Infants' anticipatory eye movements: Feature-based attention guides infants' visual attention.

Shuma Tsurumi[1,2*1], So Kanazawa[3], Masami K. Yamaguchi[1], Jun-ichiro Kawahara[4]

1. Department of Psychology, Chuo University, 742-1 Higashi-Nakano, Hachioji, Tokyo 192-0393, Japan

2. Japan Society for the Promotion of Science, 5-3-1 Kojimachi, Chiyoda-ku, Tokyo 102-0083, Japan

3. Department of Psychology, Japan Women's University, 2-8-1 Mejirodai, Bunkyo-ku, Tokyo 112-8681, Japan

4. Department of Psychology, Hokkaido University, N10 W7, Kita, Sapporo, Hokkaido 060-0810, Japan

*Correspondence: perry.super178@gmail.com S. Tsurumi

Data availability

The data that support the findings of this study are available from the corresponding author, S. T., upon request.

Ethical approval

[1] The present affiliation is Department of Psychology, Hokkaido University, N10 W7, Kita, Sapporo, Hokkaido 060-0810, Japan.

This study was approved by the ethical committee of Chuo University.

Competing interests

The authors declare no competing interests.

Funding

This research was financially supported by Grant-in-Aid for JSPS Fellows (No.19J21422), Grant-in-Aid for Scientific Research on Innovative Areas “Construction of the Face-Body Studies in Transcultural Conditions” (No.17H06343) from MEXT, and Grant-in-Aid for Scientific Research (B) from the JSPS (No.19H01774).

Acknowledgments

We thank Yusuke Nakashima, Jiale Yang, Yuki Tsuji, Nanako Yamanaka, and Machi Sugai for their assistance with data collection. Special thanks to the infants and their parents for their kindness and cooperation.

Infants' anticipatory eye movements: Feature-based attention guides infants' visual attention.

Abstract

When looking for an object, we identify it by selectively focusing our attention to a specific feature, known as feature-based attention. This basic attentional system has been reported in young children; however, little is known of whether infants could use feature-based attention. We have introduced a newly developed anticipation-looking task, where infants learned to direct their attention endogenously to a specific feature based on the learned feature (color or orientation), in 60 preverbal infants aged 7 to 8 months. We found that preverbal infants aged 7 to 8 months can direct their attention endogenously to the specific target feature among irrelevant features, thus showing the feature-based attentional selection. Experiment 2 bolstered this finding by demonstrating that infants directed their attention depending on the familiarized feature that belongs to a never-experienced object. These results that infants can form anticipation by color and orientation reflect they could drive their attention through feature-based selection.

Keywords

Feature-based attention, Infant, Anticipation, Top-down, Endogenous attention

Introduction

Feature-based attention refers to the function of enhancing the representation of image components related to a particular feature regardless of spatial locations (Liu, 2019; Liu & Mance, 2011; Maunsell & Treue, 2006). This cognitive ability formed by the learning and experience is useful during visual searches to look for a target in a cluttered environment to achieve a particular behavioral goal (Zhang & Luck, 2009). In this literature, a feature that guides attention endogenously must be a preattentive feature such as color, orientation, or motion (Wolfe & Utochkin, 2019). Researchers have studied this type of attentional function as well as others, such as spatial and object-based attention in adults. However, it remains unclear when this important attentional system, feature-based attention, is acquired during the cognitive development of infants.

Development of spatial and object-based attention has been widely investigated in infants and children (Bulf & Valenza, 2013; Frick, Colombo & Saxon, 1999; Ross-Sheehy, Schneegans &Spencer, 2015; Sun et al., 2018). However, understanding the development of feature-based attention is limited because researchers could not instruct younger infants to direct attention to a specific feature among distractors whose features are equally salient for infants. The study of feature-based attention using visual search task in toddlers revealed that the performance of the task in 18 month-olds showed the same trend as adults in terms of efficacy (Gerhardstein & Rovee-Collier, 2002). The time to detect a target did not vary in the presence of multiple distractors in feature searches (searching for a unique feature among the homogeneous array of distractors). Instead, it increased as the number of distractors increased in conjunction searches (searching for a unique feature among the distractors defined by conjunctions of two different features). Younger infants aged 3 months can search for a unique feature among the homogeneous array of distractors, suggesting that infants' attention automatically shift to salient stimuli in a feature dimension (Adler & Gallego, 2014; Adler & Orprecio, 2006; Bertin & Bhatt, 2001; Coldren & Haaf, 2000; Goldknopf et al., 2019). However, little is known about whether infants can direct endogenous attention to a specific feature among multiple features. Therefore, we investigated feature-based selection in preverbal infants using a newly developed anticipation-looking task. This task enabled us to study the feature-based attention in early infants without any verbal instructions.

