Current Biology
Magazine

CellPress

Correspondence

Visual field asymmetries vary between children and adults

Marisa Carrasco[1,2,*], Mariel Roberts[1], Caroline Myers[1], and Lavanya Shukla[1,2]

Visual perception in human adults varies throughout the visual field, both across eccentricity — decreasing with distance from the center of gaze — and around isoeccentric locations — that is, with polar angle at a constant distance from the center of gaze. At isoeccentric locations, the same visual information yields better performance along the horizontal than vertical meridian (horizontal–vertical anisotropy, HVA) and along the lower than upper vertical meridian (vertical–meridian asymmetry, VMA). These perceptual polar angle asymmetries in adults have been well characterized. Poor perception at upper visual field locations would be particularly detrimental to children: in their perceptual world, given their height, many important events occur above eye level. Developmental aspects of visual perception have been well characterized[1], and some basic dimensions, such as contrast sensitivity, continue to develop through childhood[2], but there is no research on polar angle asymmetries before adulthood. Here, we investigated whether these asymmetries are present in children, and if so, whether they differ from those of adults. We found clear differences between children and adults in performance around the visual field: the HVA is less pronounced and the VMA is not present for children.

Polar angle asymmetries in adults are pervasive: they emerge for several visual dimensions (for example, contrast sensitivity and spatial resolution), across stimulus properties (size, orientation, spatial frequency, eccentricity, luminance, head rotation), when the target appears by itself or amidst distractors, and regardless of whether they are measured monocularly or binocularly[3–6]. These perceptual asymmetries have been quantitatively linked to optical, retinal and cortical factors in adults. Optical quality, cone density and midget retinal ganglion cell density vary across the retina but can only account for a small percentage of the perceptual asymmetries[7]. Cortical surface area in primary visual cortex accounts for a higher percentage of these asymmetries[8,9].

One idea based on the ecology of vision is that the upper and lower visual fields may be specialized for processing distant and near objects, respectively[10]. For adults, many tasks requiring manual manipulation and dexterity naturally occur in the lower portion of the visual field: their perceptual world is largely composed of events occurring at or below eye level. But this is not the case

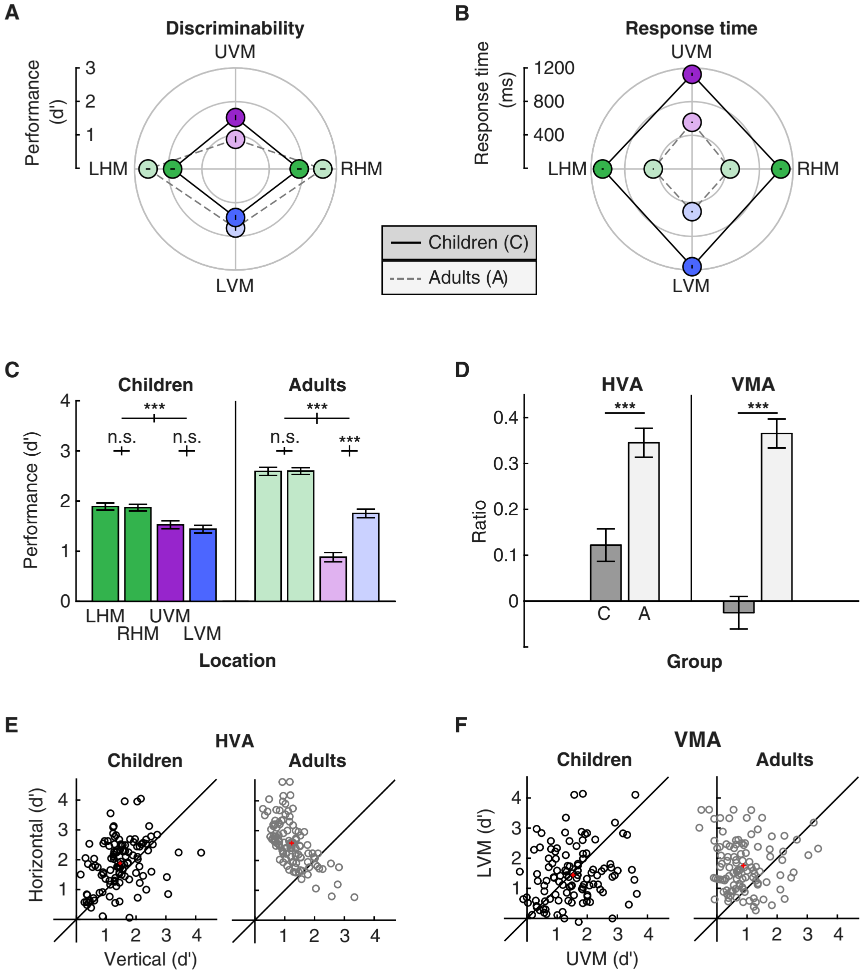

Figure 1. Polar angle asymmetries differ between children and adults.

