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

3

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14 **Data availability**

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

17 **Ethical approval**

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

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

19 **Competing interests**

20 The authors declare no competing interests.

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30

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

33

34 **Abstract**

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

47 **Keywords**

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

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50

Introduction

51 Feature-based attention refers to the function of enhancing the representation of
52 image components related to a particular feature regardless of spatial locations (Liu,
53 2019; Liu & Mance, 2011; Maunsell & Treue, 2006). This cognitive ability formed by
54 the learning and experience is useful during visual searches to look for a target in a
55 cluttered environment to achieve a particular behavioral goal (Zhang & Luck, 2009). In
56 this literature, a feature that guides attention endogenously must be a preattentive
57 feature such as color, orientation, or motion (Wolfe & Utochkin, 2019). Researchers
58 have studied this type of attentional function as well as others, such as spatial and
59 object-based attention in adults. However, it remains unclear when this important
60 attentional system, feature-based attention, is acquired during the cognitive
61 development of infants.

62 Development of spatial and object-based attention has been widely investigated
63 in infants and children (Bulf & Valenza, 2013; Frick, Colombo & Saxon, 1999; Ross-
64 Sheehy, Schneegans & Spencer, 2015; Sun et al., 2018). However, understanding the
65 development of feature-based attention is limited because researchers could not instruct
66 younger infants to direct attention to a specific feature among distractors whose features
67 are equally salient for infants. The study of feature-based attention using visual search

68 task in toddlers revealed that the performance of the task in 18 month-olds showed the
69 same trend as adults in terms of efficacy (Gerhardstein & Rovee-Collier, 2002). The
70 time to detect a target did not vary in the presence of multiple distractors in feature
71 searches (searching for a unique feature among the homogeneous array of distractors).
72 Instead, it increased as the number of distractors increased in conjunction searches
73 (searching for a unique feature among the distractors defined by conjunctions of two
74 different features). Younger infants aged 3 months can search for a unique feature
75 among the homogeneous array of distractors, suggesting that infants' attention
76 automatically shift to salient stimuli in a feature dimension (Adler & Gallego, 2014;
77 Adler & Orprecio, 2006; Bertin & Bhatt, 2001; Coldren & Haaf, 2000; Goldknopf et al.,
78 2019). However, little is known about whether infants can direct endogenous attention
79 to a specific feature among multiple features. Therefore, we investigated feature-based
80 selection in preverbal infants using a newly developed anticipation-looking task. This
81 task enabled us to study the feature-based attention in early infants without any verbal
82 instructions.

83 A key characteristic of this task is that top-down modulation induces infants to
84 direct their visual attention toward a specific feature value rather than a highly salient
85 aspect of stimuli that captures bottom-up attention. This task can highlight that infants'

86 orienting responses depended on top-down experiences because two alternative stimuli
87 were equivalent in terms of low-level visual saliency. This contrasts sharply against
88 previous infant studies that resort to a bottom-up shift of attention by introducing
89 enhanced differences of visual saliencies between target stimuli and non-target
90 distractor items. For example, infants aged 3 months can correctly detect a moving
91 object among static objects (Nagata & Dannemiller, 1996). Also, they can quickly locate
92 a unique item in a specific visual domain among other uniform background items (e.g.,
93 a target “+” among non-target “L’s”) (Adler & Orprecio, 2006; Goldknopf et al., 2019).

94 Endogenous attentional selection relying on feature-based attention requires
95 intentional and goal-driven mechanisms so that infants voluntarily choose a specific
96 feature (that differs from other features) through familiarization. This contrasts sharply
97 against exogenous attentional orienting that relies on stimulus saliencies can be
98 achieved by relatively primitive neural circuits (Richards, Reynolds & Courage, 2010).
99 Recent studies reveal that top-down modulation from the frontal area to occipital area
100 exists even in 6-month-olds (Emberson, Richards, & Aslin, 2015), and specific neural
101 responses reflecting early attentional amplification for expected events are observed in
102 12-month-old infants (Kouider et al., 2015), by the extensive familiarization of
103 expectation. Based on these studies demonstrating that the top-down signals induced by

104 the familiarization modulate the sensory processing, it is reasonable to assume that
105 infants' visual attention shifts to a specific feature by familiarization that enables them
106 to allocate their attention to the critical feature.

