Research Article

INFANTS AND TODDLERS DISCRIMINATE AMOUNT: Are They Measuring?

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Abstract—*Four experiments that show an early ability to encode and retain information about extent are presented. We found that infants discriminate between the heights of dowels in a habituation task. We also found that toddlers discriminate between heights on a choice task in which a target dowel is presented and removed and they then choose between the target and a foil. Until 4 years of age, however, discrimination occurs only in the presence of a perceptually salient standard. Adults do not require a perceptually present standard; they can assess extent across temporal or spatial gaps by imposing a standard (measure). The present findings indicate that infants and toddlers do not possess an adult ability to establish extent, but that they do possess a skill that provides a start point for this important intellectual achievement.*

The present article concerns the emergence in childhood of the ability to encode the extent of a continuous quantity (amount of stuff). Piaget, Inhelder, and Szeminska (1960) claimed that the ability to determine extent does not emerge until the school-age years. Their evidence was from a study in which children were asked to build a tower the same height as a model tower a few feet away on a higher table. The children were provided with a stick the same length as the model tower, but were not instructed about its use. Until approximately age 7, they could not tell whether their tower matched the model, nor did they use the stick to compare height. Piaget argued that to estimate extent, it is essential to understand the role of a standard.

Contrary to the findings of Piaget et al., there is evidence that even infants are sensitive to extent. Baillargeon (1991) found that infants could encode the height of a target object. The infants were shown an object that was then occluded by a drawbridge that rotated upward in front of it. Looking times increased when the drawbridge rotated past the point where its movement would be stopped by the object. Sensitivity to target height was enhanced when a visible duplicate object was presented alongside the target. More recently, Gao, Levine, and Huttenlocher (2000) found that infants could encode the amount of liquid in a container. The infants were habituated to a particular amount of liquid. When a changed amount was shown in an identical container a fixed distance away,[1] infants dishabituated, looking longer at the new amount. A parallel result was obtained for space. Newcombe, Huttenlocher, and Learmonth (2000) studied infants' ability to discriminate locations in a long, narrow sandbox (amount of distance). The infants were repeatedly shown hiding and retrieval of an object at the same location. Looking time decreased over trials. Next, the object was hidden in the same location as previously, but was retrieved at a location 6 in. away. Infants looked longer in this condition. In all three of these infant studies, information about extent was coded and retained.

At first glance, these findings suggest that the ability to encode extent is present from the start of life, and that Piaget's task simply taps an elaboration of this early ability. However, it is important to take a closer look to determine whether the mental processes required in these infant tasks are similar to those that underlie adult ability to encode extent. When stimuli are presented together and aligned, their extents can be compared directly. However, when stimuli are displaced in time or space, a standard stimulus must be used to compare the stimuli; a person may actually move the standard into alignment with each target stimulus, or the alignment process can be imagined (the mental processes involved in imagining alignment need not be conscious). In the infant studies just described, comparisons had to be made over time, so a standard was necessary. However, in these studies, potential standards were perceptually present. The target stimuli in the second and third experiments were presented in a container—either a beaker or a sandbox. In the first experiment, the identical visible object clearly provided a standard, and the revolving drawbridge also may have provided a standard as it rotated upward, occluding the target.

The question we examine here is whether infants require a salient perceptually present standard to determine amount. When a standard is perceptually available, understanding of its role in the encoding of extent may not be required. Coding relative to the standard may occur automatically. The possibility that infants require a present standard to discriminate amount suggests a seemingly counterintuitive hypothesis: Infants' ability to code extent will be substantially worse when they are presented with targets in the simplest possible condition—in isolation—than when they are presented with targets in a more complex condition—with an aligned standard. In the four experiments presented here, we compared the ability of infants and very young children to discriminate amount with and without an aligned standard. Our targets were wooden dowels that could stand alone, or fit into a container. Dowels were presented in one of three experimental conditions—in isolation, in a container, or alongside a standard. On each trial a dowel was presented and removed, and then there was a test of whether that dowel could be discriminated from a dowel of a different height. The first experiment involved infants, the second and third experiments involved 2-year-olds, and the fourth experiment involved 4-year-olds.