A key characteristic of this task is that top-down modulation induces infants to direct their visual attention toward a specific feature value rather than a highly salient aspect of stimuli that captures bottom-up attention. This task can highlight that infants' orienting responses depended on top-down experiences because two alternative stimuli were equivalent in terms of low-level visual saliency. This contrasts sharply against previous infant studies that resort to a bottom-up shift of attention by introducing enhanced differences of visual saliencies between target stimuli and non-target distractor items. For example, infants aged 3 months can correctly detect a moving object among static objects (Nagata & Dannemiller, 1996). Also, they can quickly locate a unique item in a specific visual domain among other uniform background items (e.g., a target "+" among non-target "L's") (Adler & Orprecio, 2006; Goldknopf et al., 2019).

Endogenous attentional selection relying on feature-based attention requires intentional and goal-driven mechanisms so that infants voluntarily choose a specific feature (that differs from other features) through familiarization. This contrasts sharply against exogenous attentional orienting that relies on stimulus saliencies can be achieved by relatively primitive neural circuits (Richards, Reynolds & Courage, 2010). Recent studies reveal that top-down modulation from the frontal area to occipital area exists even in 6-month-olds (Emberson, Richards, & Aslin, 2015), and specific neural responses reflecting early attentional amplification for expected events are observed in 12-month-old infants (Kouider et al., 2015), by the extensive familiarization of expectation. Based on these studies demonstrating that the top-down signals induced by the familiarization modulate the sensory processing, it is reasonable to assume that infants' visual attention shifts to a specific feature by familiarization that enables them to allocate their attention to the critical feature.

To achieve this type of feature-based selection, we used an anticipation-looking method (e.g. Kaldy, Guillory & Blaser, 2016) and induced infants to direct their endogenous attention to one of the features (color or orientation). Specifically, we showed 7- to 8- month-old infants a short animation in which a yellow object ("Pac-man") ate one of two rectangles based on a specific feature (e.g., red color for one group of infants or vertical orientation for a different group of participants), so that the infants could learn the idea: either that Pac-man eats red things or that he eats things of a certain orientation. This familiarization phase plays a vital role in inducing infants to direct their attention to a specific feature among the two rectangles whose low-level features are equivalent. Once this familiarization being established, we presented infants with two rectangles without the movement of Pac-man and tested whether infants anticipated which rectangle was expected to be eaten by Pac-man.

We decided to include the infants aged 7 to 8 months because infants of this age have already shown the basic perceptual and attentional systems relevant to object recognition (Bulf & Valenza, 2013; Yang et al., 2015). Further, infants aged within one year old can categorize objects and draw inferences about objects or events using feature information (Adler & Haith, 2003; Mandell & Raijmakers, 2012; Needham, 2001; Tamis-LeMonda & McClure, 1995; Wilcox, 1999; Wilcox & Chapa, 2004), implying that their perceptual systems are sensitive to object feature. Based on these findings, we examined the feature-based attention in 7- to 8-month-olds.

We predict that if infants can direct their endogenous attention to a specific feature through the familiarization session during which one of the features was designated as target by Pac-man, the infants should show eye movements to the rectangle of the target feature that is expected to be eaten by Pac-man in anticipation. However, if infants cannot direct their attention to the feature, infants' eye movements in the anticipation looking phase should be random. We also conducted Experiment 2 by introducing novel sets of orientations (45° and 315°) in the anticipation-looking phase to examine whether the anticipatory looking was the result of directing visual attention to a specific feature endogenously and not due to memorizing the presented identical stimuli.

Experiment 1

Methods

Participants

Forty 7–to 8-month-old infants participated in this experiment and were randomly assigned to one of the two experimental groups (color condition: 9 boys and 11 girls, mean age = 230.0 days, *SD* = 15.28; orientation condition: 5 boys and 15 girls, mean age = 232.4 days, *SD* = 16.73). An additional twenty-seven infants were excluded from the final analysis because the experiment was interrupted during the calibration phase (*n* = 10) or in the middle of the experiment (*n* = 12) due to no eye-tracking recorded, or a side bias looking at only one side of the monitor during the test phase (*n* = 5). The sample size was estimated in accordance with the guide provided by Oakes (2017) to reach a power of 0.8 with an effect size of 0.65 in the experiment. All infants were full-term at birth and healthy at the time of the experiment. The infants for the study were recruited through local newspaper flyers. The present study was approved by the ethical committee of Chuo University. Written informed consent was obtained from the parents of the infants participating in the experiment prior to testing.

