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Visual completion of partly occluded grating in infants under 1 month of age

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Abstract

Four groups of eight infants (3 weeks of age on average) were each habituated to one of four displays consisting of a grating of either low (0.4 cpd) or high (1.2 cpd) spatial frequency, whose central portion was covered up with a horizontal occluder which was either narrow (1.33°) or broad (4.17°). These habituation displays are referred to as LN (low spatial frequency grating and narrow occluder), LB (low and broad), HN (high and narrow), and HB (high and broad) displays. Posthabituation-test displays consisted of a complete grating (CG) of the same frequency as the habituated grating along with a separate grating (SG) whose central portion was replaced with a black gap of the same height as the occluder in the habituation displays. Infants habituated to the LN display looked significantly longer at the SG than the CG display during posthabituation-test trials. Infants habituated to the LB and HN displays looked at the CG and SG displays, almost equally. In contrast, infants habituated to the HB display looked longer at the CG than the SG display. These results show that infants under 1 month of age can perceive the continuation of the grating behind the occluder, and that their visual completion on habituation displays can be evoked according to the interaction between the spatial frequency of the grating and the occluder height. © 1999 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Infants' perception of object unity and completion has been of interest to developmental psychologists and visual scientists for at least 50 years. Piaget (1952, 1954) posited that infants do not conceptualize an object's continued existence at a particular location following occlusion and displacement until 18–24 months of age.

However, several reports have provided strong evidence that Piaget's theory underestimates the perceptual abilities of young infants. For example, Kellman and his colleagues conducted a series of experiments investigating young infants' perception of object completion (Kellman & Spelke, 1983; Kellman, Spelke & Short, 1986). They presented evidence that 4-month-old infants were able to perceive the unity or connectedness of partly occluded objects. In these studies, infants were presented a moving rod whose central portion was occluded by a box, called the "rod-and-box display", until habituation of looking had occurred. Following this habituation, the infants viewed posthabituation-test displays consisting of a complete rod or two rod pieces with a visible gap corresponding to the location of the box in the habituation displays. The infants typically looked longer at the broken rod than at the complete rod. These results clearly suggest that the infants were able to perceive the hidden connectedness of the rod behind the box in the first display. Kellman has pointed out that common motion of object parts would be essential and indispensable for object unity and completion to be perceived (Kellman & Spelke, 1983; Kellman et al., 1986).

Recently, Slater and his colleagues reported that neonates preferred to look at the complete rod rather than the broken rod after habituation to the rod-and-box displays, suggesting that neonates are scarcely able to perceive object unity and completion under the

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occluded condition (Slater, Morison, Somers, Mattock, Brown & Taylor, 1990; Slater, Johnson, Kellman & Spelke, 1994; Slater, Johnson, Brown & Badenoch, 1996). Moreover, 2-month-old infants showed either equal preference for the two posthabituation-test displays (Johnson & Náñez, 1995), or else a preference for the broken rod (Johnson & Aslin, 1995).

These studies have investigated the perception of object unity, such as the connectedness of rods under a variety of conditions: for example, two rod pieces occluded by a box were moved laterally (e.g. Kellman & Spelke, 1983; Slater et al., 1990), vertically or in depth (Kellman et al., 1986); the rod-and-box displays were presented on a three-dimensional display (e.g. Kellman & Spelke, 1983; Kellman et al., 1986), or on a two-dimensional display which had no three-dimensional depth cues, such as binocular disparity or motion parallax (e.g. Johnson & Aslin, 1995; Johnson & Náñez, 1995). Moreover, Johnson and Aslin (1995, 1996) examined the effects of three-dimensional depth cues, including background texture as a supplementary depth cue, and the effect of rod alignment on young infants' perception of object unity. They suggested that several cues besides the common motion of the rods play important roles in the infants' perceptual process of object unity.

Nevertheless, these previous studies seem to have used relatively complex stimuli, such as the rod-and-box display, whose figural parameters cannot be easily quantified or compared with each other psychophysically. Moreover, concerning the stimulus size, there were large variations among the studies; for example the width of the rod and the height of the occluder in the visual angle were 0.75° and 7.9° in Kellman and Spelke (1983); Experiment 1, but 1.6° and 8.8° in Slater et al. (1990); Experiment 2. These rod-and-box displays contain various kinds of visual information, such as the size of a box, luminance difference of surfaces, edge alignment, depth cues, background texture, and so on, making it difficult to decide which figural parameters are crucial for an infant's perception of object unity and completion.