EXPERIMENT 1: DISCRIMINATION IN INFANTS

In Experiment 1, we used a habituation task to study infants' ability to discriminate extents. We used three between-subjects experimental conditions—one with a container, one with a standard alongside, and one with no standard.

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1. The extent projected on the retina for a given target depends on its distance from the viewer. Infants show size constancy, correcting for variations in distance; they habituate when an object is shown repeatedly at various distances, and they dishabituate to an object of a different size even when it has the same retinal size as the object to which they were habituated (Day, 1987; Slater, Mattock, & Brown, 1990). Because our task involved judging extent at a fixed distance, the issue of size constancy is not of concern here.

Method

Participants

Forty-eight healthy, full-term infants (24 boys and 24 girls) participated in the experiment. Their mean age was 6 months 18 days (range: 5 months 18 days to 7 months 14 days). An additional 19 infants were excluded from the experiment because they cried or became fussy during the procedure.

Materials and apparatus

The two cylindrical wooden dowels used were 6 cm and 12 cm high and 3.3 cm in diameter. They were presented on an enclosed stage that was 120 cm wide, 60 cm deep, and 70 cm high and lined with black felt draped to avoid sharp corners or edges. Behind the stage, a video camera was mounted with its lens protruding through a small hole in the felt 30 cm above the base of the stage. The camera was attached to a monitor; coders could see an infant's looking behavior but could not see the stimulus. A single fluorescent light mounted 70 cm above the base diffused through a horizontal curtain, illuminating the stage. Between trials, a screen rose at the front of the stage, obstructing the stimuli.

The container was a glass cylinder 18 cm high, with a diameter of 3.5 cm. The dowel standard was a dowel the same height and diameter as the container; it was fixed in place on the stage; the target was placed 3 cm to its side. The three conditions are illustrated in Figure 1.

Procedure

Each infant was tested in a single session lasting approximately 10 min. A parent held the infant on his or her lap, 2 feet from the opening of the stage in a small booth. During the procedure, the parent wore a blindfold and was asked to avoid interacting with the infant. Participants were tested in three phases:

1. Familiarization: There were three trials with no target dowel. The screen rose to obstruct the infant's view of the stage and after a few seconds fell to reveal the empty stage. As the screen fell, a bell directed attention toward the stage. Each trial lasted until the infant looked away for 2 consecutive seconds, at which point the screen rose and the trial was repeated.
2. Habituation: Each habituation trial began with the screen up. The target (either the smaller or the larger dowel) was placed at the center of the stage approximately 75 cm from the infant. The screen fell and the display remained in view until the infant looked away for 2 consecutive seconds. Then the screen was raised. Between trials the dowel was removed and replaced so noises would be constant for habituation and test trials. Habituation trials were repeated until the infant reached the habituation criterion or the display had been shown 16 times. The habituation criterion consisted of an average fixation time on three consecutive trials that was less than 50% of the average fixation time for the first three trials.
3. Test: Four test trials were presented, alternating between novel and familiar volumes, with the dowel presented on the first trial counterbalanced across infants.

Looking times were recorded on a computer by an observer who watched the infant's looking behavior on a monitor behind the stage during the experiment. The observer pressed the shift key when the infant fixated the display and released the key when the infant looked away for 2 consecutive seconds. The observer had no knowledge of which dowel was on display during test trials. Postsession interobserver correlations assessed on 25% of the sessions were high, ranging from .91 to .99.

