

wood (8), who discuss the controversial position of tropidophine boas relative to other primitive snakes.

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Development of Sensitivity to Pictorial Depth

Abstract. *Sensitivity to static pictorial information for depth develops between 22 and 26 weeks of age. When conflicting binocular and surface-texture information was minimized, 26- to 30-week-old infants directed their reaching to the apparently closer side of a photograph of a window rotated in depth. Younger infants, from 20 to 22 weeks of age, did not direct their reaching to the pictorially nearer side of the display but did reach with a high degree of directionality when presented with a real window rotated in depth.*

In the 15th century, Leonardo da Vinci described a set of techniques for representing the third dimension on a flat canvas. He pointed out that light, shadow, and linear, detail, and aerial perspective could specify distance in a painting, but that other depth information, such as movement and binocular parallax, could not be used on a flat surface. More recently, psychologists have described additional monocular cues for depth, including relative size, interposition, and texture gradients (1). Olson and Boswell have demonstrated that 2-year-old children will respond to pictorial depth as specified by interposition and relative height in the picture plane but not to the depth information provided by relative size (2). Although earlier research has suggested that young infants are sensitive to binocular and kinetic information for depth, there are reports that infants younger than 16 weeks of age are insensitive to pictorial depth (3). Our study provides evidence that when conflicting binocular and surface information is minimized, infants from 26 to 30 weeks of age are sensitive to pictorial depth; younger infants from 20 to 22 weeks of age do not show such sensitivity.

The pictorial display used in these experiments was a fronto-parallel Ames trapezoidal window (4), which creates an effective illusion under monocular viewing of a rectangular window oriented at 45° to the viewer, such that one side appears closer than the other. We hypothesized that if an infant were sensitive to the pictorial information for depth specified in the trapezoidal window, we would expect his or her reaching to be directed to the apparently nearer side.

Other researchers have reported that an infant will reach more frequently to a

near rather than a far object (5). In a preliminary experiment, we determined that infants would direct their reaches with enough accuracy to exhibit sensitivity to the differential distances of the two sides of a slanted surface. Thirteen 26- to 30-week-old infants were presented with a real rectangular window rotated 45° about a vertical axis, with either the left or the right side of the window brought nearer to the infant. Presentations were randomized as to which side was closer. Direction of reaching was scored from a videotape recording. The infants' reaches were directed toward the closer side of the window on 75 percent of the trials, and toward the farther side on only 6 percent of the trials. The remaining reaches were directed either to the middle or simultaneously to both sides of the display.

For experiment 1, the trapezoidal window was created by photographing from

21 cm a real rectangular window rotated 45° about the vertical axis (Fig. 1A). The resulting black-and-white matte photograph was enlarged during printing to produce a retinal image that was the same size as that projected by the real window when viewed from 21 cm. The photograph was glued to a metal sheet cut to match the shape of the pictured object, allowing the infant to see through the internal spaces of the display and thereby minimizing the pictorial surface texture. The larger and apparently nearer side was actually 25.5 cm in height, and the smaller side, 14 cm in height. The width of the display was 20.3 cm.

A control display, lacking a pictorial surface, was created to test for the possibility that reaching might be determined by the unequal size of the sides of the trapezoidal display (Fig. 1B). This display was produced by photographing the real rectangular window in the fronto-parallel plane. Two prints were made, one matching the vertical dimensions of the small side of the trapezoidal print, and one matching the larger side. The two prints were combined, and the shape was cut from metal. Again, the internal spaces were removed. The surface was painted gray to match approximately the overall reflectance of the trapezoidal display. The control display therefore appeared to be a single object, with one side smaller than the other side, but with no information that the sides were at different distances.

Fifty infants from 26 to 30 weeks of age served as subjects; half were presented with the trapezoidal display, and half with the control display. To eliminate binocular information, each infant wore an eye patch over the left eye or a small pair of eyeglass frames with the left eye occluded. The infant sat upright in a

