Developmental Changes in the Use of Absolute and Relative Information: The Case of Spatial Extent

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Q4 Figure 1: Figure caption needs more explanation on original and response frames

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JOURNAL OF COGNITION AND DEVELOPMENT, *8*(4), 1–17

Developmental Changes in the Use of Absolute and Relative Information: The Case of Spatial Extent

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In the present paper we investigated the development of the ability to reproduce extent in elementary school students. Children were shown a target line in a frame and were asked to reconstruct the line in a frame of a different size. One experimental condition involved reproducing *absolute extent*, i.e., drawing a line that would be equal in length to the target line. The other condition involved reproducing relative extent; drawing a line that would preserve the relation between the target line and the frame. We found that in both conditions the length of the target and its relation to the frame affected children's responses. Yet, older children (7–9-year-olds) showed distinctive response patterns in the two conditions, indicating differentiation between absolute and relative extent. Whereas the performance of 5-year-olds in reproducing relative extent was similar to that of older children, their reproduction of absolute extent reflected a compromise between the use of absolute and relative cues. These findings extend the results of prior work suggesting an early advantage in the ability to use relative rather than absolute extent.

The ability to use information about extent (distance or length) is an essential aspect of spatial reasoning. In everyday life, we are confronted with situations that call on this ability. For example, locating points in the environment that are not

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adjacent to prominent landmarks requires reasoning about distance. Comparing objects often involves considering their lengths. The development of the ability to use distance and length has generated substantial interest among psychologists (Bryant, 1974; Liben & Downs, 1989; Miller & Baillargeon, 1990; Newcombe, Huttenlocher, & Learmonth, 1999; Piaget & Inhelder, 1948/1967). The present paper extends existing work by investigating the development of two critical facets of this ability. In particular, we examine the use of *relative extent*, which is defined in terms of relation to perceptual context and *absolute extent* that is independent of the perceptual context.

Some spatial tasks require the use of relative extent information. For example, if one has to cut a piece of paper that is one third of a length of a sheet, one must focus on the relation between the small piece and the larger sheet. In this task, the result is expected to vary with the size of the sheet. Other tasks require making judgments based on absolute extent. For example, if one has to cut a piece of paper of a given length from a larger sheet, then the size of that sheet is irrelevant. It is important to develop an ability to distinguish between relative and absolute extent and to use them flexibly in appropriate situations. That is, one needs to be able to either incorporate or ignore spatial context depending on the nature of the task. The present study explored developmental changes in this ability by examining children's performance on tasks that required the use of relative versus absolute extent.

In early research on spatial development, the focus had been on general difficulties of using distance and length by young children rather than on their ability to distinguish between absolute and relative extent. It has been argued that the use of distance and length cues emerges around 7–8 years of age (Piaget & Inhelder, 1948/1967; Piaget, Inhelder, & Szeminska, 1960). Later work has suggested that the ability to code extent arose much earlier (Hermer & Spelke, 1996; Huttenlocher, Newcombe, & Sandberg, 1994; Miller & Baillargeon, 1990). For example, it has been shown that infants who repeatedly observed an object being hidden in a certain location in a box looked longer when the object emerged from a new location (Newcombe et al., 1999). In this study, the hidden object was placed away from the edges of the box or any landmarks so children had to rely specifically on distance information. Using a habituation paradigm, researchers have also shown that infants displayed sensitivity to the height of liquid presented in a glass container (Gao, Levine, & Huttenlocher, 2000).

A closer look at the studies demonstrating early extent coding reveals a common feature that could be critical to children's successful performance. These studies typically present children with an object that is contained within a very salient frame of reference, such as a sandbox or a container. The presence of such frames may help children solve the task by allowing them to code an object's location and size using relative information. For example, the object may be coded as located about a third of a way from the left edge of the box or as taking up two thirds of a container. Although it may seem that this kind of coding may be difficult

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(since it requires considering relations between distances or lengths), there is accumulating evidence suggesting that children may use relative coding before they can use absolute coding (Bryant, 1974; Duffy, Huttenlocher, & Levine, 2005a).

Indeed, recent studies have indicated that infants may rely on relative information to judge extent. In one study, following habituation to a target object, infants looked longer at a novel object that differed from the target in height when the objects were presented in containers (Huttenlocher, Duffy, & Levine, 2002). Infants did not look longer at a novel object when both objects were presented alone, without a salient frame of reference. Further work examined more closely the mechanisms underlying early extent coding by pitting absolute size against relative size (Duffy, Huttenlocher, Levine, & Duffy, 2005b). Infants who were habituated to a dowel, which was one-third the height of a container, looked longer at the same dowel presented in a different container, apparently because the size relation between the dowel and container changed, even though the absolute size of the dowel remained constant. These findings suggest that infants may encode extent only relative to a surrounding frame.