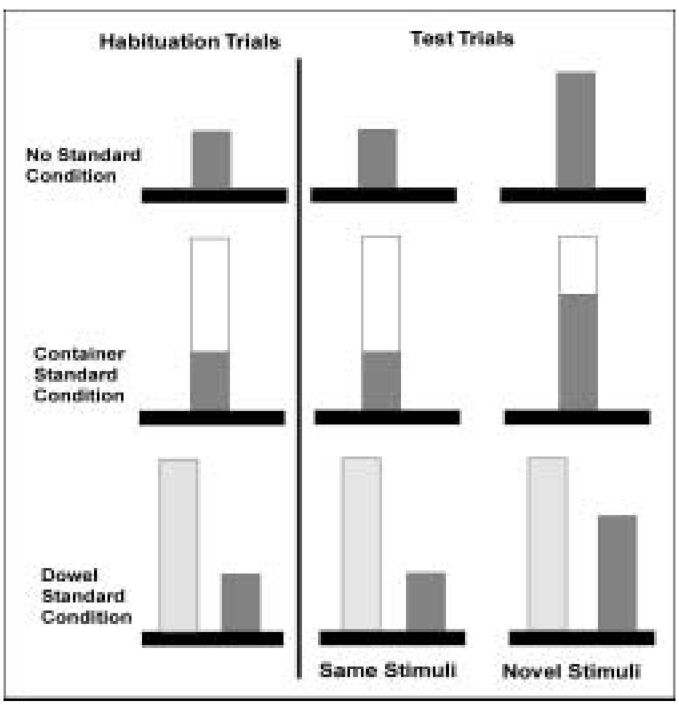

Fig. 1. Examples of the stimuli presented in habituation and test trials in the three conditions of Experiment 1.

Results and Conclusions

A preliminary analysis of variance (ANOVA) showed no sex differences. A subsequent ANOVA was conducted on mean looking times to novel and familiar dowels with the following factors: condition (container standard, dowel standard, no standard), order of testing (novel or habituated volume presented first), and habituation-stimulus size (6 cm or 12 cm). There was a significant difference between looking times at the novel and familiar displays across all conditions, $F(1, 36) = 16.05$, $p < .001$. The main effect was mediated by a significant interaction between dowel (novel vs. familiar) and condition, $F(2, 36) = 7.317$, $p < .005$, with no other main effects or interactions. This interaction was driven by infants looking longer at the novel dowel than the familiar dowel in the container- and dowel-standard conditions but not in the no-standard condition. Mean looking times on the two novel and two familiar test trials are shown in Figure 2 for each condition.

Paired *t* tests were used to determine whether looking times on novel and familiar test trials differed significantly for the three conditions. A Bonferroni-adjusted alpha of .016 (.05/3) was used to control Type I errors. In the container condition, infants looked longer at the novel dowel ($M = 5.84$ s, $SD = 3.39$ s) than the familiar dowel ($M = 3.46$ s, $SD = 2.11$ s), $t(15) = 3.59$, $p < .005$. In the dowel-standard condition, infants also looked longer at the novel dowel ($M = 6.81$ s, $SD = 5.20$ s) than at the familiar dowel ($M = 3.05$ s, $SD = 1.34$ s), $t(15) = 3.15$, $p < .01$. Finally, in the no-standard condition, there was no significant difference between looking times at the novel and familiar dowels ($M = 3.44$ s, $SD = 1.85$ s, and $M = 2.90$ s, $SD = 1.36$ s, respectively), $t(15) = 2.43$, n.s.

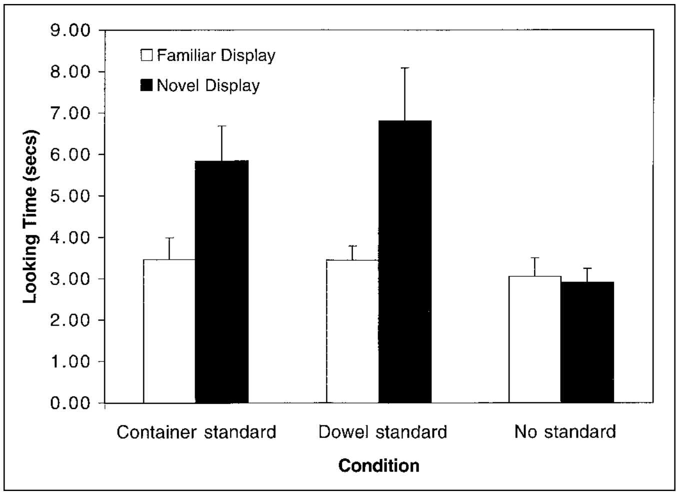

Fig. 2. Infants' looking time on test trials in the container-standard, dowel-standard, and no-standard conditions of Experiment 1. Error bars indicate 1 *SEM*.

The interaction was not driven by the performance of just a few infants. In the container condition, 15 of the 16 infants showed an increase in looking time to the novel dowel (p = .001, exact binomial test, two-tailed); in the dowel condition, 14 out of 16 showed an increase (p = .005); in the no-standard condition, only 4 out of 16 showed an increase (n.s.).