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

119 We decided to include the infants aged 7 to 8 months because infants of this
120 age have already shown the basic perceptual and attentional systems relevant to object
121 recognition (Bulf & Valenza, 2013; Yang et al., 2015). Further, infants aged within one

140 Forty 7–to 8-month-old infants participated in this experiment and were
141 randomly assigned to one of the two experimental groups (color condition: 9 boys and
142 11 girls, mean age = 230.0 days, $SD = 15.28$; orientation condition: 5 boys and 15 girls,
143 mean age = 232.4 days, $SD = 16.73$). An additional twenty-seven infants were excluded
144 from the final analysis because the experiment was interrupted during the calibration
145 phase ($n = 10$) or in the middle of the experiment ($n = 12$) due to no eye-tracking
146 recorded, or a side bias looking at only one side of the monitor during the test phase (n
147 = 5). The sample size was estimated in accordance with the guide provided by Oakes
148 (2017) to reach a power of 0.8 with an effect size of 0.65 in the experiment. All infants
149 were full-term at birth and healthy at the time of the experiment. The infants for the
150 study were recruited through local newspaper flyers. The present study was approved by
151 the ethical committee of Chuo University. Written informed consent was obtained from
152 the parents of the infants participating in the experiment prior to testing.

153 *Apparatus*

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

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

164 *Materials and Procedure*

165 A yellow circle-like "Pac-man" ($4.78^\circ \times 4.78^\circ$) was presented in the center of
166 the screen, and two of different rectangles ($1.91^\circ \times 4.78^\circ$) were presented on the right
167 and left of the center (6.68°). A V-shaped notch in the upper part of the Pac-man waxed
168 and waned repeatedly, accompanied by a brief sound, to represent the opening and
169 closing of the mouth. Pac-man's movement was used as a fixation marker. Two
170 rectangles were presented in every trial, one on the left and the other on the right of the
171 Pac-man. The pair differed depending on the two experimental conditions (color and
172 orientation). Under the color condition, two rectangles, one red and one blue, were
173 presented on the right and left, one each. The orientation (horizontal and vertical) of
174 each rectangle was assigned randomly. The features' pairs were as follows: blue and red
175 horizontals, blue and red verticals, blue vertical and red horizontal, and blue horizontal

176 and red vertical. Under the orientation condition, the vertical and horizontal rectangles
177 were presented on the right and left. The colors (red and blue) of the two rectangles
178 were assigned randomly. The features' pairs were as follows: blue vertical and red
179 horizontal, blue horizontal and red vertical, blue vertical and blue horizontal, and red
180 vertical and horizontal. There was a total of eight trials (2 colors \times 2 orientations \times 2
181 positions) in each condition. The experimental condition (color or orientation) was the
182 between-participant factor, and the feature assigned to each infant was the within-
183 participant factor.

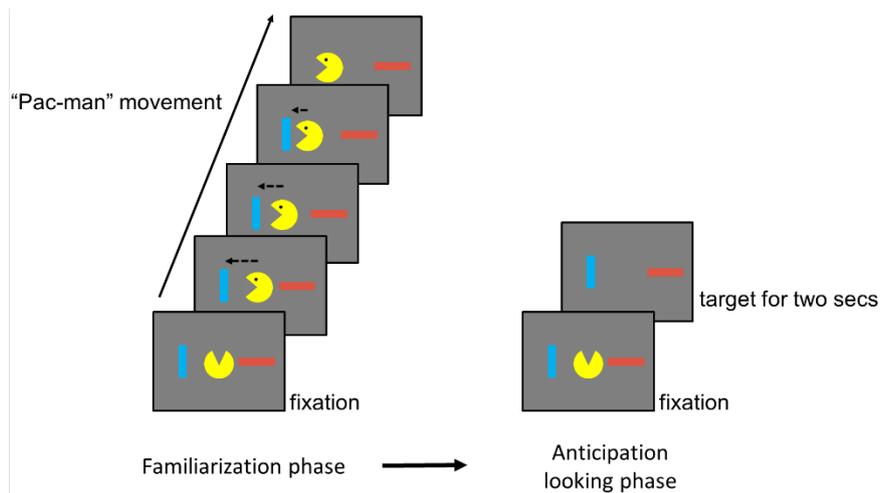
184 We adapted an anticipation-looking task (Figure.1). The task consisted of two
185 phases, the familiarization phase and the anticipation looking phase. In the
186 familiarization phase, the Pac-man and the two rectangles appeared simultaneously.
187 After infants' fixation on the Pac-man whose mouth opened and closed repeatedly, the
188 V-shaped part of Pac-man rotated 90 degrees to the left or right so that it faced a
189 rectangle. Then, the Pac-man crawled to eat one of the two rectangles, while the mouth
190 opened and shut continuously. A trial ended when the rectangle was eaten by Pac-man.
191 Pac-man consistently ate rectangles of the same color under the color condition and
192 those of the same orientation under the orientation condition. The color or orientation of
193 the target to be learned was counterbalanced across infants. The other rectangle (the

194 non-target rectangle) was never eaten by Pac-man throughout the familiarization phase.