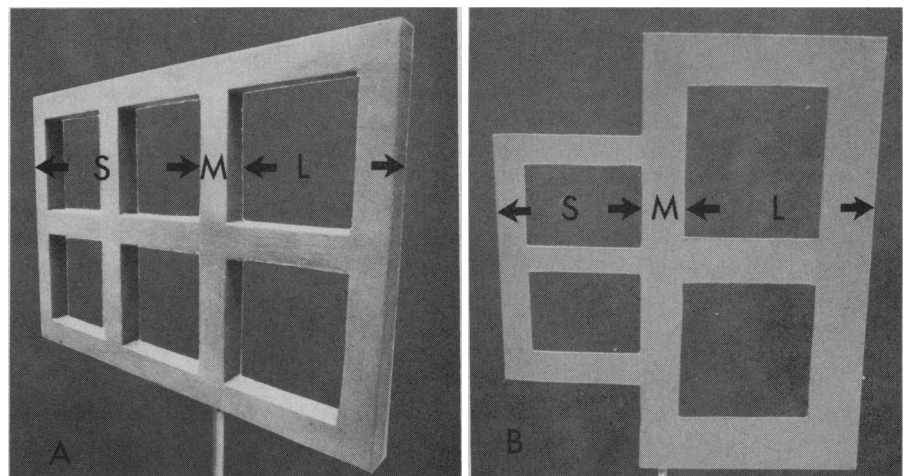


Fig. 1. Display windows, mounted on rods 3 feet (0.914 m) in front of dark blue cloth background. (A) Fronto-parallel Ames trapezoidal window. (B) Control display. Abbreviations: L, large side; M, middle area; and S, small side.

small chair and was held about the waist by a parent. The display was presented in the fronto-parallel plane, approximately 21 cm from the infant's eye. Each trial began when the experimenter removed a cardboard screen from in front of the display, and the trial was concluded when the infant touched the display. The presentations were continued until the infant stopped reaching to the display. Each session was about 30 minutes long, including one or two rest periods. Six or more reaches were required from the infant for the data to be included in the analysis (6). For half of the trials, the large side of the window was to the left of the infant; for the other half, the larger side was to the right. Trials were videotaped with an overhead camera.

Reaching was scored from the videotape recordings according to the location on the window that was first contacted by the infant. The display was divided into three regions for scoring: the large side, the middle area, and the small side (7).

Because the number of reaches varied among the infants [mean (\bar{X}) = 14], we calculated for each infant the proportion of reaches that contacted the three regions of the displays. To assess directionality of reaching, the difference between the proportion of reaches resulting in contact with the large side (L) and the proportion of reaches contacting the small side (S) was determined for each infant (Table 1). There was a significant difference between the mean difference scores ($L - S$) [$t(48) = 2.54, P < .05$], indicating that the infants showed a greater preference to reach for the larger side of the trapezoidal window than for the larger side of the control display.

In experiment 2, 50 infants 26 to 30 weeks old were randomly assigned to either binocular or monocular viewing of the trapezoidal display (8). Binocular depth information, which specifies that the display is in the fronto-parallel plane, was expected to override the pictorial depth information for infants as it does for adults (9). The infants viewing the display monocularly had the left eye occluded. The methods of presentation, scoring, and data analysis were the same as in experiment 1. Results for the group that viewed the display monocularly replicated the results of the first experiment, showing a preference to reach to the larger and pictorially nearer side. Reaching in the binocularly viewing group showed less directionality (Table 1). The mean difference score ($L - S$) for the two groups was significantly different [$t(48) = 2.36, P < .05$]. The decrease in

Table 1. Means (\bar{X}) and standard deviations (S.D.) in proportion to contacts to three regions of display windows. The display viewed in experiment 2 was the trapezoidal window. Abbreviations: L , large; M , middle; S , small; $L - S$, difference in proportion of contacts with L and S .

	L	M	S	$L - S$
<i>Experiment 1</i>				
Trapezoidal				
\bar{X}	.49	.25	.26	.23
S.D.	.19	.22	.17	.28
Control				
\bar{X}	.37	.32	.31	.06
S.D.	.13	.20	.14	.19
<i>Experiment 2</i>				
Binocular				
\bar{X}	.36	.38	.26	.10
S.D.	.15	.23	.13	.16
Monocular				
\bar{X}	.49	.27	.24	.25
S.D.	.22	.27	.14	.27
<i>Experiment 3</i>				
Trapezoidal				
\bar{X}	.40	.29	.32	.08
S.D.	.14	.23	.15	.17
Real window				
\bar{X}	.77	.20	.03	.74
S.D.	.16	.15	.06	.19

the potency of the pictorial cues under binocular viewing suggests that, for 26- to 30-week-old infants, conflicting binocular information indicates that the display is in fact in the fronto-parallel plane.