An important question arising from the findings with infants is at what point in development children can encode extent without relying upon relative information provided by a salient frame of reference? To examine the use of absolute extent in older children, Duffy et al. (2005a) conducted a study with 4- and 8-year-olds. In the study, children had to decide which of two choice dowels was exactly the same height as a target dowel. The target dowel was presented in a container of a particular height, and the choice dowels were presented in containers of another height. Note that the task of identifying the dowel identical to the target called for the use of absolute information (disregarding the size of the container). The results differed for the two age groups. Four-year-olds did not choose the dowel of the same height as the target. Instead, they tended to choose the dowel that had the same proportional relation to the container as the target had to its container. Eight-year-olds were able to identify the dowel identical to the target even though it was presented in a different size container. Their successful performance in the presence of misleading relative information suggests that they encoded extent without relying on the relation between the dowel and the container.

To summarize, the review of recent work suggests that the initial coding of extent takes advantage of relational cues. Rather than using absolute and relative extent flexibly depending on which one is called for by a given task, preschoolers appear to rely on relative information. In contrast, the performance of 8-year-olds shows evidence of their reliance on absolute information, suggesting that this ability emerges at some point during early school years. However, there is a lack of systematic research in this age range. The developmental course of the ability to use absolute extent remains to be specified. Furthermore, even when children start using absolute extent, it remains to be determined how the level of their performance on “absolute” tasks compares to the level of performance on tasks involving the use of relative information. The present study aims to fill the gap in existing research by investigating developmental changes in the use of absolute and relative extent between 5 and 9 years of age.

In designing this study, we took into account several limitations of prior work on children's extent coding. Many previous studies used methodologies that allowed only for a coarse-grained analysis of responses. For example, in the forced choice paradigm the dependent variable is whether the child chooses the correct alternative (Duffy et al., 2005a; Huttenlocher et al., 2002; Jeong, 2003). Thus, children's performance can only be compared to chance, limiting the types of conclusions that can be drawn about the relation between absolute and relative coding. In other choice tasks pitting absolute against relative size, children often can make crude relative judgments by identifying a stimulus as being "larger" or "smaller" than another one (Bryant, 1974; Spinillo & Bryant, 1991). Thus, discrimination tasks do not provide detailed information about the magnitude of children's errors or factors affecting their accuracy.

Several studies that established an early emergence of extent coding used methodologies that do not allow us to determine whether children relied on absolute or relative information, or both, to solve the task. In these studies, children judged or reproduced object location within the same frame of reference in which the object was originally placed (e.g., Huttenlocher et al., 1994; Newcombe et al., 1999). However, in order to distinguish between the uses of absolute and relative coding, one must vary the frame of reference. If children code relative extent, their responses should vary systematically with the frame of reference, but if they code absolute extent, their responses should not be as strongly affected by the frame change. Finally, to explore the relation between absolute and relative strategies, it is essential to use parallel tasks that call for either absolute or relative coding. Existing research does not allow for a direct comparison of performance across the two domains since the studies focusing on either relative or absolute coding vary in their designs.

The present study addressed the limitations of prior work by examining children's performance on parallel tasks that involved reproducing absolute or relative extent. In our reproduction task, children were presented with a target line in a frame and were asked to reconstruct the line in a frame of a different size. In one experimental condition ("Absolute length"), children were instructed to draw a line that was equal in length to the target line. In the other condition ("Relative length"), children were instructed to reproduce the relation between the line and the frame that they had originally seen. We examined children's performance to determine how absolute cues (the line length) and relative cues (the relation between the line and the frame) affected their performance in each condition. Given the reliance of infants and preschoolers on relative extent, we were particularly interested in exploring the effects of relative cues on the performance of our participants who varied in age from 5 and 9 years. Using a reproduction task allowed us to quantify the effect of relative information on reproducing absolute and relative extent and to compare this effect across age groups.

