception develops in early life.

In this paper we have distinguished between two ways in which cross-cultural differences in context perception might emerge through development. We argued that differences in perceptual bias have the potential to emerge from early in life given especially that perceptual biases to process particular kinds of visual patterns are evident early in the first year of life (e.g., Bornstein et al., 1981; Colombo et al., 1991; Frick et al., 2000; Ghim & Eimas, 1988; LoBue, 2012), and cross-cultural differences in perceptual biases have been observed to emerge as early as across the first year of life (Yoshida et al., 2010). Another possibility is that differences in the extent to which attentional filtering is employed to selectively attend to task-relevant information could explain differential processing of visual context (with greater filtering leading to a lesser influence of context on perception). This account, made particularly plausible by the observation that the traditional Himba are superior to UK observers in selectively attending to task-relevant information (Caparos et al., 2013; De Fockert et al., 2011; Linnell et al., 2013), predicts a more protracted developmental trajectory of cross-cultural differences in context perception given the later maturation of attentional filtering which continues to develop beyond 10 years of age and into early adulthood. However, as stated above, we have observed here that cross-cultural differences in the influence of the Ebbinghaus illusion are fully developed by 9-10 years of age, and so our findings strongly support the perceptual bias account in preference to the attentional filtering account. Thus, we argue that UK children, and Namibian children growing up in an urban environment develop a perceptual bias to process context more than do traditional Himba children when inspecting visual patterns.

Given that some perceptual biases emerge in the first year of life (Bornstein et al., 1981; Colombo et al., 1991; Frick et al., 2000; Ghim & Eimas, 1988; LoBue, 2012; Yoshida et al., 2012), why did we not

observe differences in visual context effects between UK and traditional Himba children at the youngest age-group we tested? The answer seems likely to lie in the nature of the environmental drivers which give rise to cross-cultural differences in bias towards or away from visual context processing. The only example (of which we are aware) of a study demonstrating cross-cultural variations in perceptual bias in infancy, highlights the emergence (by 7-8 months) of differences in grouping of auditory stimuli between infants growing up in English-speaking and Japanese-speaking environments (Yoshida et al., 2012). Yoshida and colleagues ascribed these variations to differences between the infants' language environments. Whereas language environments are particularly pertinent to the developing infant, even as early as the first year of life (e.g., Vouloumanos & Werker, 2007; Werker, Yeung & Yoshida, 2012), we might speculate that the environmental differences which give rise to cross-cultural variations in visual context processing are more pertinent later in development, that is, in early childhood.

But what are the environmental factors which drive the emergence of cross-cultural differences in visual context effects? As described earlier, researchers have suggested a range of different accounts. Nisbett et al. (2001; see also Varnum et al., 2010) have argued that cross-cultural variations in the use of context are due to differences in social structure across cultures. Other explanations appeal to the idea that the physical environments which different cultures inhabit lead them to prioritise context to different extents; visual clutter and the pictorial environment are among the factors implicated (Caparos et al., 2012; Deregowski, 1989; Doherty et al., 2010; Miyamoto et al., 2006; Szwed et al., 2012). Our findings suggest that, whatever the precise source is, it exists in differences between urban and rural environments. There are a great many potential differences between urban and rural environments, in both physical and social structure. However, our findings of greater context effects in a urban than a rural sample (see also Caparos et al., 2012) do argue against the possibility that differences in visual context processing could be driven by social differences between cultures which are not correlated with differences in the physical (urban vs. rural) environment. Indeed, of the proposals which have been made in the literature, those involving differences in social structure more generally are less consistent with our findings. Varnum et al.'s (2010) proposal has it that more individualistic cultures (e.g., Western cultures) promote "analytic" processing of the details in visual

patterns, whereas more collectivist cultures (e.g., East Asian cultures) promote "holistic" processing of continuities and relationships. This is inconsistent with findings that (as well as here see Caparos et al., 2012; Davidoff et al., 2008; De Fockert et al., 2007) traditional Himba participants who are interdependent (or collectivist) by nature (Gluckman, 1965) have a local (analytical) bias in visual processing.

