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ABSTRACT

The development of visual context effects in the Ebbinghaus illusion in the UK and in remote and urban Namibians (N = 336) was investigated. Remote traditional Himba children showed no illusion up until 9-10 years, whereas UK children showed 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. A lesser illusion was seen in remote Himba children than in urban Namibian children growing up in the nearest town to the traditional Himba villages across age groups. 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 have shown that perceptual phenomena, often assumed to be basic human endowments, vary from culture to culture (e.g., Bremner et al., 2013; Davidoff, Davies & Roberson, 1999; De Fockert, Davidoff, Fagot & Goldstein, 2007; Deregowski, 1989; Doherty, Tsuji & Phillips, 2008; Nisbett, Peng, Choi & Norenzayan, 2001; O'Hanlon & Roberson, 2006; Rivers, 1905; Roberson, Davidoff, Davies & Shapiro, 2005). Such demonstrations challenge the widely-held assumption that findings regarding 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 can further the aims of developmental research.

Cross-cultural studies illustrate the environments which give rise to particular phenotypes, whereas 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 (Mareschal et al., 2007). Here we report the findings of three experiments which combined the strengths of cross-cultural and developmental methods (cf. Franklin, Clifford, Williamson & Davies, 2005; Roberson, Davidoff, Davies & Shapiro, 2004) to shed light on the emergence of visual context effects in childhood and adolescence. More specifically, we investigated visual size contrast effects using the Ebbinghaus illusion (Titchener's circles) in which the size of contextual visual elements induces illusory distortions of the perceived size of visual target stimuli (see Fig. 1A). This task is easily applied to a range of age groups and across cultures (e.g., Caparos et al., 2012; Doherty et al., 2008; Doherty, Campbell, Tsuji & Phillips, 2010). Our findings show how different environments affect the development of even such basic perceptual phenotypes as size contrast effects. Crucially, they show how developmental data can help differentiate between alternative accounts of the functional mechanisms whereby cultural environment influences perceptual development.

The cultural mediation of visual context effects

Effects of context are considered to be fundamental to our visual and cognitive systems (Phillips & Singer, 1997). Indeed, illusory effects of context have been argued to be universal and informationally encapsulated aspects of vision, not susceptible to effects of experience in 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. For instance, many studies show that East Asian observers give greater priority than Western observers 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 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 social structure. More individualistic (Western) cultures are thought to promote analytic processing of the details in visual patterns, while more collectivist cultures (e.g., East Asian cultures) promote holistic processing of continuities and relationships. Another class of explanations, potentially compatible with the social structure account, has suggested that the physical environments which different cultures inhabit lead to different extents of prioritisation of context. Miyamoto et al. (2006) argue that greater visual clutter, 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, inhabitants of towns and cities are also much more likely to encounter formal schooling, and that entails exposure to, and training involving detailed consideration of, a range of stimuli which might otherwise be viewed infrequently. School attendees are extensively exposured to pictures and print (e.g., when learning to read). Recent research shows that learning to read enhances holistic visual processing (Szwed, Ventura, Querido, Cohen & Dehaene, 2012). Some have also argued that the extent to which different cultures are exposed to pictures shape perceptual tendencies (e.g., Deregowski, 1989). For example. Doherty et al. (2010) argued that greater processing of context is needed to resolve the conflict between pictorial cues to depth and primary depth cues specifying the real depth of the picture surface. They proposed that experience of resolving this conflict might lead to the development of the Ebbinghaus illusion.

Recent data from a population which is particularly remote from Western and East Asian cultural influences, the Himba of Northern Namibia, helps distinguish between accounts of differences in context processing. The Himba live in a traditional and distinctly uncluttered rural environment with few if any pictures. 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 physical environment 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 thus greater accuracy at discriminating the real sizes of stimuli in the Ebbinghaus task relative to UK and Japanese participants. This suggests a relative neglect of the contextual elements which lead to the illusion in Western and Japanese participants. The physical environment account is also favoured by Caparos et al. (2012) who show that Himba who had moved to live in an urban environment showed a greater influence of visual context than traditional Himba in the Ebbinghaus illusion and in a hierarchical figure matching task.

<u>The ontogeny of cross-cultural differences in the Ebbinghaus illusion</u>

Our aim was to trace the developmental trajectory of cross-cultural differences in visual context effects sing the Ebbinghaus illusion. Variations in the Ebbinghaus illusion across different groups have traditionally been argued to arise from differences in *perceptual bias* 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 have also been shown to analyse and compare local (featural) rather than global (configural) aspects of hierarchical (Navon) figures, suggesting a bias away from context (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 context processing more widely). In the Ebbinghaus task, participants are typically asked to judge the sizes of central circles. The surrounding inducing elements are thus distracting information to be ignored. So improved performance (and a greater neglect of context) in the Ebbinghaus illusion task might also be due to greater *attentional filtering*, that is, an ability to focus attention selectively on relevant information, and filter out irrelevant information (De Fockert & Wu, 2009). This explanation of variations in context effects is particularly pertinent given that there is now strong evidence that the Himba are better than 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).

The *perceptual bias* and *attentional filtering* accounts make 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 context might arise early in life (e.g., Ghim & Eimas, 1988; LoBue, 2012). Visual context plays a role in visual processing early in the first year (e.g., Bremner, Bryant, Mareschal & Volein, 2007; Yamazaki, Otsuka, Kanazawa & Yamaguchi, 2010), and even 3-month-old infants change from global to local processing of visual patterns with increased exposure (Colombo, Mitchell, Coldren & Freeseman, 1991; Frick, Colombo & Allen, 2000). There is also evidence that cross-cultural differences in perceptual biases emerge across the first year of life. Differences in auditory grouping between infants growing up in English- and Japanese-speaking environments are present by 7-8 months (Yoshida et al., 2010). The presence of, and cross-cultural variations in, perceptual biases towards and away from context in the first year of life show that cross-cultural differences in perceptual bias to context could arise from this early stage. In contrast, attentional filtering has not been observed in infancy and matures well beyond 10 years of age and into early adulthood (Comalli, Wapner & Werner, 1962; Enns, Brodeur & Trick, 1998; Ridderinkhof & Van der Stelt, 2000; Rueda et al., 2004; Waszak, Li & Hommel, 2010). Thus, if cross-cultural differences 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 these contrasting predictions of the perceptual bias and attentional filtering accounts.

In Experiment 3 we examined the nature of the environmental factors which mediate the development of cross-cultural differences in context effects in the Ebbinghaus illusion. We traced the development of the Ebbinghaus illusion in Namibian children who were growing up in an urban environment near the traditional Himba villages. Aspects of the urban environment (e.g., greater perceptual clutter and increased engagement with pictures and print) could 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 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 gleaned a relatively pure measure of the effect of an urban vs. rural environment on the development of context effects in the Ebbinghaus illusion.

Experiment 1

Experiment 1 charted the development of the Ebbinghaus illusion in HImba children between 3 and 10 years of age, who were being brought up traditionally in remote villages in Kaokoland in Northern Namibia. Several studies have examined the early development of this illusion in Western children. The majority reported an increase in context effects with age (Doherty et al., 2010; Duemmler, Franz, Jovanovic & Schwarzer, 2008; Kaldy & Kovacs, 2003; Weintraub, 1979). One study by Hanisch, Konczak, and Dohle (2001) found no difference in the extent of the illusion between 5 to 12 years of age and adulthood. However, in their study, the use of a "same-different" judgement task may have masked differences in the strength of illusion between groups via a differential response bias (Doherty et al., 2010; Kaldy & Kovacs, 2003). Following Kaldy and Kovacs (2003) we employed a two alternative forced choice task (2AFC) to identify the larger of two targets. Because the 2AFC does not require "same-different" (or "yes-no") responses, it is less susceptible to response biases. Specifically, we used the 2AFC Ebbinghaus task used by Doherty et al. (2010; see Phillips et al., 2004) in their investigation of the development of the illusion in children living in the UK, which has the additional advantage of controlling for the potential effects of local contour interactions (Haffenden, Schiff & Goodale, 2001) by keeping the separation between targets and context elements constant across conditions. Doherty et al.'s (2010) task also includes a condition which measures size discrimination ability in the absence of the illusion inducers. We compared the extent of the illusion against baseline size discrimination performance in traditional Himba children with an age-matched subset of the UK participants tested by Doherty et al. (2010).

