Journal of Educational Psychology
2013, Vol. 105, No. 2, 351–363

0022-0663/13/$12.00 DOI: 10.1037/a0031040

Extraneous Perceptual Information Interferes With Children's Acquisition of Mathematical Knowledge

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Educational material often includes engaging perceptual information. However, this perceptual information is often extraneous and may compete with the deeper to-be-learned structure, consequently hindering either the learning of relevant structure or its transfer to new situations. This hypothesis was tested in 4 experiments in which 6- to 8-year-old children learned to read simple bar graphs. In some conditions, the bars were monochromatic (i.e., No Extraneous Information), whereas in other conditions, the bars consisted of columns of discrete countable objects (i.e., Extraneous Information). Results demonstrated that the presence of extraneous information substantially attenuated learning; participants tended to count the objects and failed to acquire the appropriate strategy. The interference effects decreased with age. These findings present evidence of how extraneous information affects learning of new mathematical knowledge. Broader implications of these findings for understanding the development of the ability to filter task-irrelevant information and for educational practice are also discussed.

Keywords: inhibition, learning, mathematics, number

Elementary educators are faced with a twofold challenge: They need to communicate content to students, and they need to keep students engaged in the process of learning. This dual responsibility may be particularly challenging when teaching mathematics, because mathematical concepts and procedures are often difficult for students to acquire (e.g., Brown & Burton, 1978; English & Halford, 1995).

One response to this challenge is to incorporate colorful familiar images into the learning material, with the goal of increasing children's engagement and linking the new mathematical content to some prior knowledge. For example, when the goal is for children to learn to read bar graphs, the bars might consist of columns of candies, animals, or other objects. Such colorful images are commonly encountered in elementary educational practice and can also be found in material intended for adults (e.g., "Chipotle store openings," 2010; "Favorite pizza toppings," n.d.). Furthermore, there is a common belief that such materials are helpful for learning. For example, we informally surveyed 16 kindergarten and elementary school teachers about material used to teach children to read bar graphs. In particular, we showed teachers Graphs A and B in Figure 1 and asked them whether they would use similar graphs in their teaching and which of the two graphs would be more effective. All 16 teachers indicated that they would use graphs with columns of colorful objects in their teaching, with 14 of the teachers responding that such graphs would be more effective for teaching than graphs with monochromatic bars with no objects. Two teachers responded that they would not use the monochromatic graphs at all.

However, there is a note of caution: Although such added pictorial information may be visually appealing, such information may hinder, rather than facilitate, learning and/or transfer. This is because this information is often extraneous to the learning task, and it may also prompt well-learned strategies with unclear consequences on the to-be-learned ones. For example, items presented in Figures 1A and 1C may prompt counting, which is not an appropriate strategy for reading graphs. The inclusion of such extraneous information may be particularly problematic for children whose ability to control attention, filter irrelevant information, and inhibit prepotent responses is quite limited (see Hanania & Smith, 2010, for a review). Therefore, it is possible that such extraneous information may capture attention and prevent children from focusing on less salient to-be-learned structure or invite prepotent, well-learned strategies instead of newly presented strategies.

The goal of the present research was to examine how such extraneous perceptual information affects learning and how these effects change with development. We considered the case of learning to read bar graphs that had extraneous pictures similar to those in Figures 1A and 1C. Bar graphs present an interesting case for two reasons. First, bar graphs are a case of learning a relation (graphs depict a relation between two variables), and learning of relations is an important and challenging task during preschool and elementary school years (e.g., Goswami, 2001; Rattermann & Gentner, 1998). Second, bar graphs are an important real-life case

This article was published Online First December 17, 2012.

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This research was supported by Institute of Educational Sciences, U.S. Department of Education Grant R305B070407 and National Science Foundation Grant BCS-0720135. The opinions expressed herein are those of the authors and do not necessarily reflect the views of the Department of Education or the National Science Foundation. We thank Catherine Best and Anna Fisher for their helpful comments on this research.

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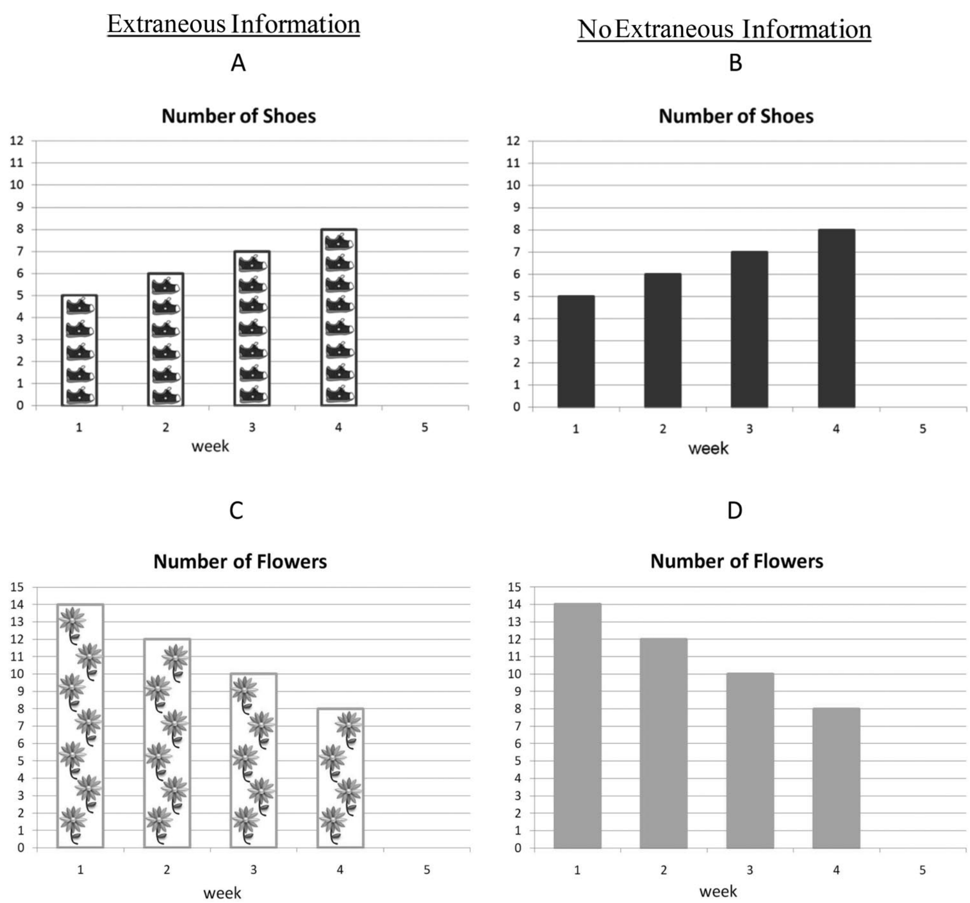

Figure 1. Sample stimuli: Graphs A and C were used in the extraneous information condition, and Graphs B and D were used in the no extraneous information condition. Graphs A and B were the example graphs shown in the Training phase, and Graphs C and D were test graphs shown in the Condition-Specific Test for each condition.

as they are part of elementary school curriculum (National Council of Teachers of Mathematics, 2000). Prior studies have investigated aspects of instruction that affect students' complex interpretations of graphs, such as noticing trends and interactions in the data (Kramarski, 2004; Shah