Proposals concerning differences in the physical structure of the environment leading to variations in in perceptual bias fare better. Visual clutter has been proposed to promote a greater processing of context (Caparos et al., 2012; Linnell et al., 2013; Miyamoto et al., 2006), as has exposure to pictures and printed material (Deregowski, 1989; Doherty et al., 2010; Szwed et al., 2012). Both visual clutter and pictorial exposure are greater in the urban environment where we observed greater effects of context on visual processing. But which of these environmental differences provides the best explanation of the trajectories of cross-cultural differences in visual context processing observed in the current investigation? We prefer the account based on exposure to pictorial stimuli, and printed matter more generally, simply because whereas a cluttered environment seems likely to impact on the developing child across early life, pictorial or printed stimuli become particularly relevant in early to middle childhood – the point at which we observed divergence between Traditional Himba, and UK children in the Ebbinghaus illusion.

As we have already argued, our data strengthen the case against accounts of cross-cultural differences in context processing which appeal to differences in the ability to selectively attend to particular kinds of information (see Kitayama et al., 2003). It is reasonable to enquire how our conclusion squares with the now large body of evidence that the Himba appear to be particularly good at focussing their attention on task-relevant aspects of visual patterns (De Fockert et al., 2011; Linnell et al., 2013). A recent study by Caparos and colleagues (2013) sheds light on this matter. They showed that the Himba's advantage in selective attention works at both local and global levels of analysis; they are less distracted by global information than Westerners, which is expected given their local bias, but they are also less distracted by global configurations. As such, differences in selective attention do not easily explain a perceptual bias to local features. An interesting question for future research will be to examine whether the opposite relation might be true. Does a lesser processing of context early in development lead to an advantage in selective

attention at both local and global levels of analysis later in development? It is possible that the advantage which traditional Himba adults show over UK participants in selective attention (attentional filtering) to both global and local information is due to their lesser perceptual bias to context in early life.

Another important question to ask concerns whether the developmental and cross-cultural effects of size contrast observed here extend across other context effects. It seems likely that the development of perceptual biases towards or away from context will have widespread effects across a range of tasks. Indeed, as well as being much less influenced by context in the Ebbinghaus illusion, traditional Himba adults tend to match two-dimensional hierarchical figures on the basis of featural rather than configural similarities (Caparos et al., 2012; Davidoff et al., 2008). It is interesting to consider whether the developmental emergence of cross-cultural differences in hierarchical figure processing mirrors that found in the emergence of the Ebbinghaus illusion. Several studies of the development of hierarchical figure processing demonstrate an extended development of an ability to report global shapes in hierarchical patterns (Elkind, Koegler & Go, 1964; Dukette & Stiles, 1996, 2001), which matches up quite well with the trajectory of visual context effects observed in the Ebbinghaus illusion by Doherty et al. (2010). Elkind and colleagues argued that the emergence of Piagetian concrete logical operations was the driving factor in the development of global shape. However, on the basis of correlational evidence alone, it is equally likely that developments in perceptual bias towards visual context might be at play.

Subsequent investigations of local vs. global processing have revealed a more complicated picture. When directed to attend to either local or global levels of description under speeded conditions, young children initially show a large global (rather than local) precedence which gradually ameliorates into late childhood and through adolescence (Mondloch, Geldart, Maurer & De Schonen, 2003). It is possible that, under speeded conditions of analysis in a selective attention task, attentional filtering comes to play a larger role, yielding a more protracted development. It will be interesting to determine whether differences in perceptual bias towards context in early life (like those seen between UK and Himba observers) will lead to different degrees and trajectories of global and local precedence in speeded selective attention tasks.

A further prediction to arise from our findings is that all illusions involving an influence of visual context should increase during childhood up until 11 years of age (at least in Westerners). The literature documenting developmental changes in Western children's responses to visual illusions beyond the Ebbinghaus illusion is somewhat conflicted on this matter. There are some reports of other illusions which increase in strength with age (Ponzo illusion: Leibowitz & Judisch, 1967), but also other context-driven illusions in which are seen no change or decreases in strength with age (Müller-Lyer and Horizontal-vertical Illusions: Brosvic, Dihoff & Fama, 2002; Pinter & Anderson, 1916; Rivers, 1905). One way of resolving these differences may be to make a more detailed analysis of the perceptual and attentional processes involved in these various illusions. If not just perceptual bias, but also other factors such as attentional filtering are involved but to differing extents, this may help explain the different developmental trajectories (e.g., developing attentional filtering could explain the reduction in the Müller-Lyer illusion with age).