Apparatus

All stimuli were presented on an LCD monitor with a refresh rate of 60 Hz and a resolution of 1920 × 1080 pixels. Two loudspeakers were placed on both sides of the monitor. The infant and the parent were placed inside an enclosure made of a black cloth. The infant sat on his or her parent's lap approximately 60 cm away from the monitor. A

CCD camera below the monitor was used to record the infants' behavior digitally, allowing the experimenter to observe the infants' behavior during the experiment. Infants' eye movements were recorded with a Tobii Pro Spectrum (Tobii Technology, Stockholm, Sweden) below the screen. The eye tracker binocularly recorded x-y coordinates of current fixation with a sampling rate of 120Hz. We analyzed the recorded data which contained x-y coordinates obtained from both eyes.

Materials and Procedure

A yellow circle-like "Pac-man" (4.78° × 4.78°) was presented in the center of the screen, and two of different rectangles (1.91° × 4.78°) were presented on the right and left of the center (6.68°). A V-shaped notch in the upper part of the Pac-man waxed and waned repeatedly, accompanied by a brief sound, to represent the opening and closing of the mouth. Pac-man's movement was used as a fixation marker. Two rectangles were presented in every trial, one on the left and the other on the right of the Pac-man. The pair differed depending on the two experimental conditions (color and orientation). Under the color condition, two rectangles, one red and one blue, were presented on the right and left, one each. The orientation (horizontal and vertical) of each rectangle was assigned randomly. The features' pairs were as follows: blue and red horizontals, blue and red verticals, blue vertical and red horizontal, and blue horizontal and red vertical. Under the orientation condition, the vertical and horizontal rectangles were presented on the right and left. The colors (red and blue) of the two rectangles were assigned randomly. The features' pairs were as follows: blue vertical and red horizontal, blue horizontal and red vertical, blue vertical and blue horizontal, and red vertical and horizontal. There was a total of eight trials (2 colors × 2 orientations× 2 positions) in each condition. The experimental condition (color or orientation) was the between-participant factor, and the feature assigned to each infant was the within-participant factor.

We adapted an anticipation-looking task (Figure.1). The task consisted of two phases, the familiarization phase and the anticipation looking phase. In the familiarization phase, the Pac-man and the two rectangles appeared simultaneously. After infants' fixation on the Pac-man whose mouth opened and closed repeatedly, the V-shaped part of Pac-man rotated 90 degrees to the left or right so that it faced a rectangle. Then, the Pac-man crawled to eat one of the two rectangles, while the mouth opened and shut continuously. A trial ended when the rectangle was eaten by Pac-man. Pac-man consistently ate rectangles of the same color under the color condition and those of the same orientation under the orientation condition. The color or orientation of the target to be learned was counterbalanced across infants. The other rectangle (the non-target rectangle) was never eaten by Pac-man throughout the familiarization phase.

The familiarization phase was directly followed by the anticipation looking phase in which the Pac-man and a pair of two different rectangles were presented. But Pac-man disappeared as soon as the infants fixated on Pac-man. The two rectangles were left visible on the screen for two seconds after this. Infants received eight trials in the anticipation looking phase enabling us to monitor whether they showed anticipatory eye movements towards the colored or oriented rectangles. The eight trials in the anticipation looking phase were similar to those in the familiarization phase except that the Pac-man disappeared as soon as infants maintain fixation in the screen's center.

Infants' eye movements were recorded throughout the experiment. The eye tracker was calibrated using the Tobii built-in calibration function for infants before the commencement of the experimental trials. During the calibration, the fixation marker moved around the screen between five points (top left, top right, bottom left, bottom right, and center) in a random order. The calibration finished when infants successfully fixated on these five positions. The calibration was suspended when infants become fussy and cried due to the repetition of the calibration exercise. After the calibration, the familiarization phase started followed by the anticipation looking phase. In each trial, Pac-man automatically started moving as soon as the infants fixated on it for two seconds. When Pac-man reached the target rectangle, the rectangle disappeared with a popping sound. During the anticipation looking phase, Pac-man disappeared after infants fixated on it and the two rectangles remained on screen for two seconds.

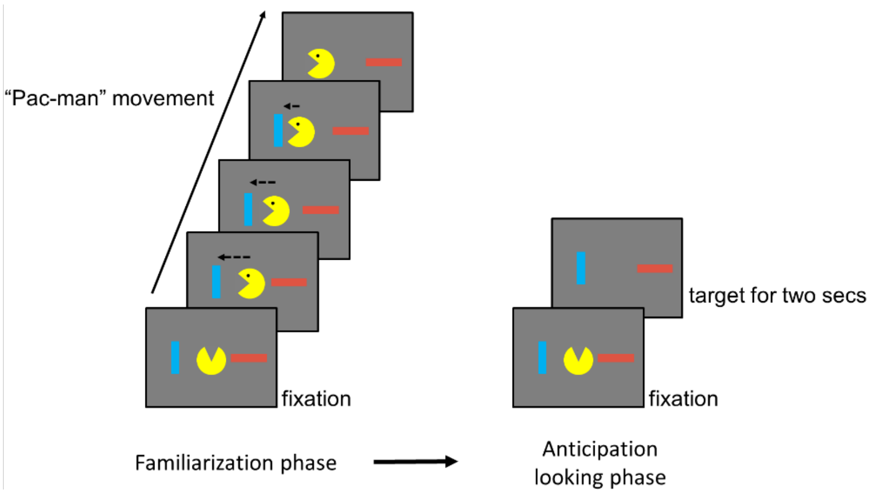

Figure 1. Illustration of the experimental procedure.