Although experiment 1 ruled out the possibility that the size of the sides of the display determined the direction of the reaching, it is possible that the results might be attributable to a preference to reach for some other property, such as acute angles. However, the finding that the infants reached with reduced directionality when binocularly viewing the same display supports the hypothesis that pictorial depth accounted for the preferential reaching observed. We therefore have evidence that when conflicting binocular information is absent, 26- to 30-week-old infants are responsive to pictorial cues for depth.

To determine the onset of sensitivity to pictorial depth information, we investigated the responsiveness of infants from 20 to 22 weeks of age in experiment 3. Methods of presentation, scoring, and data analysis were the same as in the previous experiments. The displays were viewed monocularly. A group of 26 infants 20 to 22 weeks old were presented with the real rectangular window rotated 45° about the vertical axis (Table 1). Infants at this age consistently reached to the closer side of the real window. A second group of 26 infants 20 to 22 weeks old were presented with the trapezoidal window display in the fronto-parallel plane (10). We found no evidence of di-

rectional reaching with this display (Table 1). This result suggests that, at this age, (i) motion parallax or accommodation are effective sources of depth information and (ii) pictorial information is ineffective. The differences in amount of directional reaching among the 20- to 22-week-olds and the two groups of older infants, presented monocularly with the trapezoidal window, were significant [$F(2, 72) = 6.4, P < .01$]. Tukey post hoc comparisons revealed that there were no significant differences in reaching between the two older groups but that the younger groups reached with significantly less directionality ($P < .01$).

Ames (4) has argued that experience in a carpentered environment is necessary for the development of pictorial depth sensitivity. In contrast, Gibson (11) has provided the basis for a genetic account of this sensitivity. He asserted that since objects tend to be distributed over the ground with an even scatter, the spacing between elements of texture tends to be regular. This fact provides the basis for Gibson's texture-gradient theory of slant perception and gives plausibility to the notion that sensitivity to the texture gradient presented in our displays may have developed over phylogenetic rather than ontogenetic history. The finding that sensitivity appears in humans in the short interval between the 22nd and 26th weeks would seem to raise doubts about the experiential theory. However, studies of infants raised in less carpentered environments and studies of other species raised in controlled environments should help to provide the final answer to the question of the role of early experience in responsiveness to pictorial depth information.

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6. Due to discomfort with the eye occluder, fussiness, or poor reaching ability, an additional 18 infants, 12 from the trapezoidal display condition and 6 from the control display condition, contacted the display fewer than six times and were eliminated from the study.

7. Interobserver agreement for the three scorers was 93 percent and 94 percent on judgments of location contacted. The infants would frequently contact the display with both hands. If one hand contacted the display 1/2 second or more before the other hand, the location of the first contact was scored. If one hand touched the middle region while the other hand simultaneously (within 1/2 second) contacted a side, the reach to the side was scored. If the infant simultaneously contacted both the large and small regions, the reach was classified with responses to the middle region.
8. Data on an additional three infants, one from the binocularly viewing group and two from the monocular group, was excluded from analysis because of insufficient reaching.
9. W. Schrieber, *Sehen. Z. Psychol.* 96, 113 (1925).
10. A high percentage of infants in the 20- to 22-

week-old group failed to reach six times. The 26 infants in each condition remained after eliminating data on 44 infants because of insufficient reaching; 25 were from the group viewing the real window and 11 were from the group viewing the trapezoidal window.

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12. Supported by NICHD grants HD-05027 to the Institute of Child Development and HD-01136 to the Center for Research in Human Learning and by a National Institute of Mental Health postdoctoral fellowship to W.T.C. We thank D. Miller for editorial assistance; B. Bental and G. Paajanen for laboratory assistance; and P. Salapatek, H. Pick, S. Phipps-Yonas, and T. Trabasso for helpful comments.

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Behavior and the Crustacean Molt Cycle:

Changes in Aggression of *Homarus americanus*

Abstract. *The phase of the molt cycle affects dominance status and the performance of agonistic acts in individual juvenile lobsters (Homarus americanus). Lobsters in the midphase of proecdysis are more aggressive than those in intermolt; the latter are more aggressive than lobsters in early or late proecdysis and those in postecdysis.*

Although most crustaceans are subject to continual periodic ecdysis throughout their lives, aggression has not been fully examined in the context of the molt cycle. Such diverse physiological processes as hormone production, calcium deposition, limb regeneration, and protein metabolism (1) all undergo profound changes during the molt cycle. Concomitant changes in a crustacean's behavior should also be expected. Food selection and intake vary with the molt cycle in lobsters (2), and locomotor activity and aggression vary with the stage of the molt cycle in stomatopods (3).