In order to examine if there were differences among the three conditions in the habituation portion of the experiment, we conducted an ANOVA on infants' looking times across the first three and final three habituation trials. The factors for this analysis were sex, size of the habituated dowel, and condition. There was a significant main effect of trials, $F(2, 113) = 26.335$, $p < .001$. Bonferroni-adjusted pair-wise comparisons of the six trials revealed that, in each condition, looking times were significantly longer on the first three habituation trials than on the last three habituation trials (all ps $< .01$), showing that infants did habituate over the course of the habituation trials. There was no main effect or interactions involving condition, indicating that the differences among the three conditions did not affect looking times during the habituation portion of the experiment.

The average number of trials to meet the habituation criterion was 7.13 in the no-standard condition, 8.75 in the container-standard condition, and 8.44 in the dowel-standard condition. The differences among these values were not statistically significant.

In conclusion, 7-month-old infants were given a habituation task involving two dowels that differed in extent (height). In one condition, the dowel was presented alone. In two other conditions, a potential standard aligned with the dowel was presented. Infants dishabituated to a novel amount in both conditions with a standard, but not in the no-standard condition.

EXPERIMENT 2: DISCRIMINATION IN TODDLERS (SMALL DIFFERENCES)

In this experiment, we used a choice task to study 2-year-olds' ability to discriminate extents. They were first shown a target dowel that was then removed. Next, two alternatives were shown: the target dowel and a novel dowel that was either larger or smaller than the target. The children were asked to point to the dowel that was the same as the target. There were three between-subjects conditions: container standard, dowel standard, and no standard.

Method

Participants

Participants were 48 two-year-old children (24 male, 24 female). The mean age of the children was 25 months, with the ages ranging from 23 months to 26 months. Eleven additional children were excluded for either failing to attend to the task (7) or failing to complete the entire experiment (4).

Materials

There were seven target dowels that differed in height by 2.25-cm increments; the smallest dowel was 2.25 cm high, and the largest dowel was 15.75 cm high. The container and the dowel-standard dowel were 18 cm tall. Compared with the container or dowel standard, target dowels increased by 1/8 increments from 1/8 to 7/8 of the total height (see Table 1).

The stage measured 12 in. by 24 in. and stood 24 in. from the ground. The back of the stage was 20 in. tall and was covered by a black felt curtain. At the point where the back of the stage contacted the base, the curtain was draped in a curve to avoid distinct corners or edges.

Procedure

The experimenter sat behind the stage, facing the child. The child held a stuffed dog ("Toby") and was told that he or she was to play a game with the dog. There were two pretest trials. The experimenter said, "In our game, we are going to help Toby pick which thing is his." The experimenter placed a dowel in the center of the stage with both hands and said, "This one is Toby's. Do you see Toby's thing?" The target was presented for approximately 5 s, after which the experimenter reached into the stage with both hands and removed the dowel, saying, "Now I'm going to take it away." After a delay of 5 s, the target dowel and a foil were presented on the stage separated by approximately 12 in. The experimenter then said, "Now point at Toby's." The differences in height during the training phase were very large (2.5 cm vs. 15.75 cm for the first training trial and 4.5 cm vs. 13.5 cm for the second trial), and all children performed well.

Table 1. *Heights of stimuli for Experiments 2, 3, and 4*

Stimulus number	Height (centimeters)	Ratio to standard
1	2.25	1/8
2	4.5	2/8
3	6.75	3/8
4	9	4/8
5	11.25	5/8
6	13.5	6/8
7	15.75	7/8

Next, the actual experiment began. The procedure was identical to the training phase just described. The target stimuli were of the seven sizes shown in Table 1. On each trial, after the target was removed, the target and a foil were presented together. The heights of the target and foil differed either by 2.25 cm (small difference) or by 4.5 cm (large difference). The stimulus pairings included six small differences (Stimuli 1 and 2, 2 and 3, 3 and 4, 4 and 5, 5 and 6, 6 and 7) and five large differences (Stimuli 1 and 3, 2 and 4, 3 and 5, 4 and 6, 5 and 7). Each child was assigned to one of two yoked orders in which the target size (larger, smaller of the pair) and the side of the stage on which the target was presented (left, right) were counterbalanced. If the child became distracted, a short break was given.