In this respect, Johnson postulated a "threshold model", suggesting that a certain threshold of visual information is required for infants to solve the object unity problem using various visual cues (Johnson & Aslin, 1996; Johnson, 1997). This model stipulates that perception of object unity occurs in infants when the sufficiency of visual information available matches the efficiency of their perceptual skills, cognitive skills, or both.

An idea similar to the threshold model led us to investigate whether or not infants less than 1 month old can perceive the continuation of a grating covered up with a horizontal occluder, when the spatial frequency of the grating and the occluder height are varied systematically. Although previous studies with rod-and-box displays have not been able to provide any evidence to prove that the infants less than 2 months old have the ability for perceptual completion, there is a possibility that they can grasp grating continuation across the occluder, because grating has been reported to be an effective stimuli to which infants less than 1 month old have recognizable responsiveness (Suter, Suter, Roessler, Parker, Armstrong & Powers, 1994). If true, infants can be expected to look longer at a separate grating than at a complete grating after habituation to the occluded grating. Such dishabituation is expected to occur depending both on the spatial frequency of the grating and on the occluder height, because both parameters would affect the sufficiency of visual information necessary for the infants to grasp the grating continuation. These expectations were confirmed by the experiment introduced below.

2. Method

2.1. Subjects

A total of 32 infants (average age, 25 days, ranging from 11 to 33 days) served as the subjects. An additional 12 infants were observed but not included among the final samples because they exhibited fussiness, sleeping, or crying during the experimental session. All these infants were selected from the maternity ward of the Kagoshima Municipal Hospital, Kagoshima city after permission had been obtained from their legal guardians. None of the subjects had any obvious ocular or other medical problems.

2.2. Apparatus and stimuli

All stimuli were designed and presented using an Apple Macintosh computer with a Sony 15-inch RGB monitor. The infant and the monitor screen were located inside an enclosure (1.5 m^2) which was made of iron poles and covered with black cloth. Two observers viewed the subject through small peepholes. The computer presented the stimulus displays, and recorded how long the infant looked at each display, according to the observers' judgments. The computer also calculated the habituation criterion for each infant, and changed the stimuli from a habituation display to two posthabituation-test displays after the criterion had been met. Neither of the observers was aware of the experimental conditions for any individual infant or of the displays presented to them. In addition, they were both naive to the hypotheses under investigation.

Fig. 1 shows four habituation displays. Each habituation display was subtended 21.5° × 26.5° in visual angle (at a viewing distance of 30 cm from the infant) and consisted of a computer-generated vertical sinusoidal grating with a white occluder. The grating had a space-average luminance of 34.5 cd/m^2 and a Michelson contrast of 0.86 modulated around the average luminance level. The maximum luminance level of the grating was 64 cd/m^2 while the minimum was 5 cd/m^2 which was equal to the background level of the monitor screen. The conditions provided for each habituation display were as follows. In the LN (low spatial frequency grating and narrow occluder) display, the spatial frequency was 0.4 cpd, and the occluder height was 1.33°; in the LB (low frequency grating and broad occluder) display, these were 0.4 cpd and 4.17°; in the HN (high frequency grating and narrow occluder) display, these were 1.2 cpd and 1.33°; and in the HB (high frequency grating and broad occluder) display, these were 1.2 cpd and 4.17°, respectively. In each display, the grating drifted continuously from right to left at a rate of 2 cycles/s.

There were two posthabituation-test displays following each habituation display, comprising the SG (separate grating) display plus the CG (complete grating) display (Fig. 2). The spatial frequency of the grating of the SG and CG displays always equalled that of the earlier habituation display. The SG display had a black horizontal gap, whose luminance (5 cd/m^2) was equal to the background level of the monitor screen, across the central portion, and the height of this gap was always equal to the occluder height of the earlier habituation display, whereas the CG display had no such gap. The grating of the posthabituation-test displays did not move during the presentation.