Note. In the familiarization phase, Pac-man was presented in the center flanked by two rectangles during the fixation period. Once infants fixated on the Pac-man in the center, the Pac-man crawled either to the right or to the left. Under the color condition, the Pac-man crawled toward the color-defined rectangle while ignoring its orientation. Under the orientation condition, the Pac-man crawled toward the orientation-defined rectangle while ignoring its color. Feature binding between orientation and color is not required in the current task (Treisman & Gelade, 1980). The familiarization phase consisted of eight trials followed by the anticipation looking phase of eight trials.

Results

Before the primary analysis, we counted the number of trials (valid trials) in which infants continued to observe the stimuli until the end of the trial in the familiarization and test phases. The trials in which infants looked away from the monitor once were defined as invalid trials. Thus, we removed the trials in which infants looked at the stimuli only in the first, middle and/or last few tenths of a second as invalid trials. This yielded the following remaining valid trials on average per condition: 5.7 trials in familiarization phase and 5.4 trials in anticipation looking phase under the color condition; 5.1 trials in familiarization phase and 4.5 trials in anticipation looking phase under the orientation condition. We conducted the two-tailed *t*-test between conditions and found that there was no significant difference in the number of valid trials between conditions, familiarization phase: $t(38) = 1.26$, $p = .21$, *Cohen's d* = .39; anticipation looking phase: $t(38) = 1.85$, $p = .07$, *Cohen's d* = .57.

Anticipatory looking during test phase

We calculated the raw eye-tracking data and defined a fixation as when gaze points remained within the area of interest (AOI) for at least 100 ms (Liu et al., 2011; Xiao et al., 2014). The area of each rectangle was regarded as the AOI. We defined the anticipated trial as when infants' first gaze points landed on the AOI containing the critical feature. The remaining trials in which the infants' first gaze points landed on the AOI of the non-target rectangle were regarded as non-anticipated trials. To investigate whether infants anticipatorily looked at the target rectangle containing a critical visual feature, we calculated the individual proportion of anticipated trials by dividing the number of anticipated trials by the total number of valid trials from the test phase. If infants can direct their attention to a specific feature through the familiarization where one of the features was designated as a target by Pac-man, they would show eye movements to the rectangle of the target feature expected to be eaten by Pac-man in anticipation. Thus, the proportion of the anticipated trials should be higher than the chance level of 0.5.

Figure.2 represents the proportion of trials in which anticipatory looking occurred in each condition. Prior to the analysis, an arcsine transformation was performed on the proportion of anticipated trials; however, the scores in the figure were untransformed proportions for clarity. To examine whether infants could anticipate the target, we conducted two-tailed *t*-tests against chance level (0.5) in each condition. The test revealed that the proportion of trials in which anticipation looking occurred was significantly higher than chance level in both conditions, color condition: $t(19) = 4.53$, $p < .01$, *Cohen's d* = 1.41; orientation condition: $t(19) = 2.95$, $p < .01$, *Cohen's d* = .91. We conducted the two-tailed *t*-tests between the color and orientation conditions to investigate whether there was a difference in the proportion of anticipated trials and found no difference between the two conditions, $t(38) = 1.34$, $p = .19$, *Cohen's d* = .41.

There were no differences between the two target colors (red or blue), $t(18) = 1.59$, $p = .15$, *Cohen's d* = .78, and the two target orientations (horizontal or vertical), $t(18) = 1.35$, $p = .20$, *Cohen's d* = .43, suggesting that the infants' attention to target features cannot be attributed to a biased preference to a specific color or orientation. Instead, the results can be taken as evidence indicating that infants' visual attention is shifted to the target feature. We additionally conducted binomial tests on the cumulative number of anticipated trials in both color and orientation conditions and found that infants in both conditions showed the significant anticipated trials (color condition: 76 trials from total 108 valid trials, $p < .01$; orientation condition: 55 trials from total 90 valid trials, $p < .05$). We found no significant correlation between ages and proportions of anticipated trials in either condition, color condition: $r = .21$, $p = .36$; orientation condition: $r = -.41$, $p = .07$.