Results and Conclusions

Prior to the analysis, an arcsin transformation was performed on the proportions of correct responses to equalize variance across different performance levels. A split-plot ANOVA with the following factors was performed on the test trials: Condition (no standard, container standard, dowel standard), order, and sex were between-subjects factors, and size of difference (2.25 cm, 4.5 cm) was a within-subjects factor. The only significant effect was a main effect of condition, $F(2, 42) = 11.232$, $p < .001$.

The results of Experiment 2 are shown in Figure 3. The children's performance in the three conditions was compared with chance performance (.5). In both standard conditions, their performance differed significantly from chance (all ps $< .01$, two-tailed). Without a perceptually present standard, the children performed slightly below chance in both the small-difference (.44 correct) and the large-difference (.48 correct) conditions. In conclusion, toddlers failed to discriminate extent in the absence of a standard.

EXPERIMENT 3: DISCRIMINATION IN TODDLERS (LARGE DIFFERENCES)

In Experiment 3, we explored whether 2-year-olds discriminate larger differences in extent than used in Experiment 2. The targets and foils in Experiment 3 differed by 6.75 cm and 9 cm, as well as by 4.5 cm (the larger difference in Experiment 2). Because the results for the container and dowel-standard conditions were equivalent in the previous experiments, we used only the no-standard and container conditions.

Method

Participants

Thirty-two 2-year-old children (16 males and 16 females) participated in Experiment 3. Their mean age was 27 months (range: 23–30 months).

Stimuli

The stimuli used in Experiment 3 were the dowels and containers used in Experiment 2.

Procedure

The procedure was identical to that of Experiment 2 except that there were three levels of difference between the targets and foils: We

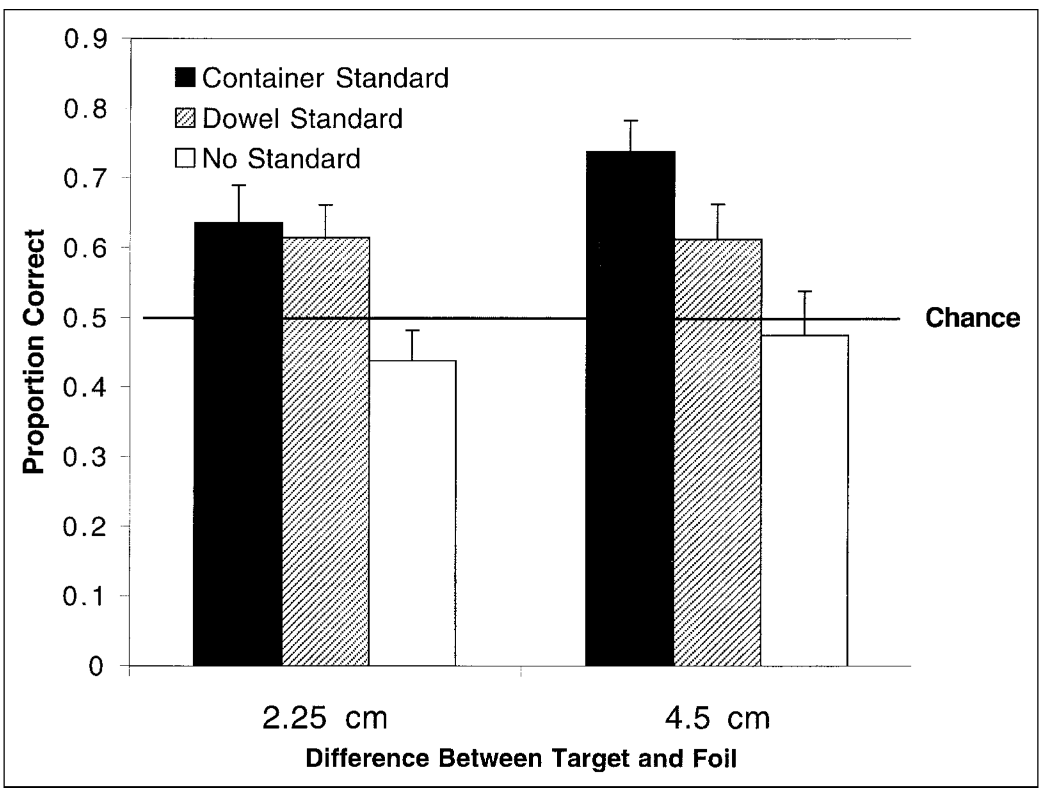

Fig. 3. Proportion correct in the container-standard, dowel-standard, and no-standard conditions of Experiment 2. Error bars indicate 1 *SEM*.