In this article we have reported the findings of a series of experiments which combine the strengths of cross-cultural and developmental methods to shed light on the emergence of visual size context effects in childhood and adolescence. The cross-cultural comparisons have shown clearly that urban vs. rural environmental contexts give rise to different ways of processing visual context; visual context plays a greater role in task-relevant decisions in individuals who have grown up in urban environments. The developmental trajectories of these cross-cultural variations shed light on the processes whereby the urban environment gives rise to a greater effect of context in visual processing. Our findings show that cross-cultural variations in visual context effects are fully developed by 9-10 years of age, indicating that the urban environment gives rise to a perceptual bias to process context, rather than fostering the processing of task-irrelevant contextual information by reducing the extent to which context is filtered out by selective attention. We tentatively propose that differences in perceptual bias to process visual context arise from the differing degrees to which children are exposed to pictorial and printed materials between traditional and urban environments, with a greater exposure leading to greater processing of visual context in urban children.

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FIGURE CAPTIONS

<u>Figure 1</u>: Examples of stimuli used in the Ebbinghaus illusion task. Participants are asked to say which of the two central (target) circles were larger. In the experiments reported in this paper, the target circles were coloured orange and the surrounding (inducer) circles were grey. In each of the three conditions shown here, the target circle on the right if 2% larger than the one on the left. In Western participants, the misleading context condition typically gives the incorrect impression that the circle on the left is larger. The helpful context condition enhances performance by emphasising the actual size differences.

<u>Figure 2</u>: Experiment 1: Size discrimination accuracy in Traditional Himba and UK children between 3 and 10 years, with and without the influence of visual size context. Accuracy at identifying the largest of the two target circles is measured (chance performance is 50%). Panels A-C show performance in each of the size difference conditions in separate graphs for each age-group. In the "context" conditions, the inducers are expected (in Western adults) to give rise to a size contrast illusion whereby the accuracy of the size discrimination was reduced, particularly when differences between the two targets were smaller. In the "helpful" condition (tested at a 2% size difference only), a size contrast illusion leads to improved performance. To aid comparisons across age group and culture, Panel D reports a measure of performance across all size difference conditions. Lower brackets indicate which groups showed a significant illusion (see Table 2). No significant illusion was observed in the Himba age-groups. Only the 9- to 10-year-old UK children showed a significant illusion. The higher brackets indicate significant differences in the extent of illusion between cultures (* = uncorrected $p < .05$, ** = uncorrected $p < .01$, *** = uncorrected $p < .001$, n.s. = not significant).

<u>Figure 3</u>: Experiment 2: Size discrimination accuracy in Traditional Himba and UK participants between 11 years and adulthood, with and without the influence of visual size context. Accuracy at identifying the

largest of the two target circles is measured (chance performance is 50%). Panels A-D show performance in each of the size difference conditions in separate graphs for each age-group. Panel E reports a measure of performance across all size difference conditions. Lower brackets indicate which groups showed a significant illusion (see Table 2). All age-groups in both cultures demonstrated a significant illusion, except the 13- to 14-year-old traditional Himba children, who nevertheless demonstrated a trend towards illusion. The higher brackets indicate significant differences in the extent of illusion between cultures (* = uncorrected $p < .05$, ** = uncorrected $p < .01$, *** = uncorrected $p < .001$, n.s. = not significant).

Figure 4: Experiment 3: Size discrimination accuracy in urban Namibian participants with between 3 years and adulthood, with and without the influence of visual size context. Accuracy at identifying the largest of the two target circles is measured (chance performance is 50%). Panels A-G show performance in each of the size difference conditions in separate graphs for each age-group. Panel H reports a measure of performance across all size difference conditions. Brackets indicate which groups showed a significant illusion (see Table 2). All age-groups demonstrated a significant illusion (* = uncorrected p < .05, ** = uncorrected p < .01, *** = uncorrected p < .001, n.s. = not significant).

Figure 5: A comparison of the extent of the illusion perceived across all experiments (1-3), including traditional Himba, UK, and urban Namibian participants, spanning age-groups from 3 years to adulthood. The percentage illusion score is calculated for each participant by subtracting participants' overall accuracy in the context condition from their accuracy in the control condition.