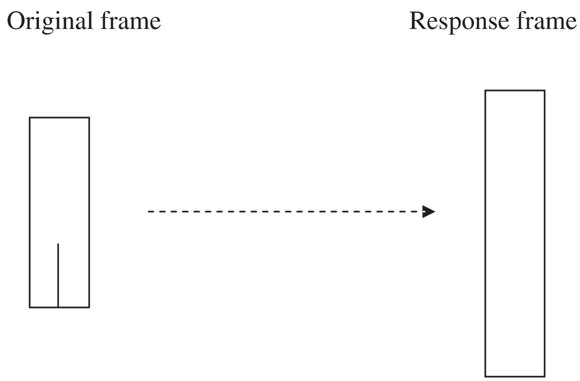
METHOD

Participants

The participants were recruited from elementary schools in the greater Chicago area. All participating schools served predominantly middle-class families. The sample included 36 five-year-olds (16 girls, 20 boys, mean age 65 months, age range 60–69 months), 39 seven-year-olds (20 girls, 19 boys, mean age 90 months, age range 84–95 months), and 39 nine-year-olds (21 girls, 18 boys, mean age 114 months, age range 108–121 months).

Materials

Q3 The stimuli were presented on a 17” screen of a laptop computer. On each trial, the child first saw a rectangular frame (henceforth referred to as ‘original frame’) with a line inside it, as shown in Figure 1. The line was always attached to the bottom of the frame and extended vertically. These stimuli appeared on the screen for 5 sec and then disappeared. Following a 3 sec delay during which the screen was blank, the child saw a new rectangular frame (henceforth referred to as ‘response frame’) without any line inside it. The positions of the frames on the screen were generated randomly with the restriction that the original and response frames could not occupy the same position on any given trial. The child’s task was to draw a line inside the response frame by pressing the marked keys on the computer keyboard. One



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key was marked with an upward arrow and was used to increase the size of the line. When the child first pressed this key, the line grew upward originating at the bottom of the response frame. The other key was marked with a downward arrow and was used to decrease the size of the line, if the child needed to adjust his or her response.

The rectangular frames had a constant width, 30 pixels, but varied in length. Five different frame lengths were used, i.e. 144, 216, 288, 360, and 432 pixels. The lines that were drawn within the original frame also varied in length; they were 72, 144 or 216 pixels. Since crossing these three line lengths with all possible combinations of original and response frames would result in too many trials for children, we selected a subset of these trials for the present study. In the subset, we included all trials that had the middle-size frame, 288 pixels-long, as the original frame. This allowed us to have response frames that were either smaller or greater than the original frame and at the same time equidistant from the original. Thus, two response frames (144, 216) were smaller than the original frame and two response frames (360, 432) were greater than the original frame. We also used a response frame (288) that was the same as the original one. These five combinations of frame sizes were crossed with three line lengths. One of the combinations (from 288–144 pixel frame) could not be used with a 216 pixel line because the line was bigger than the response frame. Therefore, this trial was eliminated, resulting in 14 main trials. In addition, we randomly selected 8-filler trials from remaining combinations of frame sizes and line lengths. We included them so that children did not always see the 288-pixel frame as the original. All 22 trials used in the experiment are listed in Table 1.

Procedure

In every participating classroom, students of each gender were randomly assigned to either Absolute or Relative condition. It was not practical to test conditions within subject because this would have resulted in a large number of trials making the task long and tiring for children. In each condition, children received five practice trials in which they were familiarized with the procedure followed by 22 experimental trials. The computer program administering the test generated the order of experimental trials randomly. The child was seated in front of the computer. The experimenter who sat near the child introduced the procedure, carried out the demonstration and practice trials, and monitored the child during the experiment.

Children in the Absolute condition were told, “You will see a box with a stick inside it. Then it will disappear and you will see a new box. Sometimes that new box will be the same as the first one and sometimes it will be different. Your job is to draw the same stick as you just saw.” Following this introduction, five practice trials were administered. On the first practice trial, the experimenter showed the child how to use the two marked keys “to make the stick bigger or smaller.” On

TABLE 1
Combinations of Frame Sizes and Line Lengths Presented to Children; All Sizes Provided in Pixels (32 Pixels = 1 cm)

	Original Frame	*Response Frame*	*Original Line*
Main trials	288	144	72
	288	216	72
	288	288	72
	288	360	72
	288	432	72
	288	144	144
	288	216	144
	288	288	144
	288	360	144
	288	432	144
	288	216	216
	288	288	216
	288	360	216
	288	432	216
Filler trials	144	216	144
	144	288	72
	216	144	72
	216	288	72
	360	288	216
	360	432	144
	432	288	216
	432	360	216

each practice trial, the child first saw the original frame with a line, and then the response frame. When the child finished producing the response line, the experimenter pressed the ‘Return’ key and the space bar, which brought the original stimulus back. The experimenter encouraged the child to compare the line in the original frame with the response line. If the lines were noticeably different, the experimenter helped the child adjust the response stick to make it like the target. All children provided evidence of understanding the procedure by the end of the practice trials. Following the practice trials, the experimental trials were administered. They were essentially parallel to the practice trials, except that no feedback was provided. That is, after the child finished drawing the line, the experimenter said, “OK, now you will see another box with a stick. Look carefully. Remember, you will need to draw the same line in the new box,” and proceeded to the next trial.

