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Infants and toddlers show enlarged visual sensitivity to nonaccidental compared with metric shape changes

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Abstract. Some shape changes are more important for object perception than others. We used a habituation paradigm to measure visual sensitivity to a nonaccidental shape change—that is, the transformation of a trapezium into a triangle and vice versa—and a metric shape change—that is, changing the aspect ratio of the shapes. Our data show that an enhanced perceptual sensitivity to nonaccidental changes is already present in infancy and remains stable into toddlerhood. We have thus established an example of how early visual perception deviates from the null hypothesis of representing similarity as a function of physical overlap between shapes, and does so in agreement with more cognitive, categorical demands.

Keywords: development, shape perception, habituation, looking time, preference, shape transformations

1 Introduction

We can adequately estimate the dimensions of an object when we want to grasp it, want to fit it in a box, or simply need to estimate its size. But, when it comes to recognizing or categorizing an object, size does not matter that much any more (eg Biederman and Cooper 1992; Uttl et al 2007). It has been found not only that size itself is of secondary importance, but also that the same is true for other metric properties like the broadness of an object, its height, or, when it applies, the amount of curvature or tapering. These metric shape properties are often of little use during object recognition, since they vary with angle of viewpoint. Biederman and Bar (1999) presented subject images of simple two-part objects varying in viewpoint and showed that it can be next to impossible to differentiate between a metric change and a change in viewpoint. Meanwhile, the same subjects could easily achieve viewpoint-independent object recognition when the objects differed in the number or nature of their features (eg the number of corners or sides, or whether the sides are curved versus straight, symmetrical versus asymmetrical); the aspects of an object that remain invariant under rotation are termed nonaccidental properties (NAPs) in the context of Biederman's recognition-by-components theory (Biederman 1987). Abecassis et al (2001) used similar objects and object changes (ie the presence versus absence of curvature or parallelism compared with gradual changes in curvature and degree of parallelism) to show that also categorization, in particular word naming, relies more on abrupt, nonaccidental changes than on metric changes, at least in adults (Abecassis et al 2001).

Op de Beeck et al (2008) used functional magnetic resonance imaging to find a higher impact of feature switches (ie curves versus corners versus peaks) compared with aspect-ratio changes on the pattern of activity in human lateral occipital complex (a cortical brain region supposedly involved in object recognition and possibly categorization), but not in the retinotopic brain regions 'lower' in the ventral visual stream (Op de Beeck et al 2008). This

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illustrates how a higher sensitivity to feature switches compared with metric changes can be linked to object recognition and maybe categorization also on a neurophysiological level.

It has been shown that the difference in importance of some shape changes over others during object recognition and categorization can lead to a difference in discriminability for these shape changes in adults (Biederman et al 2009). In this study we test whether such a difference in perceptual sensitivity can be found in infants and toddlers. If so, we will also assess whether it is a stable aspect of the visual system from early on or whether it gradually develops under pressure of an environment in which object recognition and (basic-level) categorization often depend on viewpoint-invariant properties. Therefore, we tested infants and toddlers of a broad age range—that is, between 3 months (the youngest infant) and 2 years and 7 months (the oldest toddler). Even the youngest subjects should already have had the opportunity and the possibility to notice that some aspects of objects, more than others, remain unaffected under changes in viewpoint (see eg Ruff 1980) for the general importancy of detecting invariants in perceptual development). Indeed, even newborns can, given some training with different views, achieve, for example, slant-invariant recognition of squares and trapezia (Slater and Morison 1985), or orientation-invariant recognition of corners [Cohen and Younger 1984 (in 6 week olds); Slater et al 1991]. Newborns also are sensitive to the presence of curvature in different shapes, which is an important invariant property of different objects (Fantz and Miranda 1975). After training, infants as young as 3 or 4 months are able to achieve viewpoint-independent object recognition (Kraebel and Gerhardstein 2006; Kraebel et al 2007), to estimate the size of shapes irrespective of distance (Granrud 2006; Slater et al 1990), and to learn to categorize geometrical patterns [eg squares, triangles (Bomba and Siqueland 1983)] and everyday categories [eg dogs, cats (based on perceptual similarity); Mareschal et al 2002; Quinn 2005]. They presumably do this by noticing the constancies within a changing display of exemplars.

Thus, the basic conditions for the development of a differential sensitivity to different kinds of shape changes triggered by object recognition and/or categorization are satisfied. However, the youngest group should not yet be influenced by the different names of the shapes.