(A) Adults' and children's polar angle asymmetries in visual performance (d'). The target was presented at the four isoeccentric cardinal locations. The center point represents chance performance and each of the four points represents discriminability (d') at those locations. For adults (dashed lines), performance shows the typical asymmetries: (1) horizontal–vertical anisotropy (HVA): better performance along the horizontal than vertical meridian; and (2) vertical–meridian asymmetry (VMA), better performance at the location directly below (LVM) than above (UVM) fixation. In contrast, for children (solid line), only the HVA is present. (B) Adults' and children's polar angle asymmetries in response time (ms). HVA is present in both groups. (C) Orientation discriminability (d') for each location. (D) Magnitudes of the HVA and VMA ratios for children and adults. HVA ratio indicates averaged performance between the horizontal and vertical meridian, and the VMA ratio between the lower and upper vertical meridian. Values ≥ 0 reveal better performance along the horizontal than vertical meridian (HVA) and along the lower than upper vertical meridian (VMA). (E) The HVA for each child (left) and adult (right). Data above the diagonal indicate better performance for the horizontal than the vertical meridian and vice versa. (F) The VMA for each child (left) and adult (right). Data above the diagonal indicate better performance for the lower than upper vertical meridian and vice versa. The center of the red cross in (E) and (F) indicates the mean value for each group. In all panels, error bars = ±1 within-subject SEM. *** = $p < 0.0001$.

for children: in their perceptual world, relevant visual information often appears above eye level. Given that the visual system of a child is still developing, we hypothesized that the VMA would vary between children and adults.

Children aged 5–12 years (n = 113, median age = 9.25, 52 females) and adults (n = 112, median age = 23.79, 76 females) performed an orientation discrimination task. A right-tilted or left-tilted stimulus appeared briefly (~100 ms) at one of four isoeccentric locations (left or right horizontal meridian or upper or lower vertical meridian) and participants indicated whether the stimulus was tilted right or left from vertical, via a key press and without time pressure[3,4] (Figure S1 in the Supplemental information). The orientation discriminability (d') was calculated for each location according to signal detection theory.

In our data, children had an HVA but no VMA, whereas consistent with previous findings[3–6,9] adults had both (Figure 1A). Further, these asymmetries were mimicked in response times (Figure 1B): They were faster for adults than children ($F_{(1,223)} = 89.3$, $p < 0.0001$, HVA; $F_{(1,223)} = 77.0$, $p < 0.0001$, VMA) and for horizontal than vertical locations ($F_{(1,223)} = 59.2$, $p < 0.0001$). Response times did not significantly differ between upper and lower vertical meridian locations, and location and age did not interact for horizontal *versus* vertical ($F > 1$). For upper *versus* lower, there was a significant interaction between location and age ($F_{(1,223)} = 6.9$, $p < 0.001$) as the LVM response time (0.52 sec) was faster than the UVM (0.55 sec) for adults ($F_{(1,111)} = 17.8$, $p < 0.001$), but did not differ for children ($F_{(1,112)} = 1.5$, $p > 0.1$). These results rule out speed-accuracy trade-offs in both children and adults.

The HVA was present in both groups but more pronounced for adults than children (Figure 1C). A two (age: children *versus* adults) x two (location: horizontal *versus* vertical) analysis of variance (ANOVA) revealed an interaction ($F_{(1,223)} = 44.8$, $p < 0.0001$). The superior performance on the horizontal than vertical meridian was more pronounced for adults ($F_{(1,111)} = 142.9$, $p < 0.0001$) than children ($F_{(1,112)} = 25.3$, $p < 0.0001$). We found neither a gender effect nor an interaction with age (Ps < 1). The HVA age difference is clearly demonstrated when comparing the HVA ratios (Horizontal – Vertical)/(Horizontal + Vertical; $F_{(1,223)} = 34.1$, $p < 0.0001$) (Figure 1D).