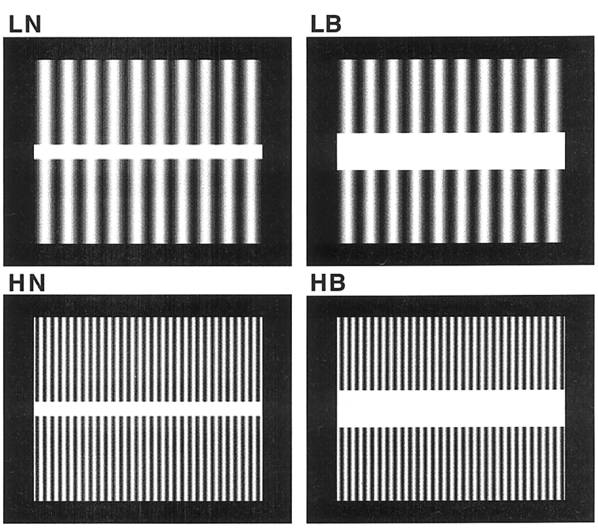

Fig. 1. Habituation displays comprise LN, LB, HN and HB. (LN) Low spatial frequency grating and narrow occluder display. (LB) Low spatial frequency grating and broad occluder display. (HN) High spatial frequency grating and narrow occluder display. (HB) High spatial frequency grating and broad occluder display.

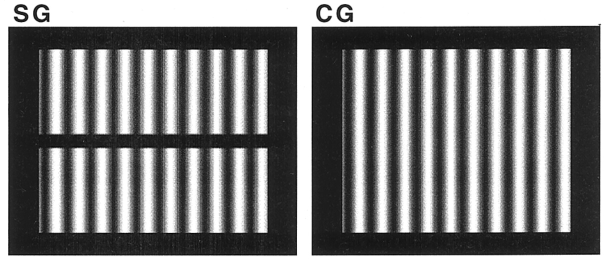

Fig. 2. Posthabituation-test displays comprise SG and CG. (SG) Separate grating display. (CG) Complete grating display. Only displays used for the LN habituation display are depicted.

2.3. Procedure

At the beginning of the experimental session, each subject was randomly assigned to view one of the four habituation displays: LN, LB, HN or HB. The mean age of the infants assigned to the groups was 24.4, 24.0, 24.9, and 26.8 days, respectively. Therefore, each habituation display was viewed by eight infants. There was no significant difference between them [$F(3, 28) = 0.439$, $P = 0.7269$].

After becoming habituated to one of the four habituation displays, all the infants viewed the two posthabituation-test displays SG and CG alternately, for three trials each, in a counterbalanced order. Half the infants in each habituation group viewed the SG display first, while the other half viewed the CG display first.

The experimental session began once the infant remained in a calm but alert state, usually shortly before or after a feed. During the experiment, the infant lay on his or her back in a cot with both sides of his or her head fixed loosely by sand-bags, and the cot was then placed in the center of the experimental enclosure approximately 30 cm from the display monitor. The monitor was darkened prior to the beginning of each trial. The black display luminance was 5 cd/m^2. The habituation display was presented repeatedly until each infant met the habituation criterion. According to a common infant-control procedure (Horowitz, Paden, Bhana & Self, 1972), the criterion was defined as when the sum of the time spent looking during three consecutive trials, equalled less than half the total looking time during the first three trials. Between trials, a smiling-face mark was presented in the center of the monitor during the interval in order to hold the infant's attention. After the infant had fixated on the display for at least 1 s, the habituation display or posthabituation-test display was then presented. The trial continued until the infant looked away continuously for 2 s. The dependent variable in each trial was the looking time accumulated before a look-away occurred. Each observer independently indicated how long the infant looked at the display by pressing the keys of a computer and holding it down for as long as the infant maintained his or her gaze on the display. These key-pressings were recorded by the computer, synchronized with the displays presented. The posthabituation-test displays were seen three times each, alternately, for a total of six posthabituation trials.

3. Results

The looking time was calculated by averaging the two observers' judgements for each posthabituation trial. Inter-observer agreement was high for the infants' data included in the analyses (Pearson correlations averaged 0.94, range = 0.91–0.99).

Fig. 3 shows the time spent looking at the displays averaged over the eight infants in each group. Logarithmic transformed looking times were subjected to a two (posthabituation-test display: SG vs. CG) × three (posthabituation trials: first, second, or third) ANOVA with repeated measurements for each habituation condition.

Following LN habituation, the posthabituation-test display produced a significant main effect, with the infants looking significantly longer at the SG than the CG display [$F(1, 7) = 9.663$, $P < 0.05$]. This was true for all eight infants. There was also a significant effect of posthabituation trials, resulting from a decline in the looking time [$F(2, 14) = 7.096$, $P < 0.01$]. There was no significant interaction.