We measured the sensitivity of infants and toddlers for different kinds of shape changes using a visual paired-comparison procedure after habituation. This procedure indexes the relative interest in the members of a pair of visual stimuli that differ in the amount to which they resemble a habituation stimulus. The participants will then have the tendency to fixate the most novel stimulus significantly longer. The main difference between this experiment and the above-mentioned categorization experiments is that our subjects were habituated to a single view of a single shape, rather than to either an entire category or different views of the same object or shape. Thus, we do not directly measure categorization, but only sensitivity for differences between shapes. This means that a higher sensitivity for nonaccidental shape changes in our study cannot be directly predicted from the results of categorization studies. Infants may be capable of habituating to those shape properties that remain constant within a changing display of category exemplars, but that does not necessitate a particularly higher sensitivity for a certain kind of shape properties during habituation to an isolated stimulus.

Our stimuli are shown in figure 1. One test stimulus differs in aspect ratio, the other one contains a feature switch (ie a corner becomes a side or vice versa; see figure 1). Both test stimuli are calibrated to be physically equally distant from the habituation stimulus (see method section). This is important, as the visual sensitivity to shape differences will be influenced by the physical overlap between the images of the shapes, certainly in the case of metric changes, and this dependence of visual sensitivity on the amount of overlap is often used as a null hypothesis against which more specific perceptual hypotheses can be tested (eg Cutzu and Edelman 1998; Kayaert et al 2003, 2005; Vuilleumier et al 2002). It should be noted that we used only this measure of physical calibration, and not the output of models that are designed to emulate visual processing up to object recognition (eg the HMAX model described by Riesenhuber and Poggio 1999) or up to certain brain regions (eg V1, in the wavelet-based model of Lades et al 1993). In principle, it is possible that these or other models could explain our results.(1)

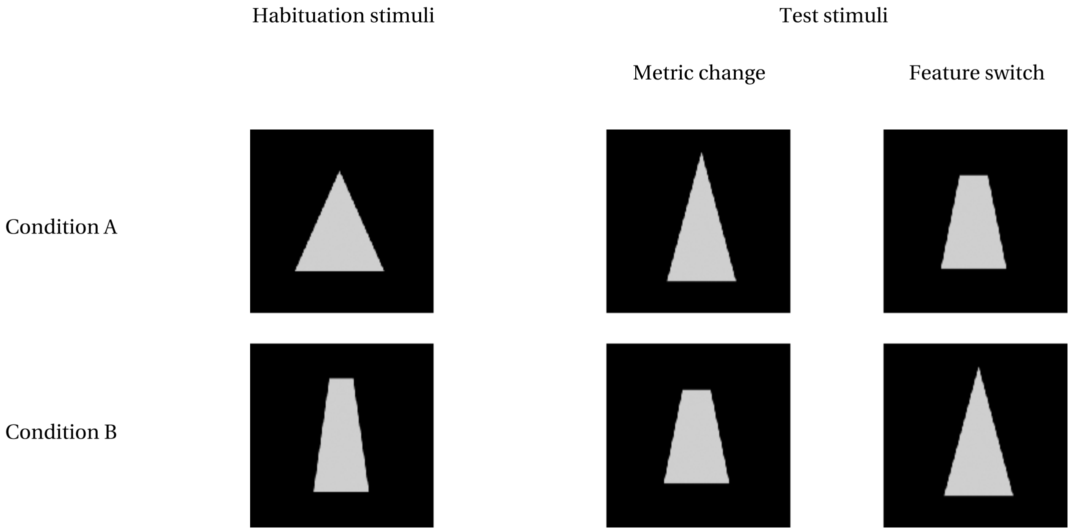

Figure 1. The stimuli used in the different conditions. The test stimuli are presented side by side (see method section).

We use two-dimensional (2D) silhouette stimuli during our experiments. It should be noticed that these might be perceived as different from three-dimensional (3D) stimuli, as infants are sensitive to the 3D aspects of 3D objects; by six months they can form a 3D percept of a shape based on only a limited view (eg Quinn and Liben 2008; Soska and Johnson 2008) or transfer the 3D aspects of a shape across different kinds of depth cues (Tsuruhara et al 2009). Also, five month old infants perceive the differences between a real 3D object, a picture, and a line drawing of this object. They are, however, sensitive to the correspondences as well; they can recognize a picture after having seen the real object, and a line drawing after having seen a picture (eg DeLoache et al 1979). We cannot exclude that the development of a differential sensitivity for NAPs and metric changes is different for different kinds of shapes, but at present it is more parsimonious to assume a parallel development for different kinds of shapes.