The VMA differed with age (Figure 1A): a two (age: children *versus* adults) x two (location: upper *versus* lower vertical meridian) ANOVA revealed an interaction ($F_{(1,223)} = 37.2$, $p < 0.0001$). The location effect was present for adults ($F_{(1,111)} = 60.8$, $p < 0.0001$) but not for children ($F_{(1,112)} < 1$) (Figure 1C). Adults had better performance on the lower than upper vertical meridian, whereas children showed no such asymmetry. We analysed differences between females and males and found neither a gender effect nor an interaction with age (Ps <1). The VMA age difference is clearly illustrated in the VMA ratios (Upper Vertical – Lower Vertical/(Upper Vertical + Lower Vertical; $F_{(1,223)} = 38.0$, $p < 0.0001$) (Figure 1D). We also analysed differences between the left and right locations of the horizontal meridian and found neither a location effect for children or adults, nor an interaction with age group ($F < 1$).

The pattern of results described for the HVA was consistent across individuals, more so for adults than children (Figure 1E). The pattern of results described for the VMA was consistent across adults, but not across children (Figure 1F). The lack of a group VMA resulted from intra-group variability, rather than consistent symmetrical performance between the lower and upper vertical meridian. The correlations between the extent of the VMA and the participants' height was not significant for either group ($p > 0.05$).

These results reveal systematic differences in visual performance around the visual field between adults and children. They provide evidence that visual perception continues to develop beyond childhood. It remains to be seen whether these late-stage changes in the human visual system result from environmental factors acting on the developing visual system, the way in which the visual system is hard-wired to develop, or a combination of both. A full account of visual development needs to explain how maturation interacts with environmental input[1].

Having established that polar angle asymmetries differ between children and adults, future studies should involve a wider age range to trace their developmental course and elucidate whether and how nature and nurture interact to shape the visual system over time. Currently we are investigating whether children's performance HVA and lack of VMA have corresponding cortical surface areas in early visual cortex. The characterization of performance around the visual field in adults and children is crucial for our understanding of how human vision develops, whether the visual system adapts to its environment, and the extent of the functional plasticity of the human brain. The difference in visual field asymmetries between children and adults we report here highlights the continued development of the human brain beyond childhood.

SUPPLEMENTAL INFORMATION

Supplemental information includes one figure, experimental procedures, author contributions, acknowledgments, declaration of interests and inclusion and diversity statements and can be found with this article online at https://doi.org/10.1016/j.cub.2022.04.052.

REFERENCES

1. Braddick, O., and Atkinson, J. (2011). Development of human visual function. Vis. Res. *51*, 1588–1609.
2. Benedek, K., Janáky, M., Braunitzer, G., Rokszin, A., Kéri, S., and Benedek, G. (2010). Parallel development of contour integration and visual contrast sensitivity at low spatial frequencies. Neurosci. Lett. *472*, 175–178.
3. Himmelberg, M.M., Winawer, J., and Carrasco, M. (2020). Stimulus-dependent contrast sensitivity asymmetries around the visual field. J. Vis. *20*, 18.
4. Barbot, A., Xue, S., and Carrasco, M. (2021). Asymmetries in visual acuity around the visual field. J. Vis. *21*, 2.
5. Baldwin, A.S., Meese, T.S., and Baker, D.H. (2012). The attenuation surface for contrast sensitivity has the form of a witch's hat within the central visual field. J. Vis. *12*, 23.
6. Greenwood, J.A., Szinte, M., Sayim, B., and Cavanagh, P. (2017). Variations in crowding, saccadic precision, and spatial localization reveal the shared topology of spatial vision. Proc. Natl. Acad. Sci. USA *114*, E3573–E3582.
7. Kupers, E.R., Benson, N.C., Carrasco, M., and Winawer, J. (2022). Asymmetries around the visual field: From retina to cortex to behavior. PLoS Comput. Biol. *18*, e1009771.
8. Benson, N.C., Kupers, E.R., Barbot, A., Carrasco, M., and Winawer, J. (2021). Cortical magnification in human visual cortex parallels task performance around the visual field. eLife *10*, e67685.
9. Himmelberg, M.M., Winawer, J., and Carrasco, M. (2022). Linking contrast sensitivity to cortical magnification in human primary visual cortex. Nat. Commun. in press.
10. Previc, F.H. (1990). Functional specialization in the lower and upper visual fields in humans: Its ecological origins and neurophysiological implications. Behav. Brain Sci. *13*, 519–542.

[1]Department of Psychology, New York University, 6 Washington Place, New York, NY 10003, USA. [2]Center for Neural Science, New York University, 4 Washington Place, New York, NY 10003, USA.
*E-mail: marisa.carrasco@nyu.edu