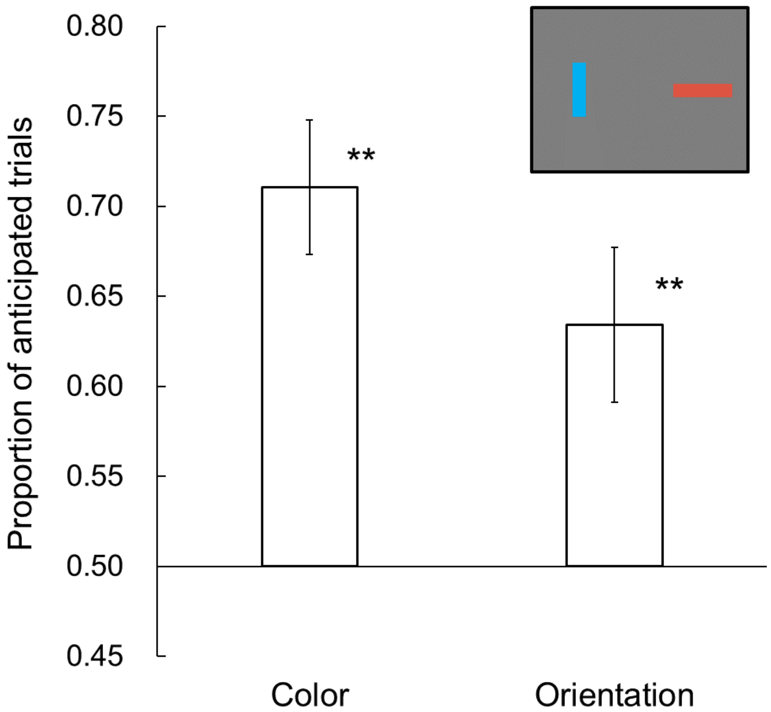

Figure 2. The results of Experiment 1.

Note. Mean proportion of anticipation looking in each condition. Error bars represent *SE*. ***p* < .01 against the chance level 0.5.

Experiment 2

One might argue that the higher proportion of anticipatory looking in Experiment 1 reflects the infants' memory of the specific stimuli that were eaten by the Pac-man during the familiarization phase. This contradicts with our hypothesis that infants showed the anticipatory looking to the specific feature by shifting their attention to the target feature. We conducted the additional experiment by introducing pairs of novel orientations in the anticipatory looking phase to exclude this possibility. If we can replicate the same results as in Experiment 1, even when the novel orientations are presented in the anticipatory looking phase, we can strengthen our hypothesis that infants showed the anticipatory looking to the specific feature by shifting their attention to the target feature, not by the role of memory.

The experimental method was the same as that in Experiment 1 except for the following. First, we conducted only color condition in Experiment 2 because there was no difference in the performance between color and orientation conditions in Experiment 1. Also, there was no preferential bias to orientations, although infants' preference depended on the colors (Brown & Lindsey, 2013). It is hard to prepare the colors that infants equally prefer in the orientation condition; therefore, we decided to carry out the color condition. Second, the orientations of the rectangles were changed in the anticipatory looking phase. In the familiarization phase, two rectangles were presented horizontally or/and vertically, while the two rectangles were tilted at 45° or/and 315° in the anticipatory looking phase. If infants' attention shifts to the specific color feature, they should show the anticipatory looking to the particular color even when the orientations of rectangles are novel for them.

Methods

Participants

Twenty 7- to 8-month-old infants participated in this experiment (11 boys and 9 girls, mean age = 226.2 days, *SD* = 18.24). An additional thirteen infants were tested but excluded from the final analysis because the experiment was interrupted during the calibration phase (*n* = 6) or in the middle of the experiment (*n* = 7) due to no eye-tracking recorded. The sample size was estimated based on the previous infant study similar as that in Experiment 1. All infants were full-term at birth and healthy at the time of the experiment. Written informed consent was obtained from the parents of the infants participating in the experiment before testing.

Results

Like the procedure in Experiment 1, we checked for the trials during which the infants looked away from the monitor in the familiarization and anticipation looking phases. This yielded the following remaining valid trials on average: 7.0 trials in the familiarization phase and 5.5 trials in the anticipation looking phase.

Anticipatory looking during test phase

We calculated the individual proportion of anticipated trials by dividing the number of anticipated trials by that of the total valid trials of the test phase and performed an arcsine transformation on these scores as done in Experiment 1. The score in Figure 3 was untransformed for clarity likewise Experiment 1. The two-tailed *t*-test against chance level (0.5) showed a higher proportion of anticipated trials than that against chance level, $t(19) = 3.64$, $p < .01$, *Cohen's* $d = .82$. There was no difference between the two target colors, red or blue, $t(18) = .28$, $p = .776$, *Cohen's* $d = -.12$. Moreover, we found no significant correlation between ages and proportions of anticipated trials, $r = -.21$, $p = .37$. An additional binomial test on the cumulative number of anticipated trials revealed that infants showed the significant anticipated trials (69 trials from total 109 valid trials, $p < .01$). This result suggests that infants generalize the target feature, i.e. infants' attention is directed to the target feature endogenously even when the other feature of stimuli was different from the familiarization phase. If infants' orienting responses were due to memorizing the presented identical stimuli, their eye movements in the anticipation-looking phase should have been random. These findings could be interpreted as another possibility that infants showed the familiar preference to the color or orientation rather than anticipation. In this case, infants endogenously direct their attention to the familiarized feature because of the repetitive presentation of the target feature. We cannot rule out this possibility completely even though infants could direct their attention to the learned feature belonging to the never experienced objects in the current experiment. However, in either case, the results in Experiment 2 support the feature-based attention in 7- to 8-month-olds.