The experiment is subdivided in two parts. In condition A the habituation stimulus is a triangle, and the NAP change turns it into a trapezium, while the metric change makes it thinner and longer. In condition B the habituation stimulus is a trapezium, and the feature switch turns it into a triangle, while the metric change makes it broader and shorter. The test stimuli are identical in both parts of the experiment, but we predict a different outcome, based on the different habituation stimulus. In each case we hypothesize that, since the infants will be more interested in the shape change that is most salient, they should look more

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(1) However, it is highly unlikely that the model of Lades et al (1993) could explain our results. In the study of Kayaert et al (2003) we used this model to calibrate the shape changes of the stimuli but retained only the physical calibration since the results of both calibrations for this kind of shape change in those stimuli were highly correlated. Our present stimuli and shape changes are very similar to the stimuli in Kayaert et al (2003).

at the NAP change. Thus, if the predictions are confirmed in both parts of the experiment, then this effect cannot be attributed to an a priori preference for one of the test stimuli.

2 Methods

2.1 Participants

Participants were recruited through daycare centers in the area of Leuven, Belgium. The majority were from Caucasian, middle-class families. Informed consent from all parents was obtained before beginning the session. The final sample consisted of fifty-one infants and toddlers (mean age = 492 days, SD = 228): twenty-nine males and twenty-two females. The youngest subject was 110 days; the oldest one was 964 days. Additional subjects were observed but excluded from the analyses due to fussiness (five subjects), experimenter error (one subject), or consistent inattention towards the screen (twenty-four subjects: exclusion before the start of the actual experiment if subjects did not want to sit still and look at the attention-getter).

2.2 Apparatus

Subjects were tested individually and seated on an assistant's lap at 57 cm from the experimental set-up in a darkened room. The assistant was naive to the purpose and conditions of the experiment, but was familiar with the stimuli, and could see the stimuli during the experiment. The assistant would not have shown overt dishabituation herself, due to her extensive familiarity with the test stimuli and the general difficulty to generate an overt dishabituation response in adults with simple shapes.(2)

The stimuli were projected through a projection screen spanned behind a black wooden board with circular holes, a small one (10°) in the middle and two large ones (20°) flanking the small one. The distance between the large circles was 45°, measured from the center of the circles. The projector (type BenQ MP 720p) was controlled by E-prime 1.1 software on a Dell Latitude laptop in interaction with the hidden experimenter, who judged whether the subject was still attending the stimuli, using real-time video images from the subject recorded through a webcam (Logitech Quickcam 9.0.2, sampling at 15.15 frames s^{-1}) and displayed on another Dell Latitude laptop which also recorded the images for off-line analyses.

2.3 Stimuli

The stimuli are depicted in figure 1. The height of the largest shape was 13°; the width of the broadest one was 6.5°. We calibrated the physical distance between the images by computing the Euclidean distance between their pixel gray levels. We thus made sure that the physical overlap between the metric change and the habituation stimulus was at least as big as the physical overlap between the NAP change and the habituation stimulus. We computed the Euclidean distance as follows: $\{[\sum n_i(G_{i1}-G_{i2})2]/n\}/2$, with G_1 and G_2 the gray levels for picture 1 and 2 and n the number of pixels. We made sure that the NAP change was never larger than the metric change, either when doing the calibration with the shapes centered upon each other, or when doing it using position correction—that is, measuring the difference between the shapes for all possible relative positions and then picking the lowest measurement. Moreover, the stimuli and stimulus differences were chosen so that the relative magnitudes of the physical distances between both test stimuli and the habituation stimulus were not affected by low-pass filtering up to 1 cycle per degree. This excluded the possibility that an age-related shift in dependency from lower towards higher spatial frequencies, if present (see eg Aslin and Smith 1988), would affect the data. The differences between the habituation stimulus and both test stimuli were still very well visible after this

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(2) We tried to measure habituation in adults using the same paradigm we used with the infants, but we could not measure any dishabituation response.

low-pass filtering, indicating that they should be readily discriminable even for very young infants (Aslin and Smith 1988).