Numerous factors affect aggression. Most previous studies focused on size, sex, food, and shelter availability (4). In this report, we describe variation in the agonistic behavior of the American lobster during its molt cycle.

The crustacean molt cycle can be subdivided into phases (molt states) correlated with known physiological and behavioral events (5-7). In this study, lobsters that had molted within 12 hours were operationally defined as being in state A; those 48 to 96 hours postmolt were considered in state B. These times fall within the ranges given by Passano (7). Hard-shelled lobsters were differentiated as C, D₀, D₁, D₂, and D₃ by Aiken's technique of examining setal development in the pleopods (5).

Juvenile lobsters, 10 and 11 molts from hatching (about 6 months), all in apparent good health and not missing appendages, were chosen for this experiment. The subjects had been cultured in a controlled seawater system and maintained in physical isolation for at least three

molt cycles. The sex, wet weight, and molt state of all subjects were determined (8). Pairs consisting of a control (state C) and a target lobster in one of the seven molt states were selected. They were of the same stage (10 or 11), sex, and approximate weight (9). Control and target lobsters were used only once.

Paired lobsters were placed into 7.6-liter aquariums (one pair per tank) on the day of the molt-state determination. Individuals were separated by an opaque divider, and allowed to acclimate to the tank for 24 to 28 hours. A shorter acclimation period (8 to 10 hours) was necessary for A-C and D₃-C pairs because of the brief duration of the A and D₃ molt states. Animals were not fed after the molt state was determined, nor during the observations. Shelter was not provided, but a 3-cm layer of silica sand covered the bottoms of the aquariums. Temperature and photoperiod were maintained as in the previous holding

Table 1. Number of target lobsters in seven molt states grouped by social rank on the basis of an individual's time spent in winning, even, or losing agonistic encounters with state C (control) lobsters.

Molt state	Social rank		
	Dominant	Equal	Subordinate
A	0	0	5
B	0	0	10
C	4	3	7
D ₀	1	3	8
D ₁	9	1	1
D ₂	4	3	0
D ₃	0	0	7

conditions (22°C; 14 hours of light in 24 hours, turned on at 0400 hours).

Fifteen-minute observations on pairs were conducted after the lights went out, between 1830 and 2130 hours. Observations were made from behind a blind, under red illumination. Three aspects of agonistic behavior were studied: (i) the type and duration of encounters, (ii) the frequency and duration of acts within these encounters, and (iii) the intra-individual act sequences. Data were simultaneously recorded onto an event recorder (Esterline-Angus) and an audiotape. The data presented here are for the target lobsters only.

Each agonistic encounter was classified as either "won" (control lobster withdrew), "lost" (target lobster withdrew), or "even" (both withdrew), and its duration was noted. A target lobster that spent significantly more than 50 percent of its total agonistic time in one of these three types of encounters was assigned the appropriate social rank (dominant, subordinate, or equal). Characterization was clear in all cases, with 84 percent of the target lobsters involved in a single class encounter in excess of 75 percent of their total agonistic time. Molt state had an obvious effect on dominance (Table 1) ($\chi^2 = 44.96$, d.f. = 12, $P < .001$). Target lobsters in D₁ and D₂ were dominant or equal, but in A, B, and D₃ they were subordinate to control animals. There was no significant difference in the distribution of social ranks between C and D₀ target lobsters when this behavioral measure was used ($\chi^2 = 1.71$, d.f. = 2, $P > .05$).

During agonistic encounters ten acts were scored: approach, meral spread, antenna touch, claw touch, fight, freeze, back, slow withdrawal, rapid withdrawal, and abdominal flex (10). A two-way analysis of variance tested the effects of molt state and sex on the frequency and duration of each act. We will address only the effect of molt state in this report. In eight of the ten acts, there was a significant difference ($\alpha = .05$) attributable to the molt state in the mean frequency [meral spread: $F(6, 49) = 8.45$; abdominal flex: $F(6, 49) = 8.11$] or duration [approach: $F(6, 49) = 7.46$; rapid withdrawal: $F(6, 49) = 15.27$] (Fig. 1). Only claw touch and slow withdrawal did not statistically differ with molt state. The Student-Newman-Keuls test for multiple comparisons among means based on unequal sample sizes was used to determine where differences existed (which molt states were to be grouped). Each act varied uniquely with molt state, but there were several typical trends in the data (Fig. 1). During the