Method

Participants. The Himba are semi-nomadic herders who have very limited contact with Western culture and artifacts. Traditional Himba participants were recruited from two traditional villages in Kaokoland. Fifty Himba children participated (see Table 1), none of whom had ever been involved in experimental research. The Himba do not usually keep accurate birth records and so we had to estimate the participants' ages; 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 vary from 3 to 10 years. Three participants (estimated ages of 4, 5, and 5 years) were excluded from analyses as two did not complete the test and one demonstrated a complete display side bias. The remaining participants were then grouped into these age groups: 3-6 years, 7-8 years, 9-10 years. To provide a fair comparison with the UK sample we selected a subset of the participants tested in Doherty et al. (2010) matched to the Himba participants in this experiment in age (in years) and gender; groups which were matched as precisely as possible. 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 custom C++ programme on a 15.4" screen (Doherty et al., 2010). The participants were seated so that their eyes were approximately 45 cm from the screen. The task required participants to select which of two orange circles (presented on either side of the 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). On control (no context) trials, the orange target circles were present on their own (see Fig. 1B).

--Insert Figure 1 about here--

For both the experimental and control conditions, on each trial the difference in diameter between the target circles was 2, 6, 10, 14, or 18 pixels. One of the targets always had a diameter of 100 pixels (23 mm; subtending approximately 3.3° of visual angle at a viewing distance of 45 cm), and so the other target varied in diameter between 82 and 118 pixels, yielding 10 possible size comparisons. Each size comparison was presented twice, once with the 100 pixel diameter 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 (diameter) contrast to the targets, and thus the majority of context trials provided misleading context. Also in the experimental condition, we 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. The decision to not fully counterbalance helpful and misleading context conditions was motivated by three considerations. Firstly, such a design avoids the use of a strategy in which participants could judge the point of objective equality between target sizes on the basis of the overall size distributions of the targets across the experimental session. Secondly, focusing on the misleading context condition enabled us to restrict the number of trials required and thus the length of the experimental session (an important factor when working with young children who are particularly prone to fatigue in experiments). Lastly, the misleading context condition is especially relevant to our experimental aims. Better performance in this condition in the Himba is predicted due to their local perceptual bias (De Fockert et al., 2007). Thus, in the helpful condition, cross-cultural differences in the effect of the illusion are potentially confounded with differences in familiarity with computers and or the experimental testing scenario. For this reason, the misleading context condition provides the most valid indication of cross-cultural differences in the Ebbinghaus illusion. This asymmetrical design is precisely that used by Doherty et al. (2010), and has been used in similar form extensively elsewhere (e.g., Phillips et al., 2004; De Fockert et al., 2007).

The additional helpful context trials allowed us to check whether the participants were employing a response strategy in the experimental condition which relied on the size of the inducers rather than the targets. If a participant chose the array on the basis of it having larger inducers, a strategy which would have led to success on the majority of experimental trials, then they would have been 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 counterbalanced across participants). Within blocks, trial order was 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 which lasted between 2 and 5 minutes.

Statistical analyses. Analyses focused on two dependent variables. Firstly, size discrimination accuracy was operationalised as percentage accuracy: the percentage of trials on which participants correctly selected the larger of the two circles, pooled across all of the size difference discrimination conditions (excluding the helpful context condition). Percentage accuracy across participant groups (Culture and Age group were independent factors) and conditions (Context / No context) was investigated using Analysis of Variance (ANOVA). Post-hoc tests were used to explore the highest order interaction which arose from this ANOVA. If the highest order interaction to arise was Culture x Age group x Condition, this was explored using two post-hoc ANOVAs examining effects of Culture and Age group within each condition (Context / No context), followed by further post-hoc analyses to explore any 1st order interactions. Secondly, to glean a measure of the extent of the illusion which was comparable across groups with varying size discrimination performance we subtracted participants' overall accuracy in the context condition from their accuracy in the control (no context) 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.

Results

Figure 2 (A-C) illustrates participants' percentage accuracy at size discrimination either with or without the presence of the illusion inducers. Trend analyses of percentage accuracy collapsed across context and no context conditions demonstrated significant linear declines in performance with reductions in diameter differences, in each age group within each culture (all *p*s < .001), providing a clear indication that all participant groups were following task instructions. The effect of the Ebbinghaus illusion - 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 all age groups of Himba participants.

--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 the main effects and interactions presented in Table 2, which were all qualified by a significant interaction of Condition x Culture x Age group. The main effect of Condition described poorer performance in the Context condition (M = 71.2, SD = 16.5) than in the No context condition (M = 81.8, SD = 14.5). The main effect of Culture described poorer size discrimination accuracy by the Himba children (M = 72.9, SD = 14.0) than the UK children (M = 80.1, SD = 9.3). The main effect of Age group described 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).

--Insert Table 2 about here--

The Condition x Culture x Age interaction was explored with two 2 x 3 post-hoc univariate ANOVAs, one within each of the Conditions, with factors of Culture and Age group (Bonferroni corrected: α level of p = .025 for all of the terms). In the No context condition ANOVA, we observed main effects of Culture, $F(1, 88) = 22.2$, $p < .001$, $\eta_p^2 = .202$ (Himba: M = 76.1, SD = 16.2; UK: M = 87.6, SD = 1.4) and Age group, $F(2, 88) = 15.5$, $p < .001$, $\eta_p^2 = .261$ (3- to 6-year-olds: M = 74.2, SD = 14.7; 7- to 8-year-olds: M = 83.8, SD = 15.1; 9- to 10-year-olds: M = 89.7, SD = 7.5), but no interaction. Post-hoc t-tests exploring the main effect of Age group (Bonferroni corrected: α was p = .017) demonstrated that the 3- to 6-year-olds were significantly outperformed by the 7- to 8-year-olds, $t(62) = 2.55$, p = .013, d = .66, and the 9- to 10-

year-olds, $t(66) = 5.24$, $p < .001$, $d = 1.05$, but that the older two age groups showed equivalent performance. In the Context condition ANOVA, we observed only a significant interaction of Culture x Age group, $F(2, 88) = 12.6$, $p < .001$, $\eta_p^2 = .222$. Post-hoc t-tests (Bonferroni corrected: α level of $p = .006$) revealed significantly greater accuracy in the UK than the Himba participants in the 3- to 6-year-olds age group, $t(36) = 3.78$, $p = .001$, $d = 1.14$, a pattern which was not significant in the 7- to 8-year-olds, but reversed in the 9- to 10-year-olds, $t(28) = 3.67$, $p = .001$, $d = 1.27$, with greater accuracy in the Himba. Effects of Age group were then investigated within each of the cultures. In both the UK and the Himba children the only significant Age group effects were between the 3- to 6-year-olds and the 9- to 10-year-olds, with the youngest group outperforming the oldest group in the UK participants, $t(32) = 3.97$, $p < .001$, $d = 1.35$, and the oldest group outperforming the youngest in the Himba, $t(32) = 3.47$, $p = .002$, $d = .15$. No other Age group effects were reliable.

While effects of Culture and Age group in the context condition are indicative of variations in the Ebbinghaus illusion, they are confounded with group-wise differences in size discrimination accuracy. In order to account for this confound, we conducted (as detailed in the Method section) planned comparisons 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 function as simple contrasts in an exploration of the second order interaction reported above. Three comparisons were made (Bonferroni correction yielded an α level of $p = .017$). Cross-cultural comparisons of this illusion score within each of the age groups revealed a 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 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 assessed whether each age group and culture demonstrated a significant illusion, by comparing the illusion score against zero using one-sample t-tests (see Table 3, first three rows). The comparisons comprised six tests (Bonferroni corrected: α level of $p = .008$. Only the oldest two UK age groups demonstrated a significant illusion (i.e. from 7 to 8 years of age).