2.4 Procedure

Subjects were randomly assigned to either the triangle or the trapezium as a habituation stimulus. They were given either no instructions, or a general instruction to look at the test apparatus. Each trial began with the presentation of an attention-getter (an animated cartoon figure) on the middle screen. Once the experimenter determined that the infant had fixated the screen, the attention-getter was replaced with the experimental stimulus and timing of each trial began. A trial ended when the infant looked away for 2 s. The habituation display consisted of the habituation stimulus (see figure 1), presented on both screens to the left and the right of the infant. This display was presented until the infant met a habituation criterion: the looking time during two consecutive trials should add up to less than half the total looking time during the first two trials. Upon meeting the criterion, the infant was shown two consecutive test displays starting on the next trial. The displays contained one of the test stimuli on the screen to the left of the infant, and one of the stimuli on the screen to the right of the infant. The position of the test stimuli on the first test trial was reversed on the second test trial, and was counterbalanced between infants. The test displays were each shown for 7 s. The looking times to the test stimuli were coded off-line on a frame-by-frame basis (although glances of less than 500 ms were discarded). To measure the reliability of the experimenter's judgments, an independent second observer coded looking times for 50% of the sample. The Pearson correlation between the two judgments of the looking times was 0.91, indicating strong agreement between both observers.

2.5 Analysis

The infant data were analyzed using t-tests for dependent samples and Z-tests for proportions. The age groups used in the analysis and in figure 2b were constructed by first ranking all participants according to age, and then dividing the sample in four groups of ten and one group (the oldest subjects) of eleven subjects, ensuring an almost equal number of participants in each group. The minimum, average, and maximum age of the children in these groups were 110, 194, 234; 291, 319, 356; 407, 473, 559; 598, 651, 689; 693, 792, 964, respectively (in days). The effect of age was analyzed using an ANOVA with age group and nature of the shape change as independent factors. For the first-look analysis the criterion for a look was 1 s.

2.6 Adult psychophysics

Apart from the physical calibration, we did a psychophysical calibration, establishing in a pilot study using a delayed matching-to-sample task that adults are more sensitive to the NAP changes compared with the metric changes in this stimulus set. The subjects were eleven young adults (average age = 27). The stimuli were shown for 180 ms, with an interstimulus interval of one second. The 'different' trials contained of a habituation stimulus (from either condition A or condition B) and one of its test stimuli that could differ from the habituation stimulus through either a metric change or a NAP change. Half of the trials were 'same' trials, containing a repetition of one of the stimuli. The trials were shown in random order.

The adult data were analyzed using repeated measures ANOVAs on the logarithms of the reaction times and on the d' (subtracting the Z-score of the false alarms from the Z-score of the hits, which is a standard procedure) (see eg Swets et al 1978). Subjects responded significantly more accurately to the comparisons involving the NAP change ($F(1,10) = 25.92$, $p < 0.0005$), performing at, on average, 95.5% correct ($d' = 3.27$) for pairs containing a NAP change versus 86% correct ($d' = 2.66$) for pairs containing the metric change. They also responded more accurately to the comparisons involving the habituation stimulus from condition A compared with condition B ($F(1,10) = 6.37$, $p < 0.05$) but there was no significant interaction between condition and kind of shape change. Subjects responded significantly faster to the comparisons involving a NAP change than to the comparisons involving a metric change (ie 602 ms for the NAP change versus 683 ms for the metric change; $F(1,10) = 7.23$, $p < 0.05$). They responded significantly faster to pairs involving the habituation stimulus of condition A compared with condition B ($F(1,10) = 6.05$, $p < 0.05$) but there was again no significant interaction with the effect.

2.7 Control experiment using larger metric changes

In order to assess whether the magnitude of the metric change made a difference to the infants and toddlers in our study, we introduced a control experiment in which the metric change was increased to 150% of the original amount, thereby increasing the saliency of its change and, hence, its novelty in our habituation paradigm. The final sample of subjects, recruited in the same way as in the main study, consisted of eighteen infants and toddlers (mean age = 624 days, SD = 214): eleven males and seven females. The youngest subject was 320 days; the oldest one was 1036 days. Additional subjects were observed but excluded from the analyses due to fussiness (three subjects) or consistent inattention (nine subjects). This experiment was run in exactly the same way as the main study, yielding approximately equal amounts of habituation and dishabituation. The 150% increase in size of the metric change was also enough for the adults performing the delayed-matching-to-sample task to detect the metric change with equal ease as they detected the NAP change [ie detection accuracy became 95.5% ($d' = 3.26$) and the reaction times became on average 652 ms].

3 Results

The total habituation time was on average 51 s and was approximately equal for both habituation stimuli. The length of the last look towards the habituation display (ie 2 s) was significantly shorter than both the length of the first look towards the habituation display (ie 7 s; $t(51) = 9.47$; $p < 0.0001$) and the length of the first look towards the test display (ie 3 s; $t(51) = 3.14$; $p < 0.005$), indicating a significant habituation followed by a dishabituation towards the test display. There was no significant effect of age on amount of habituation.