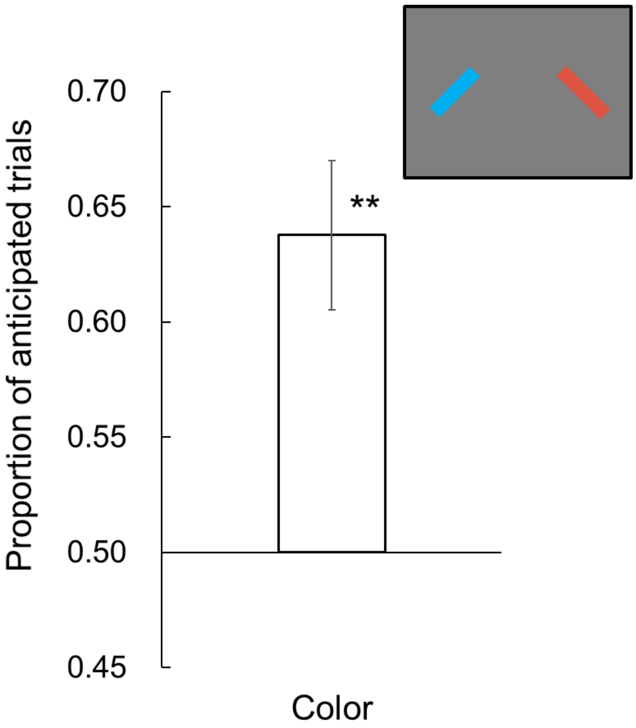

Figure 3. The result of Experiment 2.

Note. Mean proportion of anticipation looking in color condition. Error bar represents *SE*. ***p* < .01 against the chance level 0.5.

Discussion

In this study, we investigate the endogenous attention based on feature-based selection in infants using a newly developed anticipation-looking task, in which 7- to 8-month-old infants were presented with an animation depicting Pac-man eating one of two rectangles based on the color or orientation features of the rectangles. The infants' anticipatory looking behavior was recorded as an index of their looks based on whether their eyes moved to a rectangle with a specific feature (color or orientation) that would be eaten by Pac-man even after the Pac-man had disappeared. We found that these infants, indeed, showed anticipatory looking at objects containing the specific feature. Furthermore, infants could generalize the target feature, that is, infants' attention is directed to the target feature endogenously even when the other feature of stimuli was different from the familiarization phase. This result suggests that preverbal infants aged 7 to 8 months can direct their attention endogenously to a specific feature of a target.

It is noteworthy that infants' endogenous visual attention is directed to the target feature through familiarization in the present study. This contrasts previous studies examining infants' attention to objects' features because those studies have mainly used tasks that depend on infants' exogenous attention and showed that infants' attention is captured by salient stimuli exogenously (Adler & Gallego, 2014; Adler & Orprecio, 2006; Bertin & Bhatt, 2001; Coldren & Haaf, 2000; Goldknopf et al., 2019). Although infants' visual attention is prone to exogenous capture and shifts to stimuli, little is known about whether their attention is endogenously directed to a target. Recently, it has been reported that top-down knowledge, successfully acquired through the abstract rule learning, biases the visual attention to the objects' feature in 9-month-olds (Werchan & Amso, 2020). During visual searches infants can use contextual knowledge of spatial locations to search for a target efficiently (Tummeltshammer & Amso, 2017). Furthermore, even without familiarization and learning, infants can use briefly presented visual or audio information to control visual search behavior (Mitsven, Gantrell, Luck, & Oakes, 2018; Xiao & Emberson, 2019). In line with these findings, our present task revealed that the visual attention of preverbal infants, aged 7 to 8 months, shifts to a target feature based on familiarization. This finding suggests that the familiarization in the present task provides an opportunity for infants to direct their attention to a specific feature between two different, but equally salient, features. Then infants' visual attention is endogenously directed to the target feature.