In the Relative condition, the experimental procedure was similar except for the instructions the children received. They were told, “You will see a box with a stick inside it. Then it will disappear and you will see a new box. Sometimes that new box will be the same as the first one and sometimes it will be different. Your job is to draw the stick so that it will take up the same part of the box as in the picture that you just saw." During the practice trials, the experimenter further explained the meaning of this instruction. When the child was done drawing a line in the response frame, the experimenter pressed the key bringing the original stimulus back to the screen. The experimenter encouraged the child to compare the original line-and-frame stimulus with the response. If needed, the experimenter helped the child adjust the response stick so that the response line had the same relative length as the target. As for the Absolute condition, all children provided evidence of understanding the procedure by the end of the practice trials, and the practice trials were followed by the experimental trials in which children received no feedback.

RESULTS

Below we present a set of analyses in which children's performance was examined across two experimental conditions. First, we analyzed the length of response lines to determine whether responses in each condition varied with the length of the target and whether they were influenced by the frame size. Next, we examined the accuracy of children's performance, using a reproduction task allowed us to directly measure how far the responses of each age group deviated from the correct absolute and relative response. Combined data from these analyses provided a comprehensive picture of developmental changes in children's ability to reproduce absolute and relative length.

Examining the Length of Response Lines: Effects of Stimuli Characteristics

The statistical analyses focused on children's performance on the main trials on which the original frame was 288 pixels-long whereas response frames varied in length, as described in Table 1. An analysis of variance (ANOVA) was conducted with response length as the dependent variable and with four independent variables; two between-subject factors (child's age and experimental condition) and two within-subject factors (target length and frame change). In reporting the results, we should first point out that age did not systematically affect response length, producing no main effect or interactions, all p's > .05. The factors that did show main effects were target length, $F(2, 216) = 750.07$, and frame change, $F(4, 432) = 233.51$, both p's < .05. To explore the nature of these effects, we conducted pair-wise comparisons using the Least Significant Difference (LSD) method. This analysis indicated that the average responses for all three-target lengths were different from one another, p's < .05; longer target lines corresponded to longer response lines. Also, the average responses for each type of frame change differed from one another, *p*'s < .05; the increase in frame size led to longer response lines whereas the decrease in frame size led to shorter response lines.

In addition to main effects of target length and frame change, there was a significant interaction between these factors, $F(8, 864) = 16.28$, $p < .05$. Simple effect tests were conducted to compare the effects of frame change for each target length. We found that frame change had a greater effect on children's responses with larger targets (144, 216 pixels) than with the smallest target (72 pixels). Specifically, in all comparisons involving larger targets, average responses for different types of frame change were significantly different from one another, *p*'s < .05. However, when the target was 72 pixels-long, significant differences were not seen in all comparisons; there was no difference between the two types of frame decrease (288–144 and 288–216), $p > .05$.

The above results indicate that in reproducing a line, children are sensitive to the length of that line and, at the same time, are influenced by the context in which the line is presented. Note that the effect of frame change is generally indicative of relative coding; an accurate response in the Absolute condition should reflect only the target length and not the frame size. If we find that the effect of frame is comparable across conditions, it would suggest that regardless of whether children are asked to reproduce absolute or relative length, they carry out the same type of processing. A critical question then becomes whether there are any differences in the pattern of performance across the two conditions. Indeed, we found that condition interacted with frame change, $F(4, 432) = 42.18$, $p < .05$, as illustrated in Figure 2.