TABLES

A) Himba participants

Age-group	n	Gender split	Est. mean age in years	Age-group comprises
3- to 6-year-olds	19	7m, 12f	4.95 (SD = 0.97)	3-year-olds (1), 4-year-olds (6), 5-year-olds (5), 6-year-olds (7)
7- to 8-year-olds	13	4m, 9f	7.31 (SD = 0.48)	7-year-olds (9), 8-year-olds (4)
9- to 10-year-olds	15	8m, 7f	9.80 (SD = 0.41)	9-year-olds (3), 10-year-olds (12)

B) UK participants (selected from Doherty et al., 2010, to match Himba sample)

Age-group	n	Gender split	Est. mean age in years	Age-group comprises
3- to 6-year-olds	19	7m, 12f	4.95 (SD = 0.97)	3-year-olds (1), 4-year-olds (6), 5-year-olds (5), 6-year-olds (7)
7- to 8-year-olds	13	4m, 9f	7.31 (SD = 0.48)	7-year-olds (9), 8-year-olds (4)
9- to 10-year-olds	15	8m, 7f	9.80 (SD = 0.41)	9-year-olds (3), 10-year-olds (12)

Table 1. Experiment 1 Participant characteristics. yo = -year-olds. We only had estimates of the age of the Himba participants in years. For the purposes of comparing the groups, the mean age in full years only is given for both groups. These values thus underestimate the participants' actual ages. Ages of the UK participants calculated using age in years and months was as follows: 3-6-year-olds = 5.17 years (SD = 1.00), 7-8-year-olds = 7.51 years (SD = 0.47), 9-10-year-olds = 10.01 years (SD = 0.49).

Culture

Age-group	TH participants				UK participants				UH participants			
	Mean (SD)	*t (df)*	*p*	*d*	*Mean (SD)*	*t (df)*	*p*	*d*	*Mean (SD)*	*t (df)*	*p*	*d*
3- to 6-year-olds	5.26 (17.20)	1.33 (18)	.199	.31	1.58 (16.50)	.42 (18)	.682	.10	10.28 (13.00)	3.35 (17)	<u>.004</u>	.79
7- to 8-year-olds	6.92 (13.62)	1.83 (12)	.092	.51	16.54 (15.60)	3.82 (12)	<u>.002</u>	1.06	13.75 (15.12)	4.07 (19)	<u>.001</u>	.91
9- to 10-year-olds	7.00 (18.40)	1.47 (14)	.163	.38	30.67 (15.34)	7.74 (14)	<u><.001</u>	2.00	14.75 (19.09)	3.46 (19)	<u>.003</u>	.77
11- to 12-year-olds	17.50 (15.83)	4.69 (17)	<u><.001</u>	1.11	46.67 (17.15)	11.55 (17)	<u><.001</u>	2.72	21.43 (10.51)	9.35 (20)	<u><.001</u>	2.04
13- to 14-year-olds	11.18 (18.25)	2.53 (16)	.022	.61	43.53 (22.06)	8.14 (16)	<u><.001</u>	1.97	23.82 (14.53)	6.76 (16)	<u><.001</u>	1.64
15- to 17-year-olds	12.00 (9.78)	3.88 (9)	<u>.004</u>	1.23	46.50 (23.69)	6.21 (9)	<u><.001</u>	1.96	19.74 (10.86)	7.92 (18)	<u><.001</u>	1.82
Adults	10.74 (10.31)	6.07 (33)	<u><.001</u>	1.04	47.50 (15.96)	15.75 (27)	<u><.001</u>	2.98	19.31 (14.33)	6.32 (21)	<u><.001</u>	1.35