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

203 Infants' eye movements were recorded throughout the experiment. The eye
204 tracker was calibrated using the Tobii built-in calibration function for infants before the
205 commencement of the experimental trials. During the calibration, the fixation marker
206 moved around the screen between five points (top left, top right, bottom left, bottom
207 right, and center) in a random order. The calibration finished when infants successfully
208 fixated on these five positions. The calibration was suspended when infants become
209 fussy and cried due to the repetition of the calibration exercise. After the calibration, the
210 familiarization phase started followed by the anticipation looking phase. In each trial,
211 Pac-man automatically started moving as soon as the infants fixated on it for two

212 seconds. When Pac-man reached the target rectangle, the rectangle disappeared with a
 213 popping sound. During the anticipation looking phase, Pac-man disappeared after
 214 infants fixated on it and the two rectangles remained on screen for two seconds.



215

216 *Figure 1.* Illustration of the experimental procedure.

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

225

Results

226

Before the primary analysis, we counted the number of trials (valid trials) in

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which infants continued to observe the stimuli until the end of the trial in the

228 familiarization and test phases. The trials in which infants looked away from the
229 monitor once were defined as invalid trials. Thus, we removed the trials in which infants
230 looked at the stimuli only in the first, middle and/or last few tenths of a second as
231 invalid trials. This yielded the following remaining valid trials on average per condition:
232 5.7 trials in familiarization phase and 5.4 trials in anticipation looking phase under the
233 color condition; 5.1 trials in familiarization phase and 4.5 trials in anticipation looking
234 phase under the orientation condition. We conducted the two-tailed *t*-test between
235 conditions and found that there was no significant difference in the number of valid
236 trials between conditions, familiarization phase: $t(38) = 1.26, p = .21, \text{Cohen's } d = .39$;
237 anticipation looking phase: $t(38) = 1.85, p = .07, \text{Cohen's } d = .57$.

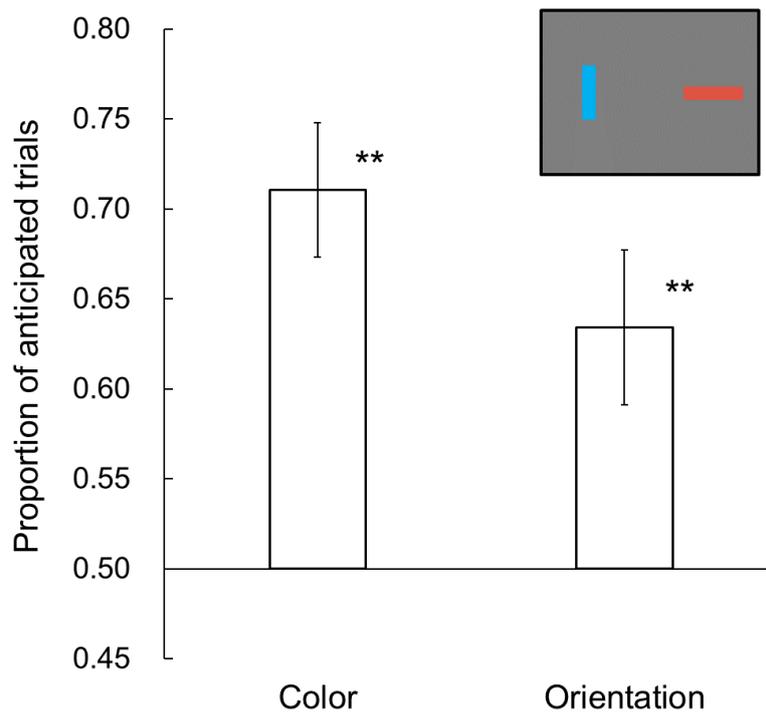
238 *Anticipatory looking during test phase*

239 We calculated the raw eye-tracking data and defined a fixation as when gaze
240 points remained within the area of interest (AOI) for at least 100 ms (Liu et al., 2011;
241 Xiao et al., 2014). The area of each rectangle was regarded as the AOI. We defined the
242 anticipated trial as when infants' first gaze points landed on the AOI containing the
243 critical feature. The remaining trials in which the infants' first gaze points landed on the
244 AOI of the non-target rectangle were regarded as non-anticipated trials. To investigate
245 whether infants anticipatorily looked at the target rectangle containing a critical visual

246 feature, we calculated the individual proportion of anticipated trials by dividing the
247 number of anticipated trials by the total number of valid trials from the test phase. If
248 infants can direct their attention to a specific feature through the familiarization where
249 one of the features was designated as a target by Pac-man, they would show eye
250 movements to the rectangle of the target feature expected to be eaten by Pac-man in
251 anticipation. Thus, the proportion of the anticipated trials should be higher than the
252 chance level of 0.5.