Simple effect tests showed that in the Relative condition, responses produced with different types of frame change were all significantly different from one an-

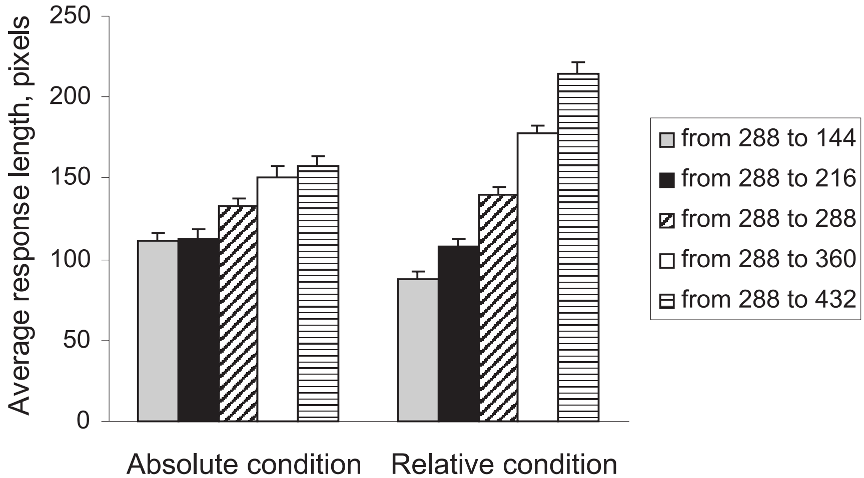

FIGURE 2 Average response length in the two conditions as a function of frame change.

other, *p*'s < .05. In contrast, in the Absolute condition only the two extreme cases of frame change (288–144 and 288–432) produced responses significantly different from each other and from the no-change trials (288–288), *p*'s < .05. The effect-size statistics (partial eta-squared) indicated that in the Relative condition, frame change accounted for a large proportion of the variance in response length, ?$_p^2$ = .81, whereas in the Absolute condition, it accounted for a smaller proportion of the variance, ?$_p^2$ = .45. Thus, although frame change affected response length in both conditions, the effect was much stronger in reproducing relative rather than absolute length.

Examining Performance Accuracy: Developmental Changes in Reproducing Extent

In this analysis, we examined how far children's responses deviated from a correct response on each trial. Note that the analysis of accuracy may provide information not available from the analysis of response length. For example, although we found that the average response length was not affected by age (that is, younger children did not produce lines that were systematically larger or smaller than those produced by older children), age may play a critical role in the accuracy of children's responses. We calculated accuracy scores as the absolute difference between the child's actual response length and the correct response on each trial. In the Absolute condition the correct response is identical to the length of the original line. In the Relative condition, the correct response is the product of the original line length and a scale factor (ratio of the response and original frame).

An ANOVA was carried out with accuracy scores as the dependent variable and with the same independent variables as in the analysis above, i.e., target length, frame change, age and experimental condition. Similar to the findings with response length, the results showed main effects of target length, $F(2, 216) = 63.32$, and frame change, $F(4,432) = 5.66$, both *p*'s < .05. Pair-wise comparisons using LSD method indicated that the errors were significantly different for all three target lengths; the smaller the target, the greater the accuracy. With respect to the effect of frame, the accuracy was greater on trials when there was no frame change compared to any type of frame change, *p*'s < .05.

In contrast to the findings with response length, age significantly affected children's accuracy, $F(2, 108) = 33.85$, $p < .05$. Pair-wise comparisons using the LSD method showed that all three age groups were significantly different from one another, all *p*'s < .05. The ANOVA also revealed a significant effect of experimental condition, $F(1, 108) = 23.32$, $p < .05$. Children made larger errors in the Absolute than in the Relative condition. This pattern held in all age groups; there was no interaction between age and condition, $p > .05$.

It should be pointed out that although age was a significant factor in the overall analysis of accuracy, it did not affect accuracy on a subset of trials where there was no frame change. This was shown by an ANOVA with errors on same-frame trials as the dependent variable and with target length, age, and condition as independent variables. The only significant finding in this analysis was the main effect of target length, $F(2, 216) = 52.60$, $p < .05$. Pair-wise comparisons using LSD methods indicated that the average errors for all three-target lengths were significantly different from one another, p's < .05; reproducing larger targets led to greater errors. The lack of the effect of condition is not surprising since on same-frame trials the absolute response is the same as relative response. The lack of age effect on children's accuracy on the same-frame trials is noteworthy; it has implications for the understanding of developmental changes in the ability to reproduce length. Our results indicate that the ability to remember and reproduce a line presented in the same context does not undergo significant changes between 5 and 9 years of age whereas the ability to reproduce a line in a new spatial context improves substantially during this period.

To further understand the nature of children's errors, we carried an additional analysis addressing the question, "Were responses in each condition closer to those expected based on absolute or relative coding?" For each trial in both conditions we calculated two scores: 'an absolute error', the deviation of the child's actual response from the ideal absolute response, and 'a relative error', the deviation of the child's actual response from the ideal relative response. To illustrate how these scores were calculated; consider a trial where the child was shown a target line 72-pixels-long in a frame that was 288-pixels-long, followed by a response frame that was 144-pixels-long. On this trial, the ideal absolute response would be 72-pixels-long and the ideal relative response would be 36-pixels-long. If the child's actual response on this trial happened to be 66 pixels, then the absolute error was 6 and the relative error was 30.