--Insert Table 3 about here--

Lastly we checked that each Age group x Culture sub-group which 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. An inspection of Figure 2 (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 show that the traditional Himba children remained unaffected by context up to 9-10 years whereas the UK children selected from Doherty et al.'s (2010) dataset already showed a significant effect of size contrast by 7- to 8-years of age. A significant difference in the influence of the illusion between cultures is observable by 9 to 10 years of age. This divergence between Himba and UK children before 10 years of age suggests that cross-cultural variations in the Ebbinghaus illusion are mediated by processes which develop in early to middle childhood. This trajectory of developmental divergence between traditional Himba and UK children is consistent with the perceptual bias account described in the introduction. However, given that perceptual biases can emerge within the first year of life it might seem surprising that crosscultural differences in visual context processing did not emerge until 9-10 years of age. One possible reason for this is that the cultural environmental factors which give rise to these differences may not be present or salient until later in childhood. We address the matter of the cultural environmental drivers of cross-cultural differences in the Ebbinghaus illusion in Experiment 3, and the General Discussion.

Experiment 2 examined whether the developing divergence between Himba and UK children continues into later childhood. It is possible that differences in perceptual bias could continue to change in later childhood. However, in addition to perceptual bias, differences in attentional filtering (an ability to ignore task-irrelevant distractors) could contribute to variations in the illusion between cultures, as this aspect of visual attention develops beyond 10 years of age and into adulthood (Goldberg et al., 2001; Waszak et al., 2010). Thus, if changes in cross-cultural differences are seen in late childhood, this could point to the continuing effects of developmental changes in perceptual bias and or additional developments in attentional filtering. Lack of changes would suggest that attentional filtering has relatively little impact on cross-cultural differences in the Ebbinghaus illusion.

Experiment 2

In this experiment we tested 11- to 17-year-olds, and adults. The apparatus, materials and procedure were very similar to Experiment 1. 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 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.

Method

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 4 for details). 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 4 presents the participant characteristics.

Results

Figure 3 (A-D) illustrates participants' percentage accuracy with and without the presence of illusion inducers. Trend analyses of percentage accuracy collapsed across context and no context conditions demonstrated significant linear declines in performance with reductions in diameter differences, in each age group in each culture (all *p*s $< .001$), showing that all participant groups were following task instructions. The illusion is observable in all age groups across cultures, but to a greater extent in the UK participants.

--Insert Table 4 and Figure 3 about here--

Participants' percentage accuracy across all conditions (except 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 the main effects and interactions presented in Table 2, which were all qualified by a first order interaction of Condition x Culture, $F(1, 144) = 132.94$, $p < .001$, $\eta_p^2 = .480$. The main effect of Condition described poorer accuracy in the Context ($M = 79.6$, $SD = 13.9$) than the No context condition ($M = 92.1$, $SD = 7.1$). The main effect of Culture described greater accuracy in the Himba ($M = 85.8$, $SD = 8.6$) than the UK participants ($M = 70.2$, $SD = 10.3$).

The interaction of Condition x Culture was explored with four t-tests (α was $p = .013$). 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 participants (Context: $M = 47.1$, $SD = 18.2$; No context: $M = 93.4$, $SD = 7.2$), $t(72) = 21.2$, $p < .001$, $d = 2.5$, with both groups performing best in the no context condition. Two independent-samples tests revealed a difference in accuracy between Himba and UK participants within the Context condition, $t(150) = 12.4$, $p < .001$, $d = 2.3$, with better performance in the Himba, but not the No context condition, $t(150) = 1.1$, *n.s.*, $d = .18$. Thus 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 (α was $p = .013$). 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 comparing the illusion score against zero were also run to determine whether each age group in each culture had demonstrated a significant illusion (see Table 3). The comparisons comprised eight tests (α was p = .006). All groups demonstrated a significant illusion, bar the 13- to 14-year-old traditional Himba group who nonetheless showed a trend towards illusion.

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. 3A-D).

Finally, we decided to determine whether there were any 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 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. 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 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 cultures. 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, with higher levels of accuracy in the traditional Himba compared to the UK participants. The extent of the illusion increased between 9-10 years and 11-12 years in parallel across cultures. However, in contrast to the comparisons of younger age groups (Experiment 1), there were no changes between 11-12 years and adulthood in the effect of culture. Thus, cross-cultural differences 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.

Experiments 1 and 2 show together that cross-cultural differences in the Ebbinghaus illusion develop in early to middle childhood (Experiment 1), but remain stable after 10 years of age (Experiment 2). On the basis of the predictions of the perceptual bias and attentional filtering accounts, we conclude that cross-cultural differences in size context effect emerge due to differences in perceptual bias, rather than attentional filtering (see Caparos et al., 2013; De Fockert et al., 2011; Linnell et al., 2013).

How might cross-cultural differences in perceptual biases emerge? In Experiment 3 we examined the role of exposure to the urban environment in the development of cross-cultural differences in size contrast in the Ebbinghaus illusion. Recent findings show that Himba adults who have moved to live in an urban environment show greater Ebbinghaus illusion than traditional Himba adults (Caparos et al., 2012). We extended this work by comparing the development of size context effects in the Ebbinghaus illusion between traditional Himba children and urban Namibian children. We had a rare opportunity to trace the influence of the urban environment on the development of cross-cultural variations in visual perceptual skills, independently of more general sociocultural differences which are unrelated to degree of urbanisation.

Experiment 3

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. The urban Namibian children were tested in a quiet room in their school. The urban Namibian adults took part in a quiet room inside the translator's house.

Method

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 (61 female, 54 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 = 22; 13 female, 9 male). Participants were sampled from across a wide range of Namibian ethnic groups living in Opuwo (including Himba, Herero, Ovambo, Banderu, Zemba, Gambue people). Many of the urban participants (especially in the older age groups) had not lived in an urban environment since birth. Table 5 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, and the highest level of school attainment (ranging from 0 to grade 12).

Statistical analyses. In addition to equivalent analyses as applied in Experiments 1 and 2 we also conducted a further ANOVA across Experiments 1-3 to examine the effects of culture and urban environment on the percentage illusion score across age groups. Significant interactions between culture and age group were explored by running three further one-way ANOVAs comparing the strength of the illusion between age groups within each of the different culture groups (urban UK, traditional Himba, urban Namibian).

Results

We ran 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 explaining or masking effects of age on the Ebbinghaus illusion. We examined correlation between years of exposure to an urban environment (see Table 5) and the percentage illusion score. Historically, older individuals in Opuwo have tended to complete less formal schooling, and so we controlled for the highest educational level attained. No relationship was found between years of exposure to the urban environment and the percentage illusion score, $r(134) = .01$, *n.s.* Secondly, as we had included a wide range of ethnic groups in this experiment (see the Participants section) we also checked whether ethnic factors could be driving any potential differences between traditional Himba participants (Experiments 1 and 2) and the urban Namibian participants (Experiment 3). A comparison of the percentage illusion score in the urban Himba participants ($M = 21.5\%$, $n = 27$, $SD = 17.3$) and urban participants from other ethnic groups ($M = 16.6\%$, $n = 110$, $SD = 13.7$) demonstrated no significant difference, $t(135) = 1.6$, *n.s.*, $d = .28$.

--Insert Table 5 and Figure 4 about here--

Figure 4 (A-G) illustrates participants' performance at size discrimination across conditions. Trend analyses of percentage accuracy collapsed across context and no context conditions demonstrated significant linear declines in performance with reductions in diameter differences, in each age group in each culture (all *p*s < .001), showing that all participant groups were following task instructions. The effect of the Ebbinghaus illusion can be observed to gradually increase with age, plateauing from 11-12 years. Participants' accuracy across all conditions (apart from the helpful context condition) was entered into a 2 x 7 mixed design ANOVA (reported in Table 2) with the within-participants factor of Condition (Context / No context), and the between-participants factor of 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. 4). This showed a main effect of Condition, describing poorer accuracy in the Context (M = 75.7, SD = 12.8) than in the No context (M = 93.3, SD = 6.5) condition. There was also a marginally significant 1st order interaction of Condition x Age-group.

We conducted planned comparisons as used in Experiments 1 and 2, in which the percentage illusion score was compared against zero at each age group (see Table 3). These seven tests (α was p = .007) revealed that all age groups of urban Namibian participants (even the youngest 3- to 6-year-olds) demonstrated 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).