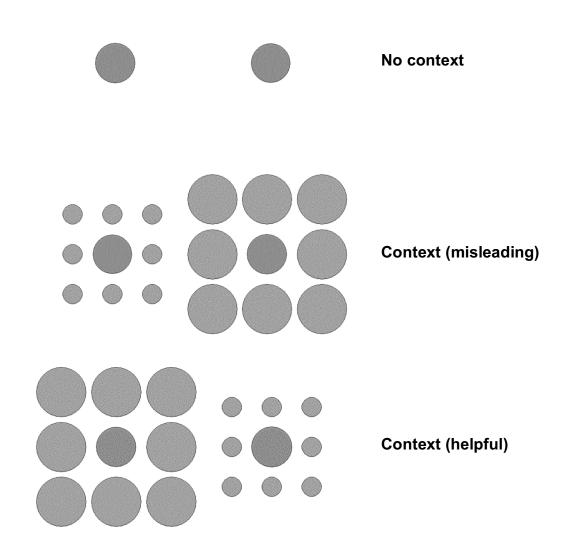<u>Table 2.</u> The results of One-sample t-tests comparing the illusion score within each age-group and each culture against chance (zero) (across Experiments 1, 2, and 3). Underlined p values indicate those groups who showed a significant illusion. Significance was determined according to a corrected alpha level (see main text for the details of what the alpha level was corrected to for each experiment).
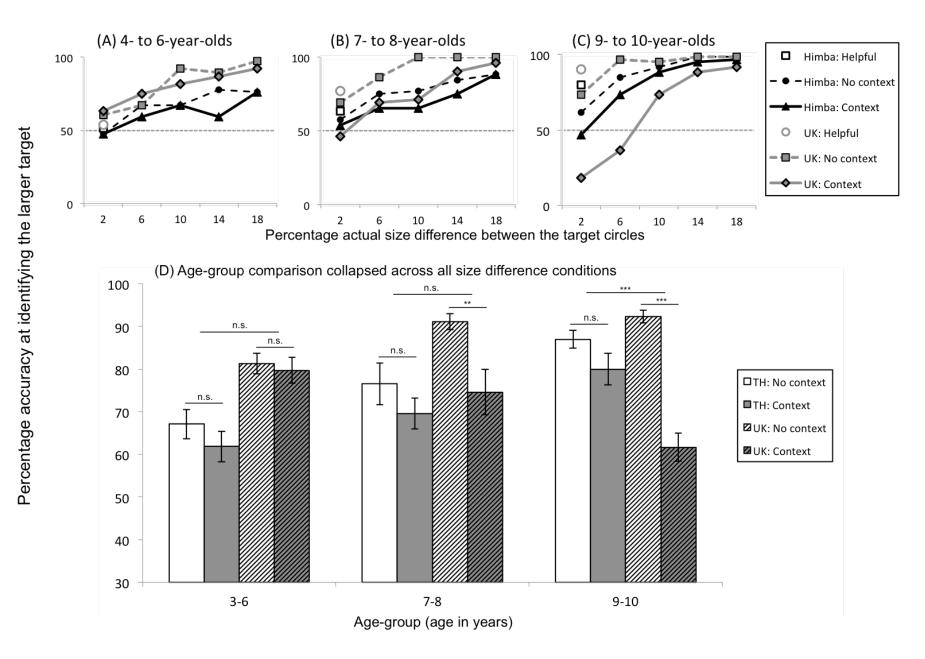
A) Himba participants

Age-group	N	Gender split	Est. mean age in years	Age-group comprises
11- to 12-year-olds	18	9m, 9f	11.67 (SD = 0.49)	11-year-olds (6), 12-year-olds (12)
13- to 14-year-olds	17	5m, 12f	13.41 (SD = 0.51)	13-year-olds (10), 14-year-olds (7)
15- to 17-year-olds	10	8m, 2f	16.30 (SD = 0.95)	15-year-olds (3), 16-year-olds (1), 17-year-olds (6)
Adults	34	14m, 20f	20.62 (SD = 2.78)	18- to 26-year-olds

B) UK participants

Age-group	n	Gender split	Est. mean age (years)	Age-group comprises
11- to 12-year-olds	18	10m, 8f	11.67 (SD = 0.49)	11-year-olds (6), 12-year-olds (12)
13- to 14-year-olds	17	5m, 12f	13.41 (SD = 0.51)	13-year-olds (10), 14-year-olds (7)
15- to 17-year-olds	10	6m, 4f	16.30 (SD = 0.95)	15-year-olds (3), 16-year-olds (1), 17-year-olds (6)
Adults	28	13m, 15f	19.36 (SD = 1.66)	18- to 25-year-olds