used all combinations of stimuli differing by 4.5 cm (5 trials), 6.75 cm (4 trials), and 9 cm (3 trials), resulting in 12 trials. As in Experiment 2, each child was assigned to one of two yoked orders in which the target size (larger, smaller of the pair) and the side of the stage on which the target was presented (left, right) were counterbalanced.

Results and Conclusions

An arcsin transformation was performed on the proportions of correct responses. Because a preliminary ANOVA showed no effect of sex, this factor was collapsed in subsequent analyses. A split-plot ANOVA with the following factors was performed: condition (container standard or no standard), order, and amount of difference (4.5 cm, 6.75 cm, and 9 cm). The analysis yielded a significant main effect of condition, $F(1, 28) = 14.274$, $p < .001$, with no other significant effects or interactions. Mean performance levels (standard deviations in parentheses) for the 4.5-, 6.75-, and 9-cm differences were, respectively, .50 (.28), .46 (.17), and .50 (.33) in the no-standard condition and .66 (.20), .64 (.21), and .68 (.26) in the container-standard condition. These results are shown in Figure 4.

In the container condition, performance levels for all three size differences were significantly greater than chance (all *p*s $< .01$). In the no-standard condition, performance was not different from chance for any size differences. Comparison of Experiment 3 and Experiment 2 showed no difference in performance for the overlapping size difference of 4.5 cm for either the container condition, $t(15) = 0.311$, n.s., or the no-standard condition, $t(15) = 1.13$, n.s.

In conclusion, the lack of interaction between differences in amount and condition (container, no standard) in Experiment 3 shows that discrimination of extent does not improve with larger differences. Across a wide range of differences, 2-year-olds do not code extent except when a perceptually present standard is provided.

EXPERIMENT 4: DISCRIMINATION IN 4-YEAR-OLDS

In Experiment 4, we examined the ability of 4-year-olds to discriminate size differences without a standard. Previous studies (e.g., Bartsch & Wellman, 1988; Fabricius & Wellman, 1993; Miller & Baillargeon, 1990) suggested that measurement abilities may emerge by this age. If the effect we observed in 2-year-olds is due to inability to impose a measure, 4-year-olds might be able to discriminate extent even for an isolated dowel.

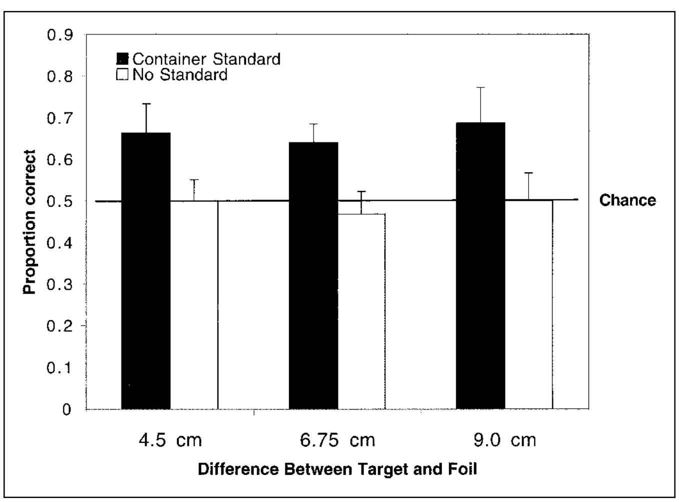

Fig. 4. Proportion correct in the container-standard and no-standard conditions of Experiment 3. Error bars indicate 1 *SEM*.

Method

Participants

Thirty-two children (16 males, 16 females) from schools and day-care centers in the Greater Chicago area participated in Experiment 4. The mean age of the children was 49 months (range: 42–55 months).

Stimuli

The stimuli were identical to those used in Experiment 2.

Procedure

The procedure was identical to that of Experiment 2 except that only the no-standard and container conditions were used in Experiment 4.