Following LB habituation, there were no significant main effects or interactions. Following HN habituation, there was a significant effect of trials, resulting from a decline in the looking time [$F(2, 14) = 20.201$, $P < 0.001$]. There were no other significant main effects or interactions.

Finally, following HB habituation, there was a marginally significant effect produced by the posthabituation-test display [$F(1, 7) = 4.207$, $P < 0.079$], showing a tendency for the infants to look longer at the CG than the SG display, contrary to the findings with LN habituation. There was also a significant effect of posthabituation trials [$F(2, 14) = 3.935$, $P < 0.05$]. There was no significant interaction.

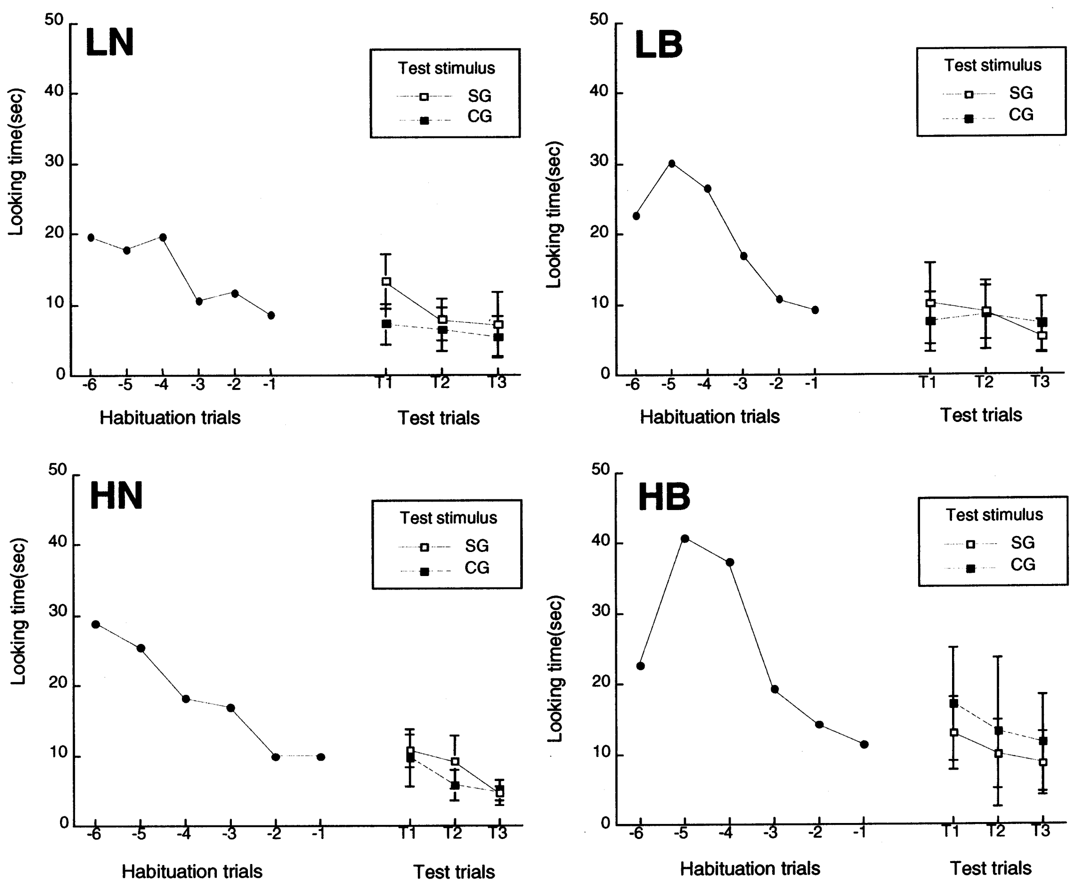

Fig. 3. The obtained dishabituation pattern in each condition. These figures show the results (group means) with LN, LB, HN, and HB displays. The vertical bars in posthabituation trials represent standard errors of the mean.

4. Discussion

These results clearly demonstrate that infants less than 1 month old habituated to the LN display were dishabituated to the separate grating display, indicating that they perceived the continuation of occluded grating in the habituation pattern. In contrast, those infants habituated to the HB display tended to be dishabituated to the complete grating, suggesting that they did not perceive the grating continuation. The infants habituated to the LB and HN displays, showed no dishabituation to either of the posthabituation-test displays.