On average, the infants and toddlers looked longer towards the test stimulus with a NAP change compared with the test stimulus that underwent a metric change. (Mean feat = 3.3 s, mean metric = 2.7 s; SD feat = 1.5 s, SD metric = 1.3 s; $t(51) = 2.33$; $p < 0.02$.)

There was no interaction between the effect and the use of either a triangle or a trapezium as habituation stimulus (figure 2a), nor was there an interaction between the effect and the age of the subjects (figure 2b; $F(4,46) = 0.41$, $p > 0.05$). The evolution through the age groups of the total looking time during the testing phase was not significant. Analyses on the level of the individual subjects did not yield any significant correlation between age and the effect either ($F(4,46) = 2.14$, $p < 0.1$).

A majority of the subjects (65%, $n = 51$, $p < 0.05$) looked more towards the test stimulus with a NAP change compared with the test stimulus that underwent a metric change, averaged over the test trials. This proportion did not differ significantly as a function of either habituation stimulus or age group. There was also no significant difference in average age between the subjects who showed a preference for the feature switch (mean age = 478, $n = 33$) and the subjects who showed a preference for the metric variation (mean age = 519, $n = 18$). The first look of the majority of the subjects (63%, $n = 51$, $p < 0.05$) was towards the shape with the NAP change. Again, there was no significant difference between age groups.

3.1 Control experiment using larger metric changes

As predicted, the subjects in this experiments looked more towards the metric change than in the main study, with looking times now equally divided between the NAP change and the

