The development of convergence and divergence to radial optic flow in infancy

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Background

We have reported a relationship between the development of depth perception and ocular motion functions including smooth pursuit in both adults and infants (VSS, 2009), ocular following response to translating gratings stimuli (VSS, 2011), and vergence to radial optic flow (VSS, 2013). With radial optic flow, an expanding flow field elicits involuntary convergent eye movements while a contracting one elicits involuntary divergent eye movements. Importantly, these responses are attenuated but remain under monocular viewing (Bussetini et al, 1997).

Our previous results indicate that infants are sensitive to information that specifies distance. Infant studies have typically used visual preferences to examine directional sensitivities or motion coherence thresholds, while few have measured the eye movements directly. We measured infants’ ocularmotor responses to expanding and contracting radial optic flow stimuli. We also included a static condition where the ROF stimulus does not move in order to compare the responses. The presence of vergence eye movements in response to expansion/contraction would provide evidence that infants are sensitive to information that specifies distance.

Method

Participants

For the two motion conditions, data were successfully recorded from 90 infants, creating three age groups with at least n = 30 in each group:

- Two-month-olds (mean age 76.4 days, range 58-95, n=30)
- Four-month-olds (mean age 112 days, range 96-125, n=30)
- Five-month-olds (mean age 149 days, range 126-208, n=30)

Data from an additional 39 infants were dropped for lack of sufficient gaze samples or equipment failure (attrition by age group: 11, 7, 21).

In the static stimulus condition, data were successfully recorded from 17 infants, mean age 147 days, range 65-208, n=17 (data from an additional 11 infants was dropped due to insufficient gaze sample or equipment failure).

Materials & Procedure

The stimulus comprised a radial optic flow pattern that expanded or contracted across 400 ms trials:

- The order of four expanding and four contracting trials was randomized
- Each trial was nominally 1.64 minutes; 30 pix = 50 min = 0.82 deg (2.3 deg/sec)
- For data analysis, the first 100 pix of each trial was removed
- Initiation of each trial was under automated eye control and began when the infant fixated a central point on the screen
- Attention was directed to the center using a flashing attention-getting stimulus
- Eye position was measured using a Tobii X20 eye-tracker calibrated to five points
- Viewing was binocular but each eye was recorded separately

Results

Overall. For the expanding pattern, we expect convergence (blue boxes); for the contracting pattern, we expect divergence (red boxes). The frequency of results was significantly different from a uniform distribution, chi² p < .001. For the two motion conditions, ANOVA computed on the gain scores found a main effect for motion (contracting, expanding), F (1, 195) = 19.41, p < .001.

- Mean gain to contracting stimulus = 0.16
- Mean gain to expanding stimulus = -0.05

These results indicate divergence to the contracting stimulus (as the difference between the two eyes increases), and convergence to the expanding stimulus (as the difference between the two eyes decreases).

Static Condition. For the static stimulus condition, ANOVA found a main effect for stimulus condition (static, expanding, contracting), F (2, 206) = 11.11, p < .001. Pairwise comparisons revealed a significant difference between the static and expanding motion conditions (mean gain 0.22 vs. -0.05, p < .001). There was no main effect for age group, F (2, 196) = 14.35, p < .001. The mean gain was 0.22 and there was no significant correlation between age (in days) and gain, r (17) = -0.04, p > .05.

Infants demonstrated significantly different eye movement responses to different directions of radial optic flow, with an overall pattern of divergence to contraction and convergence to expansion. Responses to a no-motion control condition were less systematic but more similar to divergence.

Discussion

Infants demonstrated significantly different eye movement responses to different directions of radial optic flow, with an overall pattern of divergence to contraction and convergence to expansion. Responses to a no-motion control condition were less systematic but more similar to divergence.

This result suggests that the young infants’ visual system is capable of interpreting radial optic flow as change in perceived distance. Importantly, these responses do not rely on binocular disparity as there were no disparity differences or other cues to depth in these stimuli. Similar to research on infants’ reactions to looming stimuli (Yonas et al, 1979), these results suggest that sensitivity to distance from radial optic flow may develop very early.

We can compare the sensitivity to radial optic flow from convergence/divergence to monocular cues to depth including motion parallax. It may be that these sensitivities develop ahead of depth from binocular disparity. Previous research indicates that a failure of maturation of the eye movement systems may be an early step in a developmental process leading to strabismus. It may be useful to directly compare the development of smooth pursuit and ocular following response to radial optic flow to help identify early markers of visual dysfunction.

Acknowledgements

This research is supported by NSF/HRD-0823679, NSF/HRD-1135317, and CORRE/NIGMS P20 GH6181101A13. Thanks to Dr. Claude Drouin, Enrique Arias-Vasquez, Dae Gu, Audrey Briggs, Yonas Eshete and the MSUM Child Development Lab.