Table 3. Experiment 2 participant characteristics. yo = -year-olds. We only had estimates of the age of the Himba participants in years. For the purposes of comparing the groups, the mean age in full years only is given for both groups. These values thus underestimate the participants' actual ages. Ages of the UK participants calculated using age in years and months was as follows: 11- to 12-year-olds = 12.08 years (SD = 0.52), 13- to 14-year-olds = 13.85 years (SD = 0.57), 15- to 17-year-olds = 16.66 years (SD = 1.17).
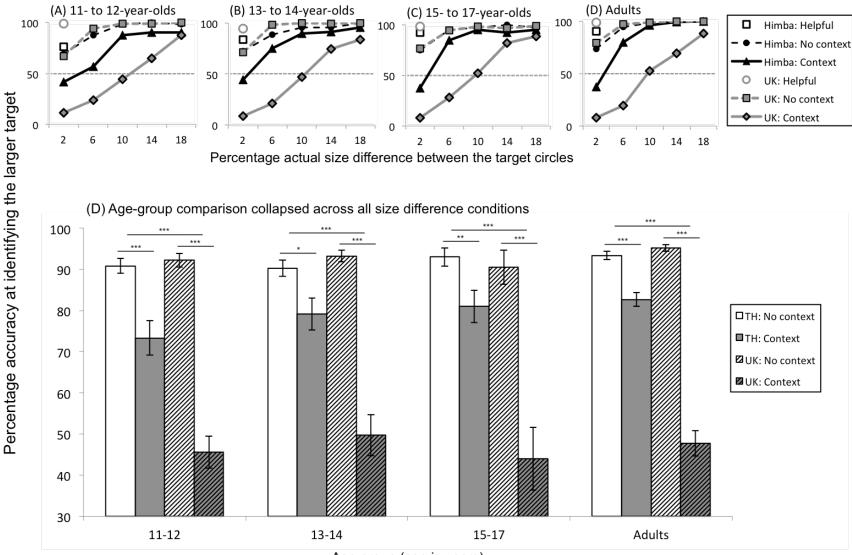
Urban Namibian participants

Age-group	n	Gender split	Mean age in years	Mean years urban	Age-group comprises
3- to 6-year-olds	18	8m, 10f	5.56 (SD = 0.62)	5.56 (SD = 0.62)	4-year-olds (1), 5-year-olds (6), 6-year-olds (11)
7- to 8-year-olds	20	11m, 9f	7.45 (SD = 0.51)	7.45 (SD = 0.51)	7-year-olds (11), 8-year-olds (9)
9- to 10-year-olds	20	11m, 9f	9.65 (SD = 0.49)	7.55 (SD = 3.61)	9-year-olds (7), 10-year-olds (13)
11- to 12-year-olds	22	13m, 9f	11.68 (SD = 0.48)	8.95 (SD = 3.76)	11-year-olds (7), 12-year-olds (15)
13- to 14-year-olds	17	6m, 11f	13.41 (SD = 0.51)	9.94 (SD = 5.09)	13-year-olds (10), 14-year-olds (7)
15- to 17-year-olds	18	7m, 11f	15.72 (SD = 0.75)	9.15 (SD = 5.79)	15-year-olds (8), 16-year-olds (7), 17-year-olds (3)
Adults	19	7m, 12f	21.00 (SD = 2.16)	10.78 (SD = 8.64)	18- to 26-year-olds

Table 4. Experiment 3 participant characteristics. yo = -year-olds. We only had access to the ages of the Urban Namibian participants in years.

Figure 1

No context

Context (misleading)

Context (helpful)

Figure 2

(A) 4- to 6-year-olds

(B) 7- to 8-year-olds

(C) 9- to 10-year-olds

Percentage actual size difference between the target circles

Percentage accuracy at identifying the larger target

Himba: Helpful
Himba: No context
Himba: Context
UK: Helpful
UK: No context
UK: Context

(D) Age-group comparison collapsed across all size difference conditions

Age-group (age in years)

TH: No context
TH: Context
UK: No context
UK: Context

Figure 3

Figure 4

(A) 4- to 6-year-olds
(C) 9- to 10-year-olds
(E) 13- to 14-year-olds
(G) Adults (n=19)

□ Helpful
● No context
▲ Context

(B) 7- to 8-year-olds
(D) 11- to 12-year-olds
(F) 15- to 17-year-olds

Percentage actual size difference between the target circles

Percentage accuracy at identifying the larger target

(H) Age-group comparison collapsed across all size difference conditions

UH: No context
UH: Context

Figure 5