An ANOVA was carried out on children's errors with age and condition as between-subject factors and with error type (absolute vs. relative) as a within-subject factor. The ANOVA revealed a main effect of error type, $F(1,108) = 35.20$, $p < .05$. Critical for the interpretation of this main effect, there was an interaction between error type and condition, $F(1,108) = 120.21$, $p < .05$. As illustrated in Figure 3, responses in the Absolute condition were closer to the ideal absolute responses than to the ideal relative responses whereas in the Relative condition the pattern was reversed. Note that the difference between the two error types was less pronounced in the Absolute condition, suggesting that in reproducing absolute length, there may have been a substantial influence of relative information.

A further clarification comes from the finding of a three-way interaction between error type, condition and age, $F(2, 108) = 11.28$, $p < .05$. Simple effect tests indicated that in the Relative condition all age groups produced responses that were closer to the ideal relative than to the ideal absolute response. However, in the Absolute condition, only the two older age groups produced responses that were closer to the ideal absolute than to the ideal relative response. As shown in Figure 4, the responses of the youngest group, 5-year-olds, were not closer to the ideal absolute responses, in fact, they tended to be somewhat

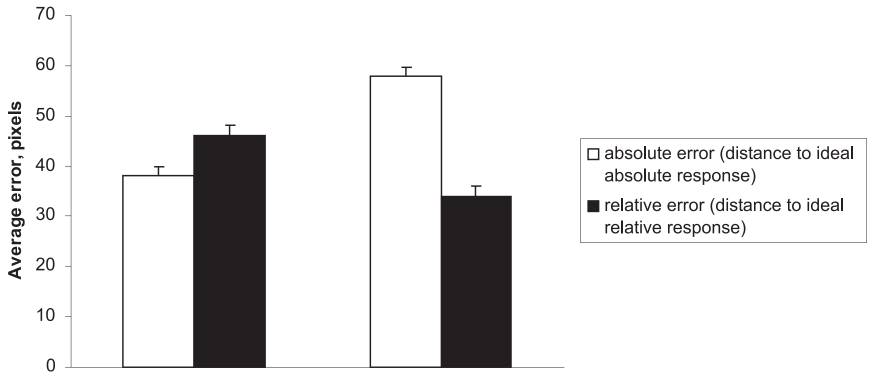

FIGURE 3 Deviation from the ideal absolute versus ideal relative response, across age

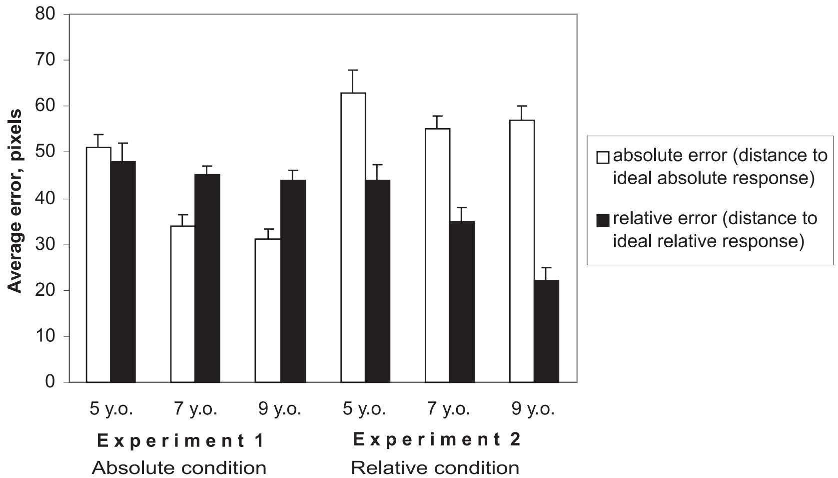

FIGURE 4 Deviation from the ideal absolute versus relative response, separately for each age group.

closer to the ideal relative response although this difference did not reach statistical significance, $p > .05$.

DISCUSSION

The present study compared children's performance in reproducing either absolute or relative extent of an object. In the first step of analysis we examined the effects of stimuli characteristics (length of the target line and the relation between the line and the frame) on children's responses. The results revealed certain commonalities across the two experimental conditions. In particular, the responses in both conditions varied systematically with the length of the target line; larger targets corresponded to larger responses. Further, the relation between the line length and the frame size affected children's performance. In both conditions, response lines varied systematically in the direction of preserving this relation. For example, if the response frame was larger than the original frame, children tended to produce response lines that were larger than the original line.