Prior works show that the neural process of top-down modulation gained through the familiarization, such as the repeated presentation of stimuli, has been observed in preverbal infants (Emberson et al., 2015; Kouider et al., 2015; Werchan & Amso, 2020). These imply the existence of feedforward and feedback connection, and this connection enables infants to anticipate the upcoming event. In line with these findings, 7- to 8-month-olds learn to direct their attention to the specific feature based on the familiarization phase where feedforward and feedback connections make infants direct their attention to features. The present results that infants can form anticipation by color and orientation reflect that they drive their attention through feature-based selection. The next step is to examine the developmental process of endogenous attentional orienting using feature-based selection.

References

Adler, S. A., & Gallego, P. (2014). Search asymmetry and eye movements in infants and adults. Attention, Perception, and Psychophysics, 76, 1590–1608. https://doi.org/10.3758/s13414-014-0667-6

Adler, S. A., & Haith, M. M. (2003). The nature of infants' visual expectations for event content. *Infancy*, 4, 389–421. https://doi.org/10.1207/S15327078IN0403_05

Adler, S. A., & Orprecio, J. (2006). The eyes have it: Visual pop-out in infants and adults. Developmental Science, 9, 189–206. https://doi.org/10.1111/j.1467-7687.2006.00479.x

Bertin, E., & Bhatt, R. S. (2001). Dissociations between Featural versus Conjunction-Based Texture Processing in Infancy: Analyses of Three Potential Contributing Factors. Journal of Experimental Child Psychology, 78, 291–311. https://doi.org/10.1006/jecp.2000.2568

Brown, A.M., Lindsey, D.T. (2013). Infant color vision and color preferences: a tribute to Davida Teller. Vis Neurosci. 30, 243-50. doi: 10.1017/S0952523813000114.

Bulf, H., & Valenza, E. (2013). Object-based visual attention in 8-month-old infants: Evidence from an eye-tracking study. Developmental Psychology, 49, 1909–1918. https://doi.org/10.1037/a0031310

Chien, S. H. L., Bronson-Castain, K., Palmer, J., & Teller, D. Y. (2006). Lightness constancy in 4-month-old infants. Vision Research, 46, 2139–2148. https://doi.org/10.1016/j.visres.2005.11.027

Coldren, J. T., & Haaf, R. A. (2000). Asymmetries in infants’ attention to the presence or absence of features. Journal of Genetic Psychology, 161, 420–434. https://doi.org/10.1080/00221320009596722

Dannemiller, J. L., & Hanko, S. A. (1987). A test of color constancy in 4-month-old human infants. Journal of Experimental Child Psychology, 44, 255–267. https://doi.org/10.1016/0022-0965(87)90033-6

Emberson, L. L., Richards, J. E., & Aslin, R. N. (2015). Top-down modulation in the infant brain: Learning-induced expectations rapidly affect the sensory cortex at 6 months. Proceedings of the National Academy of Sciences, 112, 9585–9590. https://doi.org/10.1073/pnas.1510343112

Frick, J. E., Colombo, J., & Saxon, T. F. (1999). Individual and developmental differences in disengagement of fixation in early infancy. Child Development, 70, 537–548. https://doi.org/10.1111/1467-8624.00039

Gerhardstein, P. & Rovee-Collier, C. (2002). The development of visual search in infants and very young children. Journal of Experimental Child Psychology. 81, 194-215.

https://doi.org/10.1006/jecp.2001.2649

Goldknopf, E. J., Gillespie-Lynch, K., Marroquín, A. D., Nguyen, B. D., & Johnson, S. P. (2019). Spontaneous visual search during the first two years: Improvement with age but no evidence of efficient search. Infant Behavior and Development, 57, 101331. https://doi.org/10.1016/j.infbeh.2019.101331

Kaldy, Z., Guillory, S. B., & Blaser, E. (2016). Delayed Match Retrieval: a novel anticipation-based visual working memory paradigm. Developmental Science, 19, 892–900. https://doi.org/10.1111/desc.12335

Kouider, S., Long, B., Le Stanc, L., Charron, S., Fievet, A. C., Barbosa, L. S., & Gelskov, S. V. (2015). Neural dynamics of prediction and surprise in infants. Nature Communications, 6, 1–8. https://doi.org/10.1038/ncomms9537

Liu, T. (2019). Feature-based attention: Effects and control. Current opinion in psychology, 29, 187-192. https://doi.org/10.1016/j.copsyc.2019.03.013

Liu, T., & Mance, I. (2011). Constant spread of feature-based attention across the visual field. Vision Research, 51, 26–33. https://doi.org/10.1016/j.visres.2010.09.023

Liu, S., Quinn, P. C., Wheeler, A., Xiao, N., Ge, L., & Lee, K. (2011). Similarity and difference in the processing of same- and other-race faces as revealed by eye tracking in 4- to 9-month-olds. Journal of Experimental Child Psychology, 108, 180–189.