253 Figure.2 represents the proportion of trials in which anticipatory looking
254 occurred in each condition. Prior to the analysis, an arcsine transformation was
255 performed on the proportion of anticipated trials; however, the scores in the figure were
256 untransformed proportions for clarity. To examine whether infants could anticipate the
257 target, we conducted two-tailed *t*-tests against chance level (0.5) in each condition. The
258 test revealed that the proportion of trials in which anticipation looking occurred was
259 significantly higher than chance level in both conditions, color condition: $t(19) = 4.53, p$
260 $< .01, Cohen's d = 1.41$; orientation condition: $t(19) = 2.95, p < .01, Cohen's d = .91$. We
261 conducted the two-tailed *t*-tests between the color and orientation conditions to
262 investigate whether there was a difference in the proportion of anticipated trials and
263 found no difference between the two conditions, $t(38) = 1.34, p = .19, Cohen's d = .41$.

264 There were no differences between the two target colors (red or blue), $t(18) = 1.59$, p
265 $= .15$, *Cohen's d* = .78, and the two target orientations (horizontal or vertical), $t(18) =$
266 1.35 , $p = .20$, *Cohen's d* = .43, suggesting that the infants' attention to target features
267 cannot be attributed to a biased preference to a specific color or orientation. Instead, the
268 results can be taken as evidence indicating that infants' visual attention is shifted to the
269 target feature. We additionally conducted binomial tests on the cumulative number of
270 anticipated trials in both color and orientation conditions and found that infants in both
271 conditions showed the significant anticipated trials (color condition: 76 trials from total
272 108 valid trials, $p < .01$; orientation condition: 55 trials from total 90 valid trials, p
273 $< .05$). We found no significant correlation between ages and proportions of anticipated
274 trials in either condition, color condition: $r = .21$, $p = .36$; orientation condition: $r = -.41$,
275 $p = .07$.



276

277 *Figure 2.* The results of Experiment 1.278 *Note.* Mean proportion of anticipation looking in each condition. Error bars represent *SE*.279 ** $p < .01$ against the chance level 0.5.

280

Experiment 2

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One might argue that the higher proportion of anticipatory looking in

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Experiment 1 reflects the infants' memory of the specific stimuli that were eaten by the

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Pac-man during the familiarization phase. This contradicts with our hypothesis that

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infants showed the anticipatory looking to the specific feature by shifting their attention

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to the target feature. We conducted the additional experiment by introducing pairs of

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novel orientations in the anticipatory looking phase to exclude this possibility. If we can

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replicate the same results as in Experiment 1, even when the novel orientations are

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

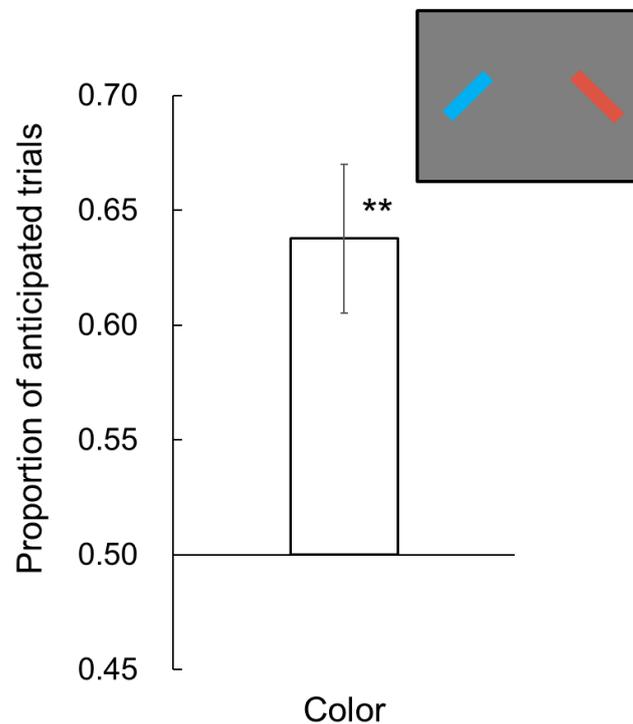
313 **Results**

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

318 *Anticipatory looking during test phase*

319 We calculated the individual proportion of anticipated trials by dividing the
320 number of anticipated trials by that of the total valid trials of the test phase and
321 performed an arcsine transformation on these scores as done in Experiment 1. The score
322 in Figure 3 was untransformed for clarity likewise Experiment 1. The two-tailed t -test
323 against chance level (0.5) showed a higher proportion of anticipated trials than that