Results and Conclusions

A preliminary ANOVA performed on arcsin-transformed proportion correct showed no effect of sex, so this factor was collapsed in subsequent analyses. A split-plot ANOVA was performed on the following factors: condition (no standard, container), presentation order, and difference between target and distractor (2.25 cm, 4.5 cm). The analysis yielded no main effect of condition or order but a significant interaction between condition and difference in amount, $F(1, 28) = 4.31$, $p < .05$. This interaction was due to the fact that children's performance on the 4.5-cm-difference trials was identical in the two conditions (.71 in each), whereas their performance on the 2.25-cm-difference trials was significantly different between conditions (.51 with no standard, .70 with container). The results are shown in Figure 5. Four comparisons against chance (.50) showed that performance was greater than chance in each condition except the 2.25-cm, no-standard condition (all *p*s $< .01$).

In conclusion, Experiment 4 indicates that 4-year-old children can discriminate amount without a standard. They discriminated differences in height between two dowels even when these dowels were presented in isolation, although only for fairly large differences. Thus, the ability to compare extents without a present standard is emerging at an earlier age than Piaget's block-tower experiment indicated, but in the same age range as more recent studies have suggested.

DISCUSSION

In this article, we have discussed the ability of infants and toddlers to encode and retain information about extent. We noted that, in prior studies, the discrimination of amount by infants generally was found under conditions in which a potential standard was perceptually present. In the present studies, we examined if a salient present standard is necessary for infants and toddlers to discriminate amount. We found that infants and toddlers failed to discriminate extent when target stimuli were presented in isolation—without a salient standard.

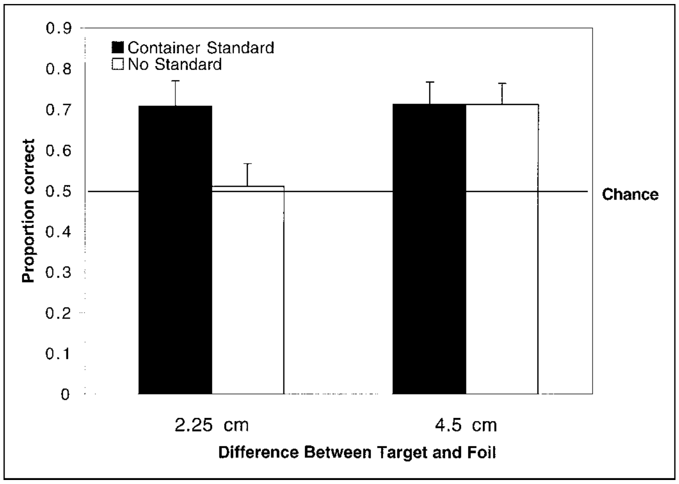

Fig. 5. Proportion correct in the container-standard and no-standard conditions of Experiment 4. Error bars indicate 1 *SEM*.

Earlier work indicates that even adults code extent relative to a salient present standard when targets are presented under perceptually impoverished conditions. Rock and Ebenholtz (1959) tested adults in a situation in which they were shown an illuminated frame containing a line on a wall in a darkened room. The participants were then shown a frame on another wall and asked to make a line of the same length as the original target line. Although they were told that the two frames differed in size, their responses were affected by the length of the target line relative to the original frame.

Adults are different from infants and toddlers in that they depend on a present standard only under perceptually impoverished conditions. In contrast, infants and toddlers depend on a standard to discriminate extent at all. Sensitivity to the height of an isolated dowel was found in 4-year-olds but not in younger children. Thus, coding in infants and toddlers seems to be relative in a different sense than coding in adults. Infants' and toddlers' dependence on a present standard may arise from a lack of understanding of the role of a standard in estimating extent, or from an inability to carry out the mental operations required to imagine aligning a target with a standard. In either case, the findings suggest that infants and toddlers do not always code stimuli as having particular extents. Rather, they may code extent as a feature of a stimulus only when that stimulus happens to be juxtaposed with another stimulus in such a way that relative extent is coded automatically.

In conclusion, our study provides information about the start point of an important developmental process. Determining extent begins in infancy with a perceptual process involving relative coding; by the school-age years, children become able to impose a standard to determine extent. Further work is needed to determine the intermediate states involved in achieving a mature ability to use a standard in measurement, and to specify the mechanisms by which this ability comes about.

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