As mentioned above, we had gathered data concerning the level of school attainment achieved across the sample of urban Namibians. Given that we have speculated that aspects of the school environment might play particularly important roles in the development of perceptual biases towards visual context, we examined the correlation between level of school attainment and the percentage illusion score, controlling for years in the urban environment, and years of age. This demonstrated a significant positive relationship between school attainment and the Ebbinghaus illusion, $r(133) = .22$, one-tailed $p = .004$.

We next compared the developmental unfolding of the Ebbinghaus illusion across UK participants, the traditional Himba (TH) and the urban Namibian (UN) participants. We entered the percentage illusion score into a 3 x 7 between participants ANOVA with the factors of Culture (UK / TH / UN), 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 the effects displayed in Table 2, which were all qualified by an interaction of Culture x Age group (explored below). The main effect of Culture is explained by significantly different mean percentage illusion scores between all three cultures with the TH demonstrating the lowest percentage illusion ($M = 10.2$, $SD = 15.0$, $N = 126$), the UN demonstrating an intermediate level of illusion ($M = 17.6$, $SD = 14.5$, $N = 137$), and the UK participants demonstrating the greatest percentage illusion ($M = 34.0$, $SD = 24.4$, $N = 120$) (TH - UK: $t(244) = 9.3$, $p < .001$, $d = 1.59$; TH - UN: $t(261) = 4.1$, $p < .001$, $d = .49$; UK - UN: $t(255) = 6.6$, $p < .001$, $d = .67$). The main effect of Age group described 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: $M = 80.1$, $SD = 11.2$).

--Insert Figure 5 about here--

To explore the interaction of Culture x Age group we conducted three one-way ANOVAs, one for each Culture group comparing the illusion score across Age groups (α was $p = .017$). These revealed an effect of age group in the UK participants, $F(6, 113) = 18.5$, $p < .001$, $\eta_p^2 = .496$, but not the TH participants, $F(6, 119) = 1.3$, n.s., $\eta_p^2 = .063$, or the UN participants, $F(6, 130) = 2.1$, $p = .057$, $\eta_p^2 = .089$. Planned comparisons were run on the percentage illusion score comparing UN and TH cultures, and UN and UK cultures at each age group. Fourteen comparisons were made and so α level was $p = .004$. These comparisons revealed significant differences between UK and UN cultures in the 11- to 12-year-old age group, $t(37) = 5.6$, $p < .001$, $d = 1.47$, the 13- to 14-year-old age group, $t(32) = 3.1$, $p = .004$, $d = .89$, the 15- to 17-year-old age group, $t(27) = 4.2$, $p < .001$, $d = 1.13$, and the adult group, $t(48) = 6.5$, $p < .001$, $d = 1.77$. No other comparisons reached significance.

Discussion

Although comparisons within individual age groups did not reach significance, the urban Namibian children showed a greater illusion than the traditional Himba children tested in Experiments 1 and 2, across age groups. Strikingly, even the youngest age group of urban Namibian children (3- to 6-year-olds) demonstrated a small but significant illusion, further evidence that the urban environment has a significant impact on the ways in which children and adults process visual context (Caparos et al., 2012) from early in development. This supports the perceptual bias account of cross-cultural variations in visual context processing. The significant illusion in the youngest urban Namibians is surprising given the lack of illusion in UK children at this age (see Experiment 1). However, this is possibly due to the average age of the urban Namibian children in this age group being a little older than that of the UK children (see Tables 1 and 5).

The strength of the illusion in the urban Namibian participants was between that of the traditional Himba and UK participants. Thus, although the urban environment of Opuwo increases its inhabitant's perception of the Ebbinghaus illusion relative to Himba participants living in traditional villages, this was still not to the extent observed in Western participants. One straightforward explanation is that there is a greater dose of environmental factors which promote a perceptual bias to process context ("context-promoting" factors) in the UK urban environments (Stirling, Sheffield), than in Opuwo. We examined two factors that could underlie the impact of the urban environment, including the extent of exposure to the urban environment (in years), and formal schooling (measured by the highest level of school attainment). Although years of exposure to the urban environment did not correlate with the extent of the illusion, exposure to formal schooling demonstrated a small but significant correlation, when age in years and years in an urban environment were controlled. We discuss this relationship further in the General Discussion. A further, compatible, explanation of the less well-developed illusion in older urban Namibian participants is that a large proportion of the older urban Namibians were not born in an urban environment. 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 context.

The lower level of illusion demonstrated by the urban Namibians stands in contrast to Caparos et al. (2012), who found a similar level of Ebbinghaus illusion between urban Himba and UK adults. One potential explanation is that, whereas in Caparos et al.'s task both target and context elements were black, here (as in Doherty et al., 2010) the target circles were orange and the context elements grey to make it easier for the younger participants to comprehend the task instructions. This colour contrast may have facilitated a perceptual separation between the target and context elements, reducing the influence of context. One way to explain the difference between UK and urban Namibian participants would be posit differences in the extent to which UK and urban Namibian participants are influenced by colour differences to perceptually separate elements of display. However, we have no *a priori* reason to do this. Perhaps a more likely account is that our stimuli (in contrast to Caparos et al.'s stimuli) control for the influence of the proximity of the context elements to the target circles on the perceived size of the target circles (Phillips et al., 2008; Doherty et al., 2010). It may be that both size contrast effects and local contour interactions mediated by the separation of the context elements and the targets (Haffenden et al., 2001) contributed to the urban Himba participants' illusions in Caparos et al.'s study, making them greater than those reported in this experiment. A greater bias to process the local features (as Caparos et al. also observed in their urban Himba sample in a Navon matching task; Davidoff et al., 2008), might have enhanced the Ebbinghaus illusion.

General Discussion

The findings reported in this paper add to the mounting body of evidence that the cultural environment in which we develop has a significant impact on our processing of visual context (see Caparos et al., 2012; Davidoff et al., 2008; De Fockert et al., 2007). Across age groups, UK participants showed the greatest influence of visual context on their size judgements as evidenced by a sizable Ebbinghaus illusion. But traditional Himba participants who were living in a rural environment with little if any exposure to urban or Western artefacts, showed very little Ebbinghaus illusion and thus a greater level of accuracy in their size judgements in the illusion condition. Our third experiment, with Namibian participants who were living in the nearest town to the traditional Himba villages. agrees with Caparos et al.'s (2012) evidence showing that this cross-cultural difference is mediated by exposure to an urban environment. Urban Namibians showed a level of illusion here which was intermediate between those of the UK and traditional Himba participants.

Separating perceptual bias and attentional filtering accounts of the development of cross-cultural differences in size contrast effects

The most notable contribution of the current report is to demonstrate the developmental emergence of cross-cultural differences in size contrast effects. This information sheds light on the perceptual processes which mediate such effects of culture. We have distinguished two means whereby cross-cultural differences in context perception might develop, namely, variations in: i) perceptual bias, and ii) attentional filtering. Perceptual biases (interindividual, intraindividual and cross-cultural) are evident early in the first year of life (e.g., Colombo et al., 1991; Frick et al., 2000; Ghim & Eimas, 1988; Yoshida et al., 2010), in contrast to attentional filtering which has not been observed in infancy and continues to mature well beyond 10 years of age and into early adulthood (e.g., Rueda et al., 2004; Waszak et al., 2010). Thus, under the perceptual bias account, differences might be expected from as early as infancy, and under the attentional filtering account differences would be expected to continue to develop beyond 10 years and into adulthood.

We have reported marked cross-cultural differences which are broadly consistent with the perceptual bias account, and inconsistent with the attentional filtering account. Whereas UK children show a robust illusion from 7 to 8 years of age (Doherty et al., 2010), no significant illusion was seen in the traditional Himba children until 11-12 years of age. Importantly, 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, in a sustained manner across development. Thus, we argue that cross-cultural differences in processing context between the groups tested here are due to differences in perceptual bias to process context. Crucially, we are not making the argument that the development of the Ebbinghaus illusion is due only to perceptual bias. Both perceptual bias and attentional filtering contribute to the Ebbinghaus illusion and so it seems likely that both of these factors will be involved in its development. What we argue here is that perceptual bias is responsible for the development of the culturally mediated aspects of the illusion which are demonstrated in cross-cultural comparisons.