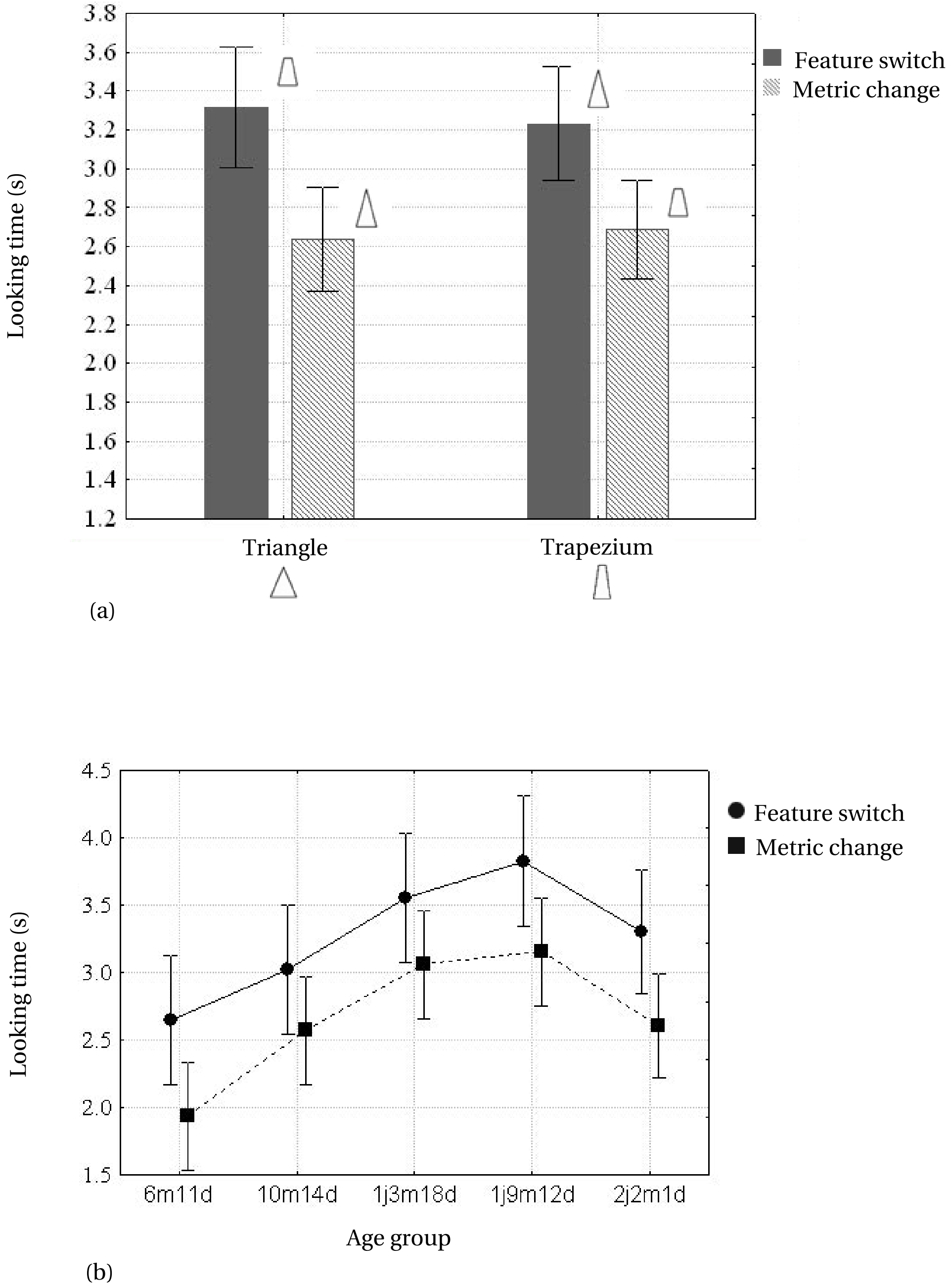

Figure 2. (a) The average looking times towards the test stimuli that differ from the habituation stimulus by a NAP change (full gray) or a metric change (striped), in seconds. (b) The average looking times towards the test stimuli that differ from the habituation stimulus by a NAP change (circles) or a metric change (squares) as a function of age group, in seconds. The whiskers denote standard errors, derived from an ANOVA with nature of the shape change and age group as independent variables.

metric change (ie average looking times being 3.18 s versus 3.03 s, respectively). Only ten out of the eighteen subjects preferred the NAP change in this control experiment. There was again no effect of age. Thus, the magnitude of the metric change does matter for the infants, as they look relatively more towards the metric change when it is larger.

4 Discussion

When it comes to object recognition and categorization, some shape changes are undoubtedly more important than others. We have shown that, at least in one pair of changes, this importance is reflected in higher perceptual sensitivity for a nonaccidental shape change on a lower-level visual task—that is, short-term recognition of shapes. The higher sensitivity is present from infancy, and remains stable into early toddlerhood. These results complement studies using adult subjects (Biederman et al 2009), and animal studies that also have found less sensitivity for metric changes, using similar shapes in (adult) pigeons (Lazareva et al 2008), and, on a neurophysiological level, in single macaque inferotemporal neurons (Kayaert et al 2003; Vogels et al 2001).

The result of our control experiment, in which the effect of a higher sensitivity for the NAP change is compensated for by pitting it against a physically much larger amount of metric change, shows that infants are sensitive to metric changes as well, in accordance with studies that measured the capability of infants to perceive differences in, for example, size (Brannon et al 2006; Granrud 2006; Slater et al 1990).

Huttenlocher et al (2002) have shown that infants and toddlers rely heavily on cues in the environment to assess the dimensions of shapes. Thus, it is important to point out that the stimuli were presented within circular holes carved in a black wooden board. These holes appeared gray, due to the light of the projector on the projection screen spanned behind the wooden board, and provided to the subjects a standard with which to compare the length and width of the stimuli.

We did not observe any interaction between the age of our infants/toddlers and their relative sensitivities to the metric change and the NAP change. It is unlikely that this lack of an interaction with age is due to the closure of a general developmental window for the acquisition of differential visual sensitivity, since different studies on a range of developmental windows situate them within or beyond our age range. Pascalis et al (2002) have shown that infants of between 6 and 9 months develop a differential sensitivity to monkey and human faces. The infant's proficiency in discriminating between monkey faces actually declines between 6 and 9 months, probably under the influence of an increasingly specialized human face representation. This age window falls within our age range. Also, in normal development low-level perceptual functions like spatial acuity and contrast sensitivity keep on improving until between 5 and 7 years of age, and are susceptible to damage through lack of visual input up until about age 12 (Lewis and Maurer 2005). Thus, either the larger sensitivity to NAP changes versus metric changes is an inherent property of the visual system right from birth, or it develops very rapidly, with this development coming to an early end (at least temporarily) before the age of 6 months. If the difference in sensitivity appears and then stabilizes due to developmental pressure, then it could be because, on the one hand, sensitivity to feature switches is promoted, especially for object recognition, while, on the other hand, sensitivity to metric changes is also needed, especially for object grasping. The visual system could support sensitivity to both shape changes in a relative amount that is a compromise between different needs. If so, this compromise could have been reached before 6 months.

