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The Role of Three-dimensional Depth Cues in Infants' Perception of Partly Occluded Objects

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Newborn infants were familiarized to a three-dimensional display consisting of a rod which moved behind a central occluder, so that only the top and bottom of the rod were visible. The infants' eyes were 38 cm from the rod and the occluder was 15 cm in front of the rod, a separation intended to ensure that the gap between the two was detected by the infants. On subsequent test trials the infants looked longer at a complete rod than at two rod pieces, suggesting that the hidden unity, or completeness of the rod had not been perceived. In a study by Johnson and Náñez (in press), using computer-generated stimuli, 4-month-olds perceived the hidden unity of a similar display presented on a VDU in the complete absence of three-dimensional depth cues. Taken together, these findings suggest that, for these displays, perception of three-dimensional depth cues is not necessary for the detection of the unity of partially hidden objects. It is suggested that age changes in early infancy in the perception of occluded objects may result either from the emergence of abilities to perceive objects from kinematic information or from the emergence of sensitivity to that information itself.

Key words: Infancy, perception, occluded objects.

In experiments described by Kellman and Spelke (1983) and Kellman *et al.* (1986), 4-month-old infants were habituated to a stimulus (usually a rod) which moved behind a central occluder, so that only the top and bottom of the rod were visible. On subsequent test trials the infants increased responding to a stimulus consisting of two object pieces with a gap where the occluded block had been, but they did not increase responding to a continuous rod. These results suggest that the infants perceived a connected, continuous rod during the habituation trials, detecting object unity

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from the common movements of the top and bottom of the display. Infants' novelty response to the two rod pieces is of particular interest because the broken display is literally closer to what the babies saw on the habituating trials than the continuous rod; the babies had to *infer* the existence of the missing, middle portion of the rod from the moving display.

These results are consistent with the view that 'perception of objects may depend on an inherent conception of what an object is' (Kellman and Spelke, 1983, p. 483). Spelke (1985) put forward the view that infants begin life with an innate conception of the underlying unity, persistence and coherence of objects. In order to test this view, Slater *et al.* (1990) repeated the basic experiment with newborn infants and discovered that they do not act like 4-month-olds. For the newborns the *continuous* rod was the novel stimulus, a finding which suggests that perhaps infants' understanding of objects changes in the early months from birth, and that at birth perception is dominated by that which is visible, not by that which can be inferred.

There are, however, alternative interpretations of the age differences. In particular, developmental changes in object perception may result from an increase in sensitivity to the information on which object perception depends: information about the spatial arrangements and the motions of surfaces. If newborn infants cannot perceive how two surfaces are arranged in depth or whether two surfaces are moving together, then they will not be able to use the depth and motion relations between the surfaces to determine how the surfaces connect to form objects.

This research note presents data bearing on the thesis that changes in perceived depth relations underlie the changes in object perception reported by Slater *et al.* (1990). In Slater *et al.*'s experiments, the gap between the far edge of the occluder and the near edge of the rod was small (about 4 mm). Given the poor visual acuity of newborn infants, it is possible that this gap was not detectable, and that newborn infants therefore saw the rod as moving *in the same plane* as the occluder, rather than behind it. In contrast, this gap may have been detectable by 4-month-olds, because of the substantial increase in visual acuity between these ages. If this interpretation is correct, then it would be quite reasonable for the newborns to perceive the continuous rod as novel on the test trials; this would not imply an inability to 'fill in' the unseen portion of the rod, since there would be nothing to fill in!

There are two ways of testing this interpretation. One would be to test newborn infants in a condition where the gap between occluder and rod was large enough to be reasonably confident that they detected the separation, and the other would be to test 4-month-olds in a condition where the rod *did* move in the same plane as the occluder; if the infants gave a novelty preference for the rod pieces in this latter condition, this would indicate that perception of the separation was not critical to perception of a complete rod. The study described here presents evidence concerning the first test. Findings by Johnson and Náñez (in press) bearing on the second test are described later.

METHOD

Subjects

The sample consisted of 16 newborn babies, nine boys and seven girls, mean age 3 days, 9 hr (range 1 day, 10 hr–6 days, 13 hr), recruited from the maternity ward of the Royal Devon and Exeter Hospital, Heavitree, Exeter, England, and throughout testing they remained in the state of alert inactivity (Ashton, 1973).