Previous studies (Slater et al., 1990, 1996; Johnson & Náñez, 1995) reported that neonates and 2-month-old infants could not perceive object unity in two- or three-dimensional displays. However, it would appear that the rod-and-box displays used in these studies were too complicated for infants' spatial mechanisms within the first month. In contrast, the displays in the present study contained relatively simple visual information; periodic luminance alternations of the grating drifting with a steady temporal frequency and the homogeneous luminance of the static occluder. These simple spatial stimulations may have been just sufficiently limited for an infant's visual system to allow the infants to complete the unseen parts of the grating. These views are in line with the threshold model (Johnson & Aslin, 1996; Johnson, 1997) that describes the relationship between the sufficiency of visual information and the efficiency of an infant's perceptual and cognitive skills. That is, the spatial frequency of the grating and the occluder height in the LN display seemed to be sufficient for the infants to perceive the continuation of gratings, but this was not so with the other displays.

It is well known that the spatial vision of young infants is quite limited compared to that of adults with regard to various aspects including spatial contrast sensitivity, especially for high-frequency gratings (e.g. Norcia & Tyler, 1985; Wilson, 1988). However the luminance contrast of the gratings used in the present displays seemed to be high enough (0.86) even for infants who are less than 1 month old, considering their spatial contrast sensitivity function (CSF) (e.g. Norcia & Tyler, 1985; Wilson, 1988). The spatial frequency grating in the HB display may have been close to the upper limits of acuity for the infants used in this study. Even if some infants had not perceived the high spatial frequency grating with the HB display, they should have become dishabituated to the separate grating which had a larger luminance decrement produced by the black gap (5 cd/m^2) than the complete grating (34.5 cd/m^2 in space average luminance), when we consider that all the habituation displays actually had a white occluder (64 cd/m^2). This is because infants less than 1 month old have been reported to detect luminance decrements better than increments (Mercer, Courage & Adams, 1991; Adams, Courage & Mercer, 1994). In contrast, the present results show that infants habituated to the HB display tended to look longer at the complete grating display than at the separate grating display. This fact enhances the possibility that infants are able to grasp the grating itself within their first month, but unable to perceive the grating continuation when the spatial frequency of the grating is high and the occluder height is large.

In psychophysical experiments concerning adults' visual completion, similar displays (a vertical grating covered up with a horizontal occluder) have been used (Tynan & Sekuler, 1975; Gyoba, 1983; Brown & Weisstein, 1991). In these patterns, the top and bottom sections of the grating are initially perceived as continuing amodally behind the occluder. However, an interrupted grating often appears modally to complete in front of the occluded region. This kind of completion effect is called "visual phantoms" (Tynan & Sekuler, 1975). It has been reported that visual phantoms can be perceived when the occluder height does not exceed an extent corresponding to two to six cycles (in period) of the inducing grating frequency (Tynan & Sekuler, 1975; Gyoba, 1983). In the present study when the infants showed perceptual completion following habituation to the LN display, the occluder height was 0.53 cycles (in period) of the grating frequency, whereas when the occluder height was five cycles, the infants did not perceive the grating continuation following habituation to the HB display. With the LB and HN displays where the occluder height was 1.67 and 1.60 cycles, respectively, the data were ambiguous. These results are almost in line with those of adult studies.

The above-mentioned agreements lead to the following discussion. In the case of the rod-and-box display, infants are presumably supposed to perceive the rod continuation amodally. In contrast, the displays used in the present study include the possibility that the grating is completed modally. For the infants habituated to the HB display, we can conclude that they did not perceive the grating continuation either amodally or modally, because the obtained results suggest that they perceived two separate gratings in the habituation display consisting of the high frequency grating and the broad occluder. However, the question which remains to be answered is whether the infants habituated to the LN display perceived the grating continuation modally or amodally. The low grating frequency and the narrow occluder height of the LN display, including the luminance relationships between the grating and the occluder, are suitable for seeing white visual phantoms which appear connecting the white bars of the grating across the occluder (Sakurai & Gyoba, 1985). It has been reported that phantom visibility is severely affected by the occluder luminance (Sakurai & Gyoba, 1985). Therefore, using larger sample sizes, further experiments in which the luminance of the occluder is manipulated are necessary in order to determine whether infants less than 1 month old perceive grating continuation modally or amodally.

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