Our lack of an ageing effect does by no means indicate that a relatively higher importance of feature switches cannot be further enhanced later in life. The evolution in perceptual categorization from relying on general similarity towards identity on a single dimension [starting in childhood and culminating in adolescence (Smith 1989)] seems to have a polarizing effect that could strongly amplify the importance of abrupt shape changes in categorization. Indeed, a NAP change is more important in assigning names to new objects for adults than it is for preschoolers (Abecassis et al 2001). Thus, what is called a 'NAP change' on the perceptual level, and turns out to be already more salient than a metric change in infants, becomes a 'categorical change' for adults. In summary, an enhanced perceptual sensitivity for the nonaccidental feature change that turns a triangle into a trapezium is already present in infancy, before language acquisition, and remains stable into toddlerhood. This study therefore brings us one step closer to defining what 'visual perceptual similarity' actually is, and how it may be tailored, from early on, to be used for tasks like object recognition and categorization.

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References

Abecassis M, Sera M D, Yonas A, Schwade J, 2001 "What's in a shape? Children represent shape variability differently than adults when naming objects" *Journal of Experimental Child Psychology* **78** 213–239 ◄

Aslin R N, Smith L B, 1988 "Perceptual development" *Annual Review of Psychology* **39** 435–473 doi:10.1146/annurev.ps.39.020188.002251 ◄

Biederman I, 1987 "Recognition-by-components: a theory of human image understanding" *Psychological Review* **94** 115–147 doi:10.1037/0033-295X.94.2.115 ◄

Biederman I, Bar M, 1999 "One shot-viewpoint invariance in matching novel objects" *Vision Research* **39** 2885–2899 doi:10.1016/S0042-6989(98)00309-5 ◄

Biederman I, Cooper E E, 1992 "Size invariance in visual object priming" *Journal of Experimental Psychology Human Perception & Performance* **18** 121–133 doi:10.1037/0096-1523.18.1.121 ◄

Biederman I, Yue X, Davidoff J, 2009 "Representation of shape in individuals from a culture with minimal exposure to regular, simple artifacts: Sensitivity to nonaccidental versus metric properties" *Psychological Science* **20** 1437–1442 doi:10.1111/j.1467-9280.2009.02465.x ◄

Brannon E M, Lutz D, Cordes S, 2006 "The development of area discrimination and its implications for number representation in infancy" *Developmental Science* **9** 59–64 doi:10.1111/j.1467-7687.2006.00530.x ◄

Bomba P C, Siqueland E R, 1983 "The nature and structure of infant form categories" *Journal of Experimental Child Psychology* **35** 294–328 doi:10.1016/0022-0965(83)90085-1 ◄

Cohen L B, Younger B A, 1984 "Infant perception of angular relations" *Infant Behavior and Development* **7** 37–47 doi:10.1016/S0163-6383(84)80021-1 ◄

Cutzu F, Edelman S, 1998 "Representation of object similarity in human vision: psychophysics and a computational model" *Vision Research* **38** 2229–2257 doi:10.1016/S0042-6989(97)00186-7 ◄

DeLoache J S, Strauss M S, Maynard J, 1979 "Picture perception in infancy" *Infant Behavior and Development* **2** 77–89 doi:10.1016/S0163-6383(79)80010-7 ◄

Fantz R L, Miranda S B, 1975 "Newborn infant attention to form of contour" *Child Development* **46** 224–228 doi:10.2307/1128853 ◄

Granrud C E, 2006 "Size constancy in infants: 4-month-olds' responses to physical versus retinal image size" *Journal of Experimental Psychology Human Perception & Performance* **32** 1398–1404 doi:10.1037/0096-1523.32.6.1398 ◄

Huttenlocher J, Duffy S, Levine S, 2002 "Infants and toddlers discriminate amount: are they measuring?" *Psychological Science* **13** 244–249 doi:10.1111/1467-9280.00445 ◄

Kayaert G, Biederman I, Vogels R, 2003 "Shape tuning in macaque inferior temporal cortex" *The Journal of Neuroscience* **23** 3017–3027 ◄

Kayaert G, Biederman I, Vogels R, 2005 "Representation of regular and irregular shapes in macaque inferotemporal cortex" *Cerebral Cortex* **15** 1308–1321 doi:10.1093/cercor/bhi014 ◄

Kraebel K S, Gerhardstein P C, 2006 "Three-month-old infants' object recogntion across changes in viewpoint using an operant learning procedure" *Infant Behavior and Development* **29** 11–23 doi:10.1016/j.infbeh.2005.10.002 ◄

Kraebel K S, West R N, Gerhardstein P, 2007 "The influence of training views on infants' long-term memory for simple 3D shapes" *Developmental Psychobiology* **49** 406–420 doi:10.1002/dev.20222 ◄