Interestingly, the effect of relative information was particularly pronounced in reproducing longer lines. One possible explanation of this finding is that the longer the line the closer it is to the edge of the frame. Thus, the relation between the longer line and the frame may have been more salient making it easier to use this information in reproducing the line. Another possible explanation of the observed pattern has to do with the psychophysical principle positing that judgments involving larger magnitudes are associated with greater uncertainty leading to larger errors (Gescheider, 1985; Stevens, 1957). Indeed, we observed lower accuracy on trials involving longer target lines. In the face of uncertainty in reproducing the absolute extent of the longer target, children may be more likely to rely on other types of information, namely on the target's relation to the frame.

The effects of stimuli characteristics discussed so far highlight commonalities between the two conditions: in reproducing both absolute and relative extent, children's responses reflected the length of the target line and the relation between the line and the frame size. Note that the effect of frame size is generally indicative of relative coding. The fact that we observed this effect in both conditions raises a question of whether, in the presence of a salient frame of reference, our participants even distinguished reproducing absolute length from reproducing relative length. Our data provide clear indications that children did differentiate between the two tasks. We found that even though the responses always reflected the relation between the line and the frame, the contribution of this factor varied substantially across experimental conditions. In particular, in all age groups frame change had a much greater effect on performance in reproducing relative extent than in reproducing absolute extent.

Our results showed substantial developments in reproducing extent during the early school period. One type of change concerned the overall level of performance. We found that in reproducing both absolute and relative extent children's accuracy improved substantially between 5 and 9 years of age. To better understand the nature of this improvement, we examined separately the responses on a subset of trials in which children reproduced a line in the same-sized frame. We found that on this subset of trials, age did not significantly affect accuracy. This finding indicates that the overall increase in accuracy across trials was not simply due to the fact that older children had a better ability to remember the length of the target line or had greater manual skills involved in drawing lines on a computer screen. Rather, it shows that the observed age-related differences reflected improvement in the ability to reproduce a line in a different spatial context (i.e., a different-size frame). That is, children became better at ignoring changes in spatial context when reproducing absolute length; they also became more accurate in taking into account changes in spatial context when reproducing relative length.

Developmental changes revealed in the present study concerned not only the overall accuracy level but also the pattern of responses across the two experimental conditions. This age-related change was most strikingly revealed in the analysis comparing responses in each condition to the ideal absolute and relative responses. Consider first the performance of the older children, 7- and 9-year-olds. In these age groups, the responses on the absolute task were closer to the ideal absolute than to the ideal relative response whereas responses on the relative task showed the opposite pattern. Thus, even though in reproducing absolute extent children were influenced by relative information, the effect was not strong enough to turn “absolute responses” into “relative responses”. At the same time, it should be noted that children showed greater accuracy at reproducing relative length than at reproducing absolute length. Thus, 7- and 9-year-olds have not yet attained the same level of skill in using absolute and relative extent even though they are capable of carrying out either task.

While relative cues affected performance on the absolute task in all age groups, the effect was strongest in 5-year-olds. In fact, in contrast to the older children, the responses of 5-year-olds in the Absolute condition were as close to the ideal absolute as to the ideal relative response. However, this does not mean that 5-year-olds do not distinguish between the two types of extent. If they engaged in the same processes on both absolute and relative tasks, their performance would be identical in the two conditions. Yet this was not the case as their responses in the Relative condition were not equidistant from the ideal absolute and relative responses; instead they were closer to the ideal relative responses. It seems then that 5-year-olds are at the beginning stages of differentiating between absolute and relative tasks. Although their performance on the absolute task was different from that on the relative task, they did not yet show a distinct pattern of absolute responses observed in older groups. Rather, their responses on the absolute task reflected a “compromise” between absolute and relative information.

Combined with the findings from earlier studies, the present results provide a picture of the developmental trajectory that begins with the relative coding of extent and proceeds through a gradual emergence of the ability to use absolute extent. The work with infants and preschoolers shows their complete reliance on relative information even in tasks that require the use of absolute extent (Bryant, 1974; Duffy et al., 2005a; Huttenlocher et al., 2002). Our findings indicate that 5-year-olds begin to show evidence of differentiation between absolute and relative tasks. The ability to ignore spatial context increases substantially between 5 and 9 years of age, but even 9-year-olds continue to show the influence of relative information in reproducing absolute extent. In fact, the work with adults suggests that the effect of spatial context persists well beyond elementary school years (Rock & Ebenholtz, 1959; Witkin, 1962). In a classical study by Rock and Ebenholtz (1959) where adults were shown a line in a square frame and were asked to reproduce that line in a square of a different size, their responses reflected the influence of relative cues.