https://doi.org/10.1016/j.jecp.2010.06.008

Mandell, D. J., & Raijmakers, M. E. J. (2012). Using a single feature to discriminate and form categories: The interaction between color, form and exemplar number. Infant Behavior and Development, 35, 348–359. https://doi.org/10.1016/j.infbeh.2012.04.003

Maunsell, J. H. R., & Treue, S. (2006). Feature-based attention in visual cortex. Trends in Neurosciences, 29, 317–322. https://doi.org/10.1016/j.tins.2006.04.001

Mitsven, S. G., Cantrell, L. M., Luck, S. J., & Oakes, L. M. (2018). Visual short-term memory guides infants' visual attention. Cognition, 177, 189–197. https://doi.org/10.1016/j.cognition.2018.04.016

Nagata, Y., & Dannemiller, J. L. (1996). The Selectivity of Motion-Driven Visual Attention in Infants. Child Development, 67, 2608–2620. https://doi.org/10.1111/j.1467-8624.1996.tb01878.x

Needham, A. (2001). Object Recognition and Object Segregation in 4.5-Month-Old Infants. Journal of Experimental Child Psychology, 78, 3–24. https://doi.org/10.1006/jecp.2000.2598

Oakes L. M. (2017). Sample size, statistical power, and false conclusions in infant looking-time research. *Infancy*, 22, 436–469. https://doi.org/10.1111/infa.12186

Richards, J. E., Reynolds, G. D., & Courage, M. L. (2010). The neural bases of infant attention. Current Directions in Psychological Science, 19, 41–46. https://doi.org/10.1177/0963721409360003

Ross-Sheehy, S., Schneegans, S., & Spencer, J. P. (2015). The infant orienting with attention task: Assessing the neural basis of spatial attention in infancy. Infancy, 20, 467-506. https://doi.org/10.1111/infa.12087

Sun, M., Wang, E., Huang, J., Zhao, C., Guo, J., Li, D., Li, S., Du, B., Ding, Y., & Song, Y. (2018). Attentional selection and suppression in children and adults. Developmental Science, 21, 1–13. https://doi.org/10.1111/desc.12684

Tamis-LeMonda, C. S., & McClure, J. (1995). Infant visual expectation in relation to feature learning. *Infant Behavior and Development*, 18, 427–434. https://doi.org/10.1016/0163-6383(95)90032-2

Treisman, A. M., & Gelade, G. (1980). A Feture-Integration Theory of Attention. Cognitive Psychology, 12, 97–136. https://doi.org/10.1016/0010-0285(80)90005-5.

Tsurumi, S., Kanazawa, S., & Yamaguchi, M. K. (2018). The development of object-based attention in infants. Infant Behavior and Development, 52, 14–21. https://doi.org/10.1016/j.infbeh.2018.05.001

Tummeltshammer, K. & Amso, D. (2017). Top-down contextual knowledge guides visual attention in infancy. Developmental Science, 21, e12599. https://doi.org/10.1111/desc.12599

Werchan, D. M. & Amso, D. (2020). Top-down knowledge rapidly acquired through abstract rule learning biases subsequent visual attention in 9- month-old infants. Developmental Cognitive Neuroscience, 42, 100761. https://doi.org/10.1016/j.dcn.2020.100761

Wilcox, T. (1999). Object individuation: Infants' use of shape, size, pattern, and color. Cognition, 72, 125–166. https://doi.org/10.1016/S0010-0277(99)00035-9

Wilcox, T., & Chapa, C. (2004). Priming infants to attend to color and pattern information in an individuation task. Cognition, 90, 265–302. https://doi.org/10.1016/S0010-0277(03)00147-1

Wolfe, J. M., & Utochkin, I. S. (2019). What is a preattentive feature?. Current Opinion in Psychology, 29, 19-26. 10.1016/j.copsyc.2018.11.005

Xiao, N. G., & Emberson, L. L. (2019). Infants use knowledge of emotions to augment face perception: Evidence of top-down modulation of perception early in life. Cognition, 193, 104019. https://doi.org/10.1016/j.cognition.2019.104019

Xiao, N. G., Quinn, P. C., Wheeler, A., Pascalis, O., & Lee, K. (2014). Natural, but not artificial, facial movements elicit the left visual field bias in infant face scanning.

Neuropsychologia, 62, 175–183. https://doi.org/10.1016/j.neuropsychologia.2014.07.017

Yang, J., Kanazawa, S., Yamaguchi, M. K., & Motoyoshi, I. (2015). Pre-constancy Vision in Infants Report Pre-constancy Vision in Infants. Current Biology, 25, 3209–3212. https://doi.org/10.1016/j.cub.2015.10.053

Zhang, W., & Luck, S. J. (2009). Feature-based attention modulates feedforward visual processing. Nature Neuroscience, 12, 24–25. doi:10.1038/nn.2223