Lades M, Vorbruggen J C, Buhmann J, Lange J, Von der Malsburg C, Wurtz R P, Konen W, 1993 "Distortion invariant object recognition in the dynamic link architecture" *IEEE Transactions on Computers* **42** 300–311 doi:10.1109/12.210173 ◂

Lazareva O F, Wasserman E A, Biederman I, 2008 "Pigeons and humans are more sensitive to nonaccidental than to metric changes in visual objects" *Behavioural Processes* **77** 199–209 doi:10.1016/j.beproc.2007.11.009 ◂

Lewis T L, Maurer D, 2005 "Multiple sensitive periods in human visual development: evidence from visually deprived children" *Developmental Psychobiology* **46** 163–183 doi:10.1002/dev.20055 ◂

Mareschal D, Quinn P C, French R M, 2002 "Asymmetric interference in 3- to 4-month-olds' sequential category learning" *Cognitive Science* **26** 377–389 doi:10.1207/s15516709cog2603_8 ◂

Op de Beeck, Torfs K, Wagemans J, 2008 "Perceived shape similarity among unfamiliar objects and the organization of the human object vision pathway" *Journal of Neuroscience* **28** 10111–10123 doi:10.1523/JNEUROSCI.2511-08.2008 ◂

Pascalis O, de Haan M, Nelson C A, 2002 "Is face processing species-specific during the first year of life?" *Science* **296** 1321–1323 doi:10.1126/science.1070223 ◂

Quinn P C, 2005 "Young infants' categorization of humans versus nonhuman animals: Roles for knowledge access and perceptual process" in *Building Object Categories in Developmental Time* Eds L Gershkoff-Stowe, D H Rakison pp 107–130 (Mahwah, NJ: Lawrence Erlbaum Associates) ◂

Quinn P C, Liben L S, 2008 "A sex difference in mental rotation in young infants" *Psychological Science* **19** 1067–1070 doi:10.1111/j.1467-9280.2008.02201.x ◂

Riesenhuber M, Poggio T, 1999 "Hierarchical models of object recognition in cortex" *Nature Neuroscience* **2** 1019–1025 doi:10.1038/14819 ◂

Ruff H A, 1980 "The development of perception and recognition of objects" *Child Development* **51** 981–992 doi:10.2307/1129536 ◂

Slater A, Morison V, 1985 "Shape constancy and slant perception at birth" *Perception* **14** 337–344 doi:10.1068/p140337 ◂

Slater A, Mattock A, Brown E, 1990 "Size constancy at birth: Newborn infant's responses to retinal and real size" *Journal of Experimental Child Psychology* **49** 314–322 doi:10.1016/0022-0965(90)90061-C ◂

Slater A, Mattock A, Brown E, Bremner G J, 1991 "Form perception at birth: Cohen and Younger (1984) revisited" *Journal of Experimental Child Psychology* **51** 395–406 doi:10.1016/0022-0965(91)90084-6 ◂

Smith L B, 1989 "A model of perceptual classification in children and adults" *Psychological Review* **96** 125–144 doi:10.1037/0033-295X.96.1.125 ◂

Soska K C, Johnson S P, 2008 "Development of three-dimensional object completion in infancy" *Child Development* **79** 1230–1236 doi:10.1111/j.1467-8624.2008.01185.x ◂

Swets J A, Green D M, Getty D J, Swets J B, 1978 "Signal detection and identification at successive stages of observation" *Perception & Psychophysics* **23** 275–289 ◂

Tsuruhara A, Sawada T, Kanazawa S, Yamaguchi M K, Yonas A, 2009 "Infant's ability to form a common representation of an object's shape from different pictorial depth cues: a transfer-across-cues study" *Infant Behavior and Development* **32** 468–475 doi:10.1016/j.infbeh.2009.09.002 ◂

Uttl B, Graf P, Siegenthaler A L, 2007 "Influence of object size on baseline identification, priming, and explicit memory" *Scandinavian Journal of Psychology* **48** 281–288 doi:10.1111/j.1467-9450.2007.00571.x ◂

Vogels R, Biederman I, Bar M, Lorincz A, 2001 "Inferior temporal neurons show greater sensitivity to nonaccidental than to metric shape differences" *Journal of Cognitive Neuroscience* **13** 444–453 doi:10.1162/08989290152001871 ◂

Vuilleumier P, Henson R N, Driver J, Dolan R J, 2002 "Multiple levels of visual object constancy revealed by event-related fMRI of repetition priming" *Nature Neuroscience* **5** 491–499 doi:10.1038/nn839 ◂

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