The primacy of using relative extent over absolute extent may seem counterintuitive given the logical complexity of the two tasks. Encoding absolute extent requires focusing upon only the size of the target object, whereas encoding relative extent requires considering the size of that object, the size of the frame, and the relation between the two. Clearly, the use of relative extent in infants and preschoolers cannot be based on a mathematical computation of ratios for distances or lengths. However, it is possible that the early extent coding involves a form of perceptually based judgment that registers the relation between the object and its surroundings. The advantages of this early ability to use relational information are highlighted by research on early quantitative development (Resnick & Singer, 1993; Singer-Freeman & Goswami, 2001; Sophian, 2000). This research suggests that young children use perceptually based proportional reasoning (in which they compare relations between distances and sizes) to solve a variety of tasks long before they learn formal procedures for solving proportions.

However, as the ability to encode relative extent emerges as early as infancy, performance on relative tasks continues to improve through elementary school years. It is possible that younger children encode relations in a rather coarse-grained manner, and later on their coding becomes more fine-tuned leading to an increase in accuracy. This possibility is consistent with the findings of spatial mapping studies, which require the use of relative distance cues. Even though preschoolers produce nonrandom responses on such tasks demonstrating sensitivity to distance presented on the map, their accuracy is low (Vasilyeva & Huttenlocher, 2004). The level of performance on mapping tasks improves gradually throughout the elementary school (Liben & Downs, 1989; Uttal, 1996).

The improvement in the use of relative extent during this period could be actually related to the acquisition of mathematical knowledge about ratios (Nunes & Bryant, 2004; Wearne & Hiebert, 1989). Quantitative relations captured in ratios are often introduced in a spatial visual way (Clements & Bright, 2003; National Council of Teachers of Mathematics, 2000). Children generally begin with simple spatial ratios in second grade (e.g., half a square, third of a pie). In fourth grade they learn about the correspondence between spatially presented proportions and abstract ratios (e.g., ½, ?). This experience may promote performance on a relative task leading to continuous improvements throughout the elementary school.

As indicated above, the mechanism of coding extent as a relation between the object and its context allows children to solve a variety of tasks. It may work well even in situations that call for the use of absolute extent, as long as the context remains constant. For example, measuring the amount of sugar that goes into a dish as half a cup will produce consistent results as long as one uses the same cup. Yet when the context changes, as it did in the present study, the relative strategy leads to biased performance on the absolute task. Thus, at some point in development it is important to learn how to use information about absolute extent and to minimize the effect of immediate spatial context on judging or reproducing size. The findings with adults pointing to the influence of relative information on absolute judgments probably should not be taken to suggest that adults do not have a concept of absolute size distinct from that of the relative size. When equipped with measurement tools, they are capable of judging and reproducing absolute size or distance. Even without measurement tools adults are quite accurate in reproducing absolute extent (Kitayama, Duffy, Kawamura, & Larsen, 2003). An important question is when and how this ability is acquired?

The present findings indicate that substantial improvements in the use of absolute information take place during the elementary school years. The increase in the accuracy of absolute coding may be facilitated by the development of cognitive skills during this period. In particular, around 5 years of age children show significant progress in their ability to ignore irrelevant aspects of stimuli (e.g., Muller, Zelazo, Hood, Leone, & Rohrer, 2004; Zelazo, 2004), which may help them consider a target object independently of the frame size. Further, the increased use of absolute extent may be related to the emergence of transitive inferences over the early elementary years, which is an important conceptual prerequisite for understanding quantitative invariance (Miller, 1989; Piaget et al., 1960). It is also possible that children's educational experiences play a role in the growth of their ability to use absolute extent. Specifically, the acquisition of measurement skills and especially practice in measuring objects presented in different spatial contexts may help children gain the ability to focus on the size of the object independently of its context (Clements & Bright, 2003; Miller, 1989).

More work is needed to examine directly the relation between formal learning experiences and children's ability to judge and reproduce extent. It would be informative to see if activities designed to increase children's conceptual understanding of measurement may also lead to improvements in their ability to code and reproduce extent without measurement tools. For example, the use of tasks in which children measure with different standards (a ruler vs. a yardstick) or unit sizes (centimeters vs. inches) might help children develop the distinction between absolute and relative extent.

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