Procedure

An infant-controlled habituation procedure was used (Horowitz *et al.*, 1972; Slater *et al.*, 1990). Each newborn subject was tested while positioned seated upright on one experimenter's knee, and with his/her eyes 40 cm (±3 cm) from the centre of a matt white stimulus screen. During habituation trials a black rod, 18 cm high and 0.8 cm wide, angled 20° from the vertical, moved back and forth behind a central grey occluder, the occluder being 4.4 cm high and 8.3 cm wide. One complete cycle of movement of the rod took 4 s, and the rod moved 2.5 cm to each side of the centre point; at no time did the rod move far enough for its occluded centre portion to become visible. The occluder was 23 cm from the infant's eyes and the front surface of the moving rod was 38 cm from the viewing position. Thus the gap between the nearer occluder and the moving rod was 15 cm, and it is very likely that this separation would be detected by the subjects; in other experiments newborns have shown reliable changes in preferential looking in response to smaller changes of stimulus distance (Slater *et al.*, 1990). The criterion of habituation was a decline in looking to at least 50% of the accumulated looking time on the first three trials, and on the test trials

suggest rod pieces, whereas the common motion of the rod pieces would suggest a single rod. We do not know what would happen in such a case, although Needham and Baillargeon (1993) suggest that different responses might result in this sort of situation depending on whether or not the infants 'are able to produce an explanation for the (impossible) events' (p. 144). Nevertheless, the findings from the study described here with newborn babies, in association with Johnson and Náñez's findings with 4-month-olds, give convincing evidence that perception of the three-dimensional depth relationship between the occluded object (the rod) and the occluder is not an essential factor in making the inference that the rod is (or is not) complete or continuous; 4-month-olds 'fill in' the occluded portions of objects in the absence of 3-D information, while newborn infants fail to fill in the occluded parts despite being given adequate 3-D depth information.

There appears to be an age-related transition period in infants' perception of these displays. Johnson and Náñez (in press), using VDU displays, found that 2-month-olds showed no difference in looking time to the two test objects. The pattern of equal looking has been observed often with 4-month-olds viewing stationary displays, and in some cases follow-up tests suggest it indicates neutrality about how objects continue behind the occluder (e.g. Kellman and Spelke, 1983, expt 3). It would be tempting to interpret this finding in terms of 2-month-olds' inability to resolve the cue conflict described earlier; however, one of us (Slater), in unpublished research, has found that 1- and 2-month-olds similarly show no difference in looking times to the test objects, when the displays shown both on habituation and test are real objects. A proper interpretation of this apparent transition period (and, indeed, of the changes from birth to 4 months) awaits future research.

If developing sensitivity to three-dimensional depth information does not account for the differences in the responses of newborn and 4-month-old infants to partly occluded object displays, what does? One possibility is that increasing sensitivity to two-dimensional depth cues, either static (in particular interposition) or kinematic (in particular, accretion and deletion of surface texture), underlies this change. This possibility is unlikely, however. Four-month-old infants do not appear to be sensitive to static, pictorial depth information (Yonas and Granrud, 1984). Although 4-month-old infants do appear sensitive to kinematic depth information such as accretion and deletion of texture or boundary (Craton and Yonas, 1990), these sources of information were not available in the occlusion displays used in the present and past research.

One critical factor is an ability to appreciate that the common motion of the two rod pieces means that they are connected. Wattam-Bell (1991, 1992) presents evidence to suggest that functional cortical direction-selective motion detectors might emerge between 1 and 2 months of age. Johnson (1990), in a paper on cortical maturation, uses human anatomical work and evidence from monkey physiology to speculate that mechanisms for detecting coherent motion mature at about 2 months. It might, therefore, be the case that the newborn infant's limitations result from an inability to detect the common motion *per se* of the two rod pieces, rather than an inability to make perceptual inferences. The finding that 1- and 2-month-olds seem to be in a transition period with respect to their perception of these displays might thus be explicable in terms of the immaturity to emerging motion-detectors.

The findings from the present study, taken together with the findings from the study by Johnson and Náñez, suggest that detection of the three-dimensional depth relationship between object and occluder is not critical to perception of the completeness (or incompleteness) of a partly occluded object. For the displays used in these studies 4-month-old infants clearly perceive object unity, while newborn infants may not. Slater *et al.* (1990) have argued that newborn infants 'appear to perceive only that which is immediately visible, and they seem to be unable to make perceptual inferences from visual input' (p. 33), but the considerations discussed above suggest that such a conclusion, while it might ultimately be found to hold, is unwarranted at the present time. Since these issues bear on the origins of object perception and understanding, studies intended to distinguish between the various interpretations of the age-related changes in early infancy would be of great interest.

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