<u>Developmental drivers of bias to process context in the urban environment</u>

Given the effects of the urban environment on the development of the Ebbinghaus illusion (Caparos et al., 2012; Experiment 3 of this report), we propose that the emergence of greater perceptual bias towards context in urban children than in the traditional Himba children is due to a greater preponderance of context-promoting environmental factors in the urban environment. We can speculate about what these context-promoting environmental factors are by considering the ages at which differences in perceptual biases to context emerge. Relatedly, we can ask: why, given that some perceptual biases emerge in the first year of life (see above), did we not observe cross-cultural differences in visual context effects in the youngest age group we tested? One pertinent study highlights the emergence in infancy of cross-cultural biases with regard to auditory stimuli which the authors ascribed to the infants' different language environments (Yoshida et al., 2010). 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 early to middle childhood.

As described earlier, researchers have suggested a range of different accounts of the environmental factors (social and physical) which drive the emergence of cross-cultural differences in visual context. The dominant proposal in the literature appealing to differences in social structure is inconsistent with our findings. Varnum et al. (2010) argue that more individualistic (e.g., Western) cultures promote "analytic" processing of the details in visual patterns, whereas more collectivist (e.g., East Asian) cultures promote "holistic" processing of continuities and relationships. However, as shown here and elsewhere (Caparos et al., 2012; Davidoff et al., 2008; De Fockert et al., 2007) traditional Himba participants who are collectivist by nature (Gluckman, 1965) have a local (analytical) bias in visual processing. Of course, there are a great many potential differences between urban and rural environments, in both social and physical structure. Nonetheless, our findings (and those of Caparos et al., 2012) place important qualifications on any argument that differences in visual context processing are driven by social differences between cultures which are not correlated with differences in the physical (urban vs. rural) environment.

Visual clutter and engagement with pictures and print (which are greater in the urban environment) have both been proposed to promote greater processing of context (Doherty et al., 2010; Miyamoto et al., 2006; Szwed et al., 2012). But which of these these accounts provides the best explanation of the trajectories of cross-cultural differences observed in the current investigation? We prefer the account based on engagement with pictorial stimuli and print, 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 when the child enters school – the point at which we observed divergence between traditional Himba and UK children in the Ebbinghaus illusion. Furthermore, in Experiment 3, whereas we found no relationship between visual context effects in the Ebbinghaus illusion and years in the urban environment (which might be considered a proxy for exposure to visual clutter), we did find a relationship between the illusion and highest level of school attainment, which might reasonably be considered a proxy for engagement with a school environment, including pictures and printed material.

Relationships between cross-cultural differences in perceptual bias and selective attention

As argued above, our data speak 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). However, we might ask how this squares with the now significant body of evidence that the Himba are particularly good at focussing their attention on task-relevant aspects of visual patterns (De Fockert et al., 2011; Linnell et al., 2013). Caparos and colleagues (2013) shed light on this matter by showing that the Himba's advantage in selective attention works at both local and global levels of analysis; they are less distracted by task-irrelevant global information than Westerners, but they are also less distracted by task-irrelevant local features. As such, differences in selective attention do not easily explain a perceptual bias to local features. Thus, Caparos et al.'s (2013) findings like ours suggest that selective attention is rather a poor account of cross-cultural differences in the extent to which global visual context is processed, strengthening the perceptual bias account. It will be interesting to determine next whether there is a developmental relationship between perceptual bias and selective attention. The advantage which traditional Himba adults show over UK participants in selective attention to both global and local information may be due to their lesser perceptual bias to context in early life.

Implications for the development of cross-cultural differences in visual context processing more generally

Do the developmental and cross-cultural effects of size contrast observed here extend to 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. The local bias which traditional Himba adults show in Navon (hierarchical figures) matching tasks (Caparos et al., 2012; Davidoff et al., 2008) is consistent with this. Thus, one consideration is whether the development of cross-cultural differences in hierarchical figure processing mirrors the emergence of cross-cultural differences in the Ebbinghaus illusion. Studies of the development of hierarchical figure processing have tended to demonstrate a developmental increase in global matching of shapes (Elkind, Koegler & Go, 1964; Dukette & Stiles, 1996), which coincides with the emergence of context effects in the Ebbinghaus illusion (Doherty et al., 2010). Elkind et al. argued that the emergence of Piagetian concrete logical operations was the driving factor in the development of global shape but it is equally likely that developments in perceptual bias towards visual context might be at play. However, more recent studies have complicated the 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 in a selective attention task, attentional filtering comes to play a larger role, yielding a more protracted development. One possibility is that differences in perceptual bias towards context in early life (like those between UK and Himba observers) lead to later differences in global and local precedence in speeded selective attention.

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 concerning the development of visual context illusions beyond the Ebbinghaus illusion is somewhat conflicted. Some illusions, like the Ebbinghaus, are reported to increase in strength with age (Ponzo illusion: Leibowitz & Judisch, 1967), but decreases or no development are seen in others (Müller-Lyer and Horizontal-vertical Illusions: Brosvic, Dihoff & Fama, 2002; Pinter & Anderson, 1916; Rivers, 1905). Detailed analysis of the perceptual and attentional processes involved in these illusions may help here. For instance, developing attentional filtering might explain the reduction in the Müller-Lyer illusion with age.

Summary

We have reported the findings of three experiments which combined the strengths of cross-cultural and developmental methods to shed light on the emergence of cross-cultural differences in visual size context effects in childhood and adolescence. Urban vs. rural environmental contexts give rise to different ways of processing visual context; context plays a greater role in visual processing in individuals who have grown up in urban environments (see also Caparos et al., 2012). 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 perception. Our findings show that cross-cultural variations in visual context effects are fully developed by 9-10 years of age, and indicate that the urban environment gives rise to a perceptual bias to process context. We propose that differences in perceptual bias to process visual context arise from the differing degrees to which children engage with pictorial and printed materials in formal schooling 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

Figure 1: Examples of stimuli used in the Ebbinghaus illusion task. Participants were asked to say which of the two central (target) circles were larger. The target circles were coloured orange and the surrounding circles (inducers) were grey. In each of the three conditions shown here: (A) No context, (B) Misleading context, and (C) Helpful context, one of the target circles is 6% larger than the other. In (A), the circle on the right is the larger. In (B) the circle on the right is also the larger, but due to the misleading context Western (UK) adult participants typically say that the circle on the left is the larger. In (C), the circle on the left is the larger. The helpful context provided in (C) enhances correct identification of the larger target in UK adults.

Figure 2: 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 = 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 were expected (in Western adults) to give rise to an Ebbinghaus illusion whereby the accuracy of the size discrimination was reduced, particularly at smaller diameter differences. In the "helpful" condition (tested at a 2% diameter difference only), an Ebbinghaus illusion leads to better performance. Panel D reports performance across all size difference conditions. Error bars represent the standard error of the mean. Lower

brackets indicate the uncorrected *p* values associated with tests of the illusion (* = $p < .05$, ** = $p < .01$, *** = $p < .001$; see Table 3). The higher brackets indicate uncorrected *p* values associated with tests of differences in the illusion between cultures. No groups showed a significant illusion apart from the 9- to 10-year-old UK children.

Figure 3: 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 = 50%). Panels A-D show performance in each of the diameter difference conditions in separate graphs for each age group. Panel E reports performance across all diameter difference conditions. Error bars represent the standard error of the mean. Lower brackets indicate the uncorrected *p* values associated with tests of the illusion (* = $p < .05$, ** = $p < .01$, *** = $p < .001$; see Table 3). The higher brackets indicate uncorrected *p* values associated with tests of differences in the illusion between cultures. After correction, all groups demonstrated a significant illusion, except the 13- to 14-year-old traditional Himba children, who demonstrated a trend towards illusion.

Figure 4: Experiment 3: Size discrimination accuracy in urban Namibian participants 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 = 50%). Panels A-G show performance in each of the diameter difference conditions in separate graphs for each age group. Panel H reports performance across all diameter difference conditions. Error bars represent the standard error of the mean. Brackets indicate the uncorrected *p* values associated with tests of the illusion (** = $p < .01$, *** = $p < .001$; see Table 3). After correction, all age groups demonstrated a significant illusion.

Figure 5: A comparison of the Ebbinghaus illusion across all experiments (1-3), including TH, UK, and UN participants, spanning age groups from 3 years to adulthood. The percentage illusion score is calculated by subtracting participants' accuracy in the context condition from their accuracy in the control condition. Error bars represent the standard error of the mean.