324 against chance level, $t(19) = 3.64, p < .01, \text{Cohen's } d = .82$. There was no difference
325 between the two target colors, red or blue, $t(18) = .28, p = .776, \text{Cohen's } d = -.12$.
326 Moreover, we found no significant correlation between ages and proportions of
327 anticipated trials, $r = -.21, p = .37$. An additional binomial test on the cumulative
328 number of anticipated trials revealed that infants showed the significant anticipated
329 trials (69 trials from total 109 valid trials, $p < .01$). This result suggests that infants
330 generalize the target feature, i.e. infants' attention is directed to the target feature
331 endogenously even when the other feature of stimuli was different from the
332 familiarization phase. If infants' orienting responses were due to memorizing the
333 presented identical stimuli, their eye movements in the anticipation-looking phase
334 should have been random. These findings could be interpreted as another possibility that
335 infants showed the familiar preference to the color or orientation rather than
336 anticipation. In this case, infants endogenously direct their attention to the familiarized
337 feature because of the repetitive presentation of the target feature. We cannot rule out
338 this possibility completely even though infants could direct their attention to the learned
339 feature belonging to the never experienced objects in the current experiment. However,
340 in either case, the results in Experiment 2 support the feature-based attention in 7- to 8-
341 month-olds.



342

343 *Figure 3.* The result of Experiment 2.344 *Note.* Mean proportion of anticipation looking in color condition. Error bar represents *SE*.345 ****** $p < .01$ against the chance level 0.5.

346

Discussion

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In this study, we investigate the endogenous attention based on feature-based

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selection in infants using a newly developed anticipation-looking task, in which 7- to 8-

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month-old infants were presented with an animation depicting Pac-man eating one of

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two rectangles based on the color or orientation features of the rectangles. The infants'

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anticipatory looking behavior was recorded as an index of their looks based on whether

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their eyes moved to a rectangle with a specific feature (color or orientation) that would

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be eaten by Pac-man even after the Pac-man had disappeared. We found that these

354 infants, indeed, showed anticipatory looking at objects containing the specific feature.
355 Furthermore, infants could generalize the target feature, that is, infants' attention is
356 directed to the target feature endogenously even when the other feature of stimuli was
357 different from the familiarization phase. This result suggests that preverbal infants aged
358 7 to 8 months can direct their attention endogenously to a specific feature of a target.

359 It is noteworthy that infants' endogenous visual attention is directed to the
360 target feature through familiarization in the present study. This contrasts previous
361 studies examining infants' attention to objects' features because those studies have
362 mainly used tasks that depend on infants' exogenous attention and showed that infants'
363 attention is captured by salient stimuli exogenously (Adler & Gallego, 2014; Adler &
364 Orprecio, 2006; Bertin & Bhatt, 2001; Coldren & Haaf, 2000; Goldknopf et al., 2019).
365 Although infants' visual attention is prone to exogenous capture and shifts to stimuli,
366 little is known about whether their attention is endogenously directed to a target.

367 Recently, it has been reported that top-down knowledge, successfully acquired through
368 the abstract rule learning, biases the visual attention to the objects' feature in 9-month-
369 olds (Werchan & Amso, 2020). During visual searches infants can use contextual
370 knowledge of spatial locations to search for a target efficiently (Tummeltshammer &
371 Amso, 2017). Furthermore, even without familiarization and learning, infants can use

372 briefly presented visual or audio information to control visual search behavior (Mitsven,
373 Gantrell, Luck, & Oakes, 2018; Xiao & Emberson, 2019). In line with these findings,
374 our present task revealed that the visual attention of preverbal infants, aged 7 to 8
375 months, shifts to a target feature based on familiarization. This finding suggests that the
376 familiarization in the present task provides an opportunity for infants to direct their
377 attention to a specific feature between two different, but equally salient, features. Then
378 infants' visual attention is endogenously directed to the target feature.

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

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