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* = .97)	3yo (1), 4yo (6), 5yo (5), 6yo (7)
7- to 8-year-olds	13	4m, 9f	7.31 (*SD* = .48)	7yo (9), 8yo (4)
9- to 10-year-olds	15	8m, 7f	9.80 (*SD* = .41)	9yo (3), 10-yo (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* = .97)	3yo (1), 4yo (6), 5yo (5), 6yo (7)
7- to 8-year-olds	13	4m, 9f	7.31 (*SD* = .48)	7yo (9), 8yo (4)
9- to 10-year-olds	15	8m, 7f	9.80 (*SD* = .41)	9yo (3), 10yo (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).

		Experiment								
		Exp. 1			**Exp. 2**			**Exp. 3 / All Exps.**		
Measure	*ANOVA term*	*F* (d.f.)	*p*	η_p^2	*F* (d.f.)	*p*	η_p^2	*F* (d.f.)	*p*	η_p^2
% accuracy	Condition	44.3 (1, 88)	< .001	.335	418.5 (1, 144)	< .001	.682	209.1 (1, 130)	< .001	.617
	Culture	8.6 (1, 88)	.004	.089	89.9 (1, 144)	< .001	.384			
	Age group	4.9 (2, 88)	.010	.100	1.6 (3, 144)	n.s.	.032	.6 (6, 130)	n.s.	.025
	Condition x Culture	8.4 (1, 88)	.005	.087	132.9 (1, 144)	<.001	.480			
	Condition x Age group	7.6 (2, 88)	.001	.147	.5 (3, 144)	n.s.	.010	2.1 (6, 130)	.057	.089
	Culture x Age group	9.9 (2, 88)	< .001	.184	.8 (3, 144)	n.s.	.015			
	Condition x Culture x Age group	5.9 (2, 88)	.004	.118	.4 (3, 144)	n.s.	.009			
% illusion	Culture							63.8 (2, 362)	< .001	.261
	Age group							16.6 (6, 362)	< .001	.216
	Culture x Age group							5.4 (12, 362)	< .001	.151

Table 2. ANOVAs of percentage accuracy scores and percentage illusion scores across Experiments 1-3, reporting the main effects of, and interactions between Condition (Context / No context), Culture (levels vary across experiments), and Age group (levels vary across experiments).

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

Table 3. The results of One-sample t-tests comparing the illusion score within each age group and each culture against baseline (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 α level (see main text for the details of what the α 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* = .49)	11yo (6), 12yo (12)
13- to 14-year-olds	17	5m, 12f	13.41 (*SD* = .51)	13yo (10), 14yo (7)
15- to 17-year-olds	10	8m, 2f	16.30 (*SD* = .95)	15yo (3), 16yo (1), 17yo (6)
Adults	34	14m, 20f	20.62 (*SD* = 2.78)	18 to 26yo (34)
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* = .49)	11yo (6), 12yo (12)
13- to 14-year-olds	17	5m, 12f	13.41 (*SD* = .51)	13yo (10), 14yo (7)
15- to 17-year-olds	10	6m, 4f	16.30 (*SD* = .95)	15 yo (3), 16yo (1), 17yo (6)
Adults	28	13m, 15f	19.36 (*SD* = 1.66)	18 to 25yo

Table 4. 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*	*Mean school attainment***	*Age group comprises*
3- to 6-year-olds	18	8m, 10f	5.56 (*SD* = .62)	5.56 (*SD* = .62)	.0 (*SD* = .0)	4yo (1), 5yo (6), 6yo (11)
7- to 8-year-olds	20	11m, 9f	7.46 (*SD* = .51)	7.45 (*SD* = .51)	1.45 (*SD* = .69)	7yo (11), 8yo (9)
9- to 10-year-olds	20	9m, 11f	9.65 (*SD* = .49)	7.55 (*SD* = 3.61)	4.05 (*SD* = 1.36)	9yo (7), 10yo (13)
11- to 12-year-olds	21	12m, 9f	11.71 (*SD* = .46)	8.95 (*SD* = 3.76)	5.95 (*SD* = .59)	11yo (6), 12yo (15)
13- to 14-year-olds	17	6m, 11f	13.41 (*SD* = .51)	9.94 (*SD* = 5.09)	6.29 (*SD* = .77)	13yo (10), 14yo (7)
15- to 17-year-olds	19	8m, 11f	15.74 (*SD* = .73)	9.16 (*SD* = 5.79)	7.16 (*SD* = .76)	15yo (8), 16yo (8), 17yo (3)
Adults	22	9m, 13f	21.86 (*SD* = 3.00)	10.18 (*SD* = 8.48)	9.27 (*SD* = 3.45)	18yo to 28yo (22)

Table 5. Experiment 3 participant characteristics. yo = -year-olds. *We only had access to the ages of the urban Namibian participants in years. **School attainment ranged from 0 through grades 1-12.

Figure 1

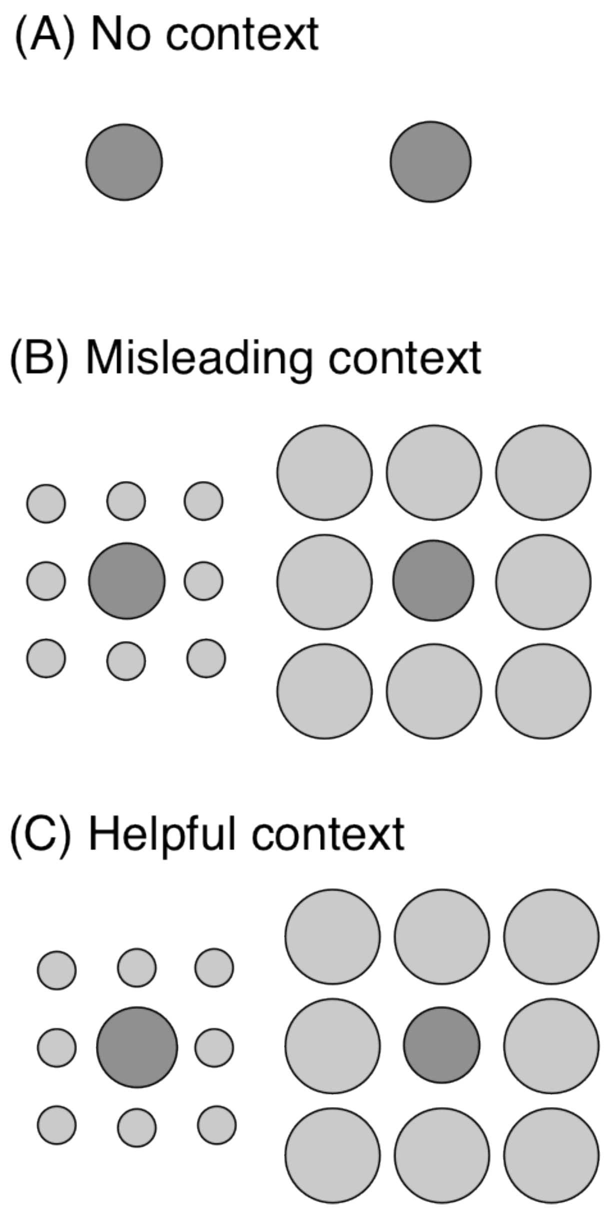


Figure 2

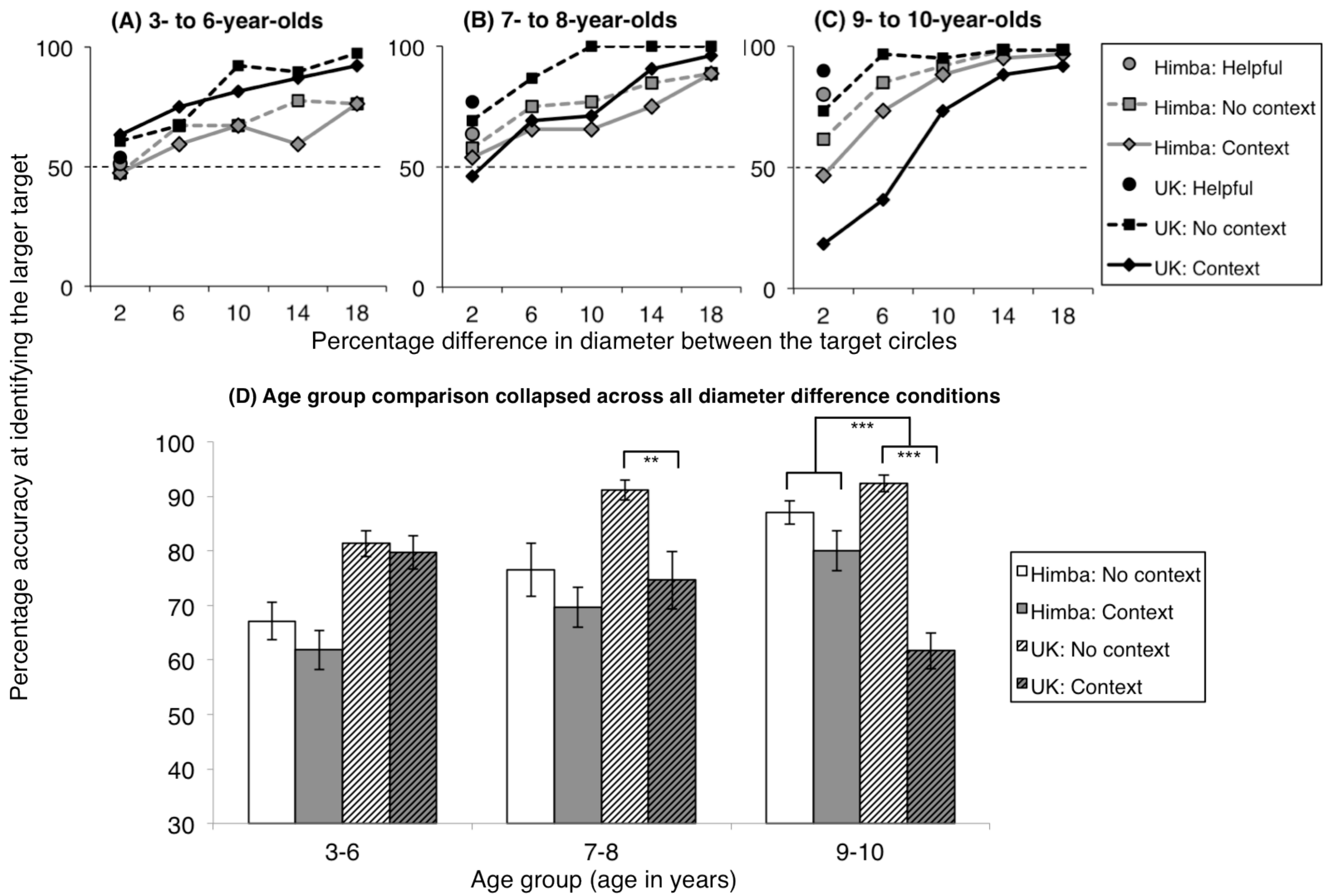
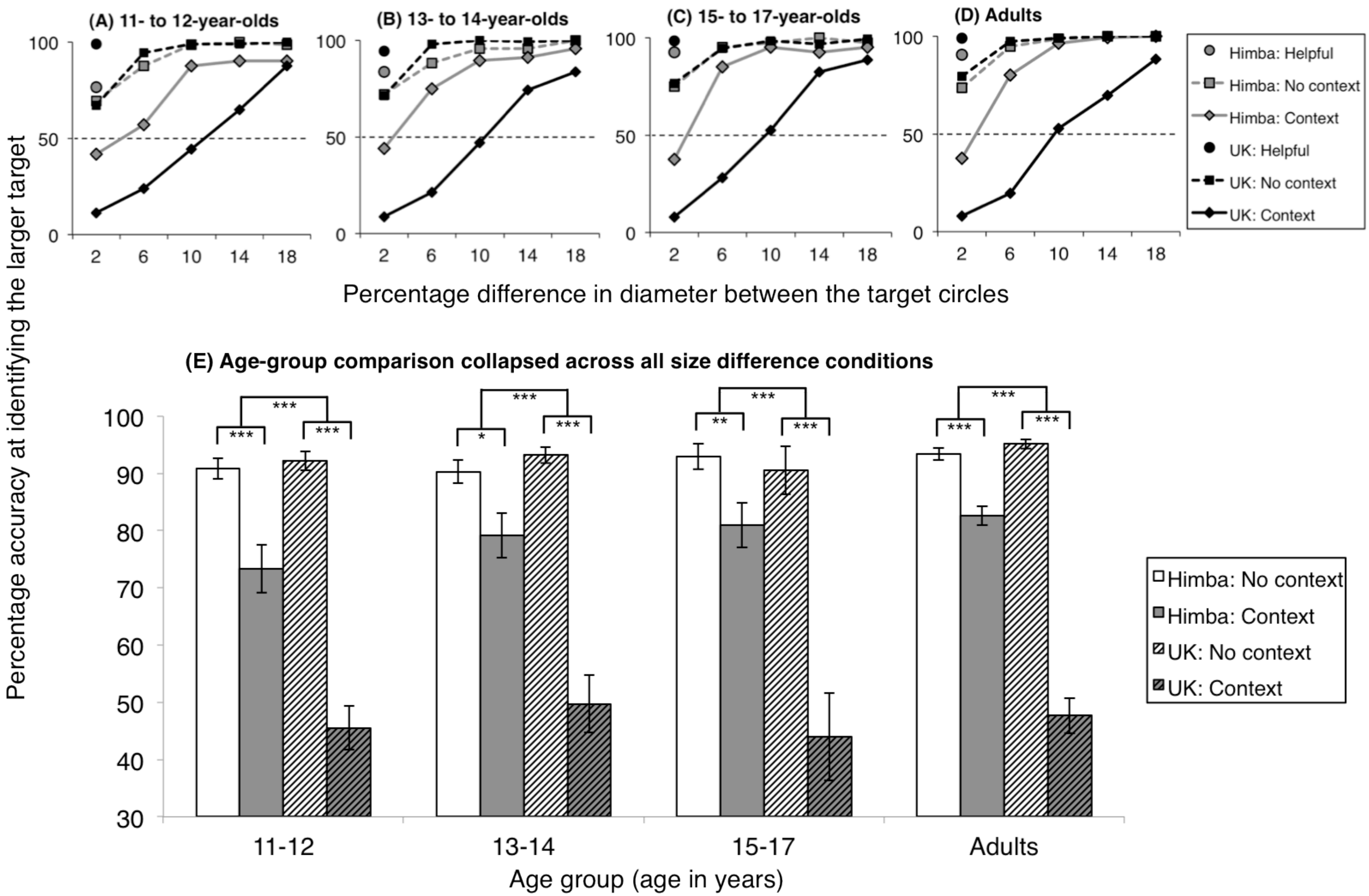

(A) 3- to 6-year-olds
(B) 7- to 8-year-olds
(C) 9- to 10-year-olds
100
50
0
2
6
10
14
18
Himba: Helpful
Himba: No context
Himba: Context
UK: Helpful
UK: No context
UK: Context
Percentage accuracy at identifying the larger target
Percentage difference in diameter between the target circles
(D) Age group comparison collapsed across all diameter difference conditions
100
90
80
70
60
50
40
30
**
***
***
Himba: No context
Himba: Context
UK: No context
UK: Context
3-6
7-8
9-10
Age group (age in years)

Figure 3



(A) 11- to 12-year-olds
(B) 13- to 14-year-olds
(C) 15- to 17-year-olds
(D) Adults
Himba: Helpful
Himba: No context
Himba: Context
UK: Helpful
UK: No context
UK: Context
Percentage difference in diameter between the target circles
Percentage accuracy at identifying the larger target
(E) Age-group comparison collapsed across all size difference conditions
Himba: No context
Himba: Context
UK: No context
UK: Context
11-12
13-14
15-17
Adults
Age group (age in years)

Figure 4

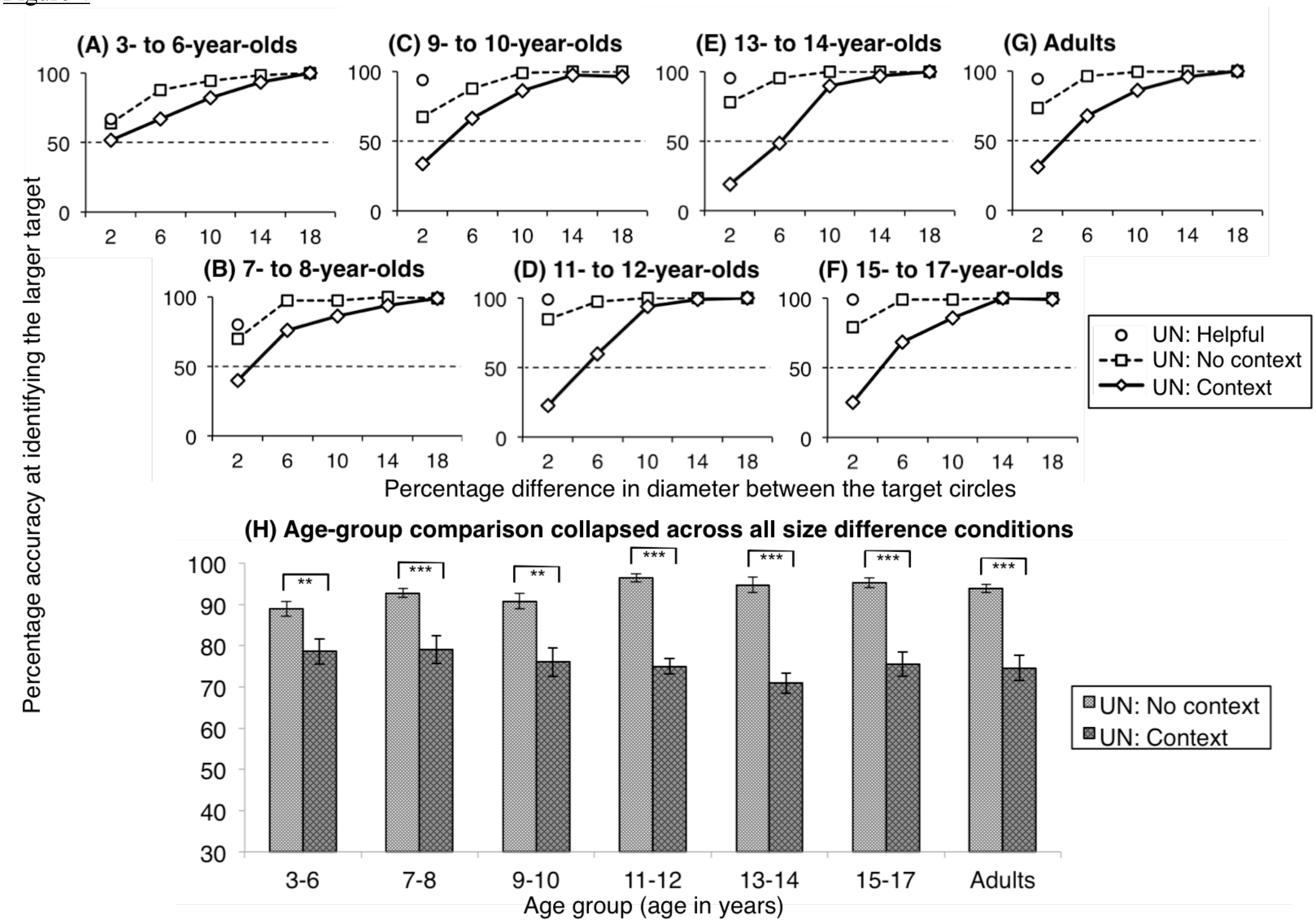
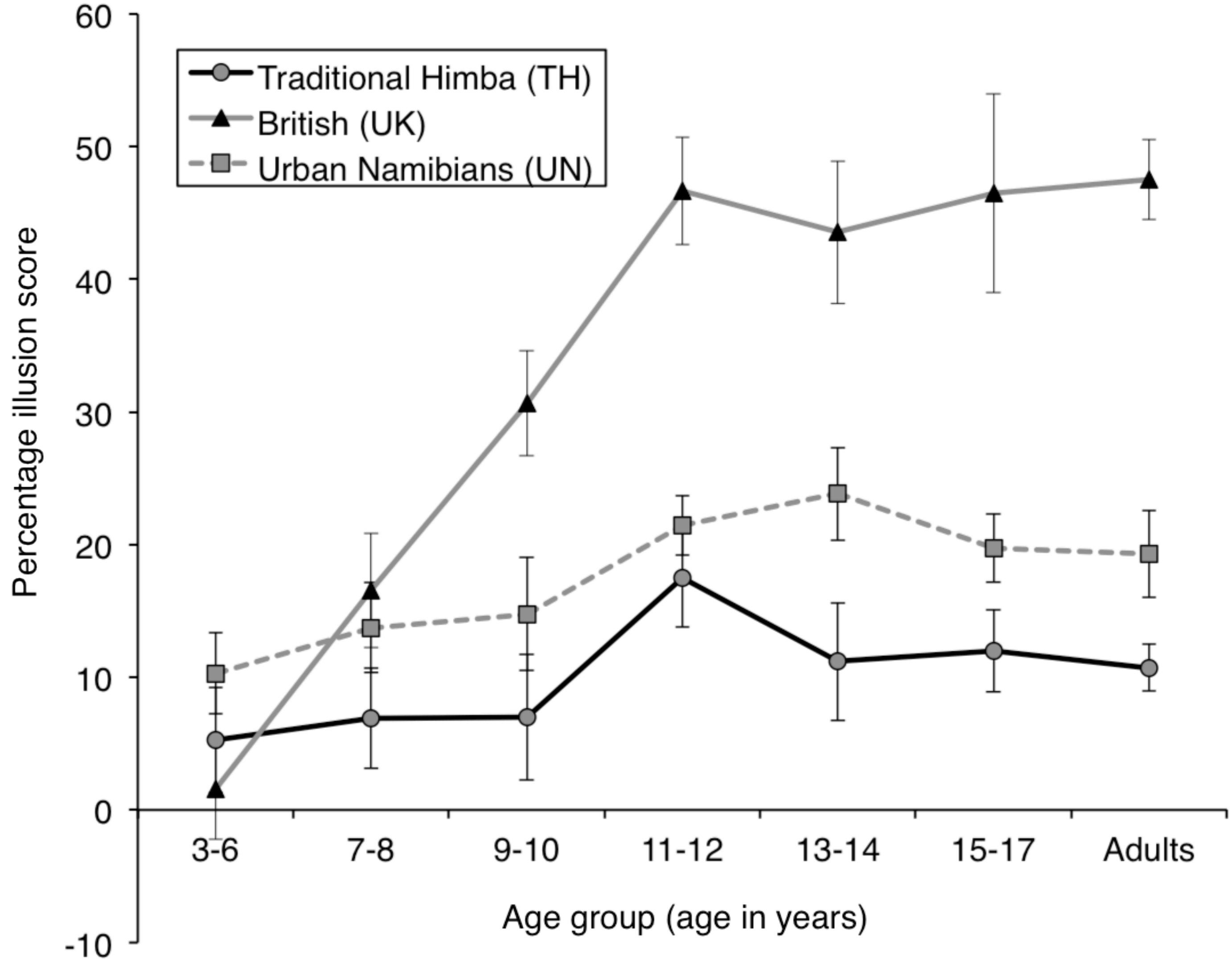

(A) 3- to 6-year-olds
(B) 7- to 8-year-olds
(C) 9- to 10-year-olds
(D) 11- to 12-year-olds
(E) 13- to 14-year-olds
(F) 15- to 17-year-olds
(G) Adults
UN: Helpful
UN: No context
UN: Context
Percentage accuracy at identifying the larger target
Percentage difference in diameter between the target circles
(H) Age-group comparison collapsed across all size difference conditions
UN: No context
UN: Context
3-6
7-8
9-10
11-12
13-14
15-17
Adults
Age group (age in years)

Figure 5



Traditional Himba (TH)
British (UK)
Urban Namibians (UN)
Percentage illusion score
60
50
40
30
20
10
0
-10
3-6
7-8
9-10
11-12
13-14
15-17
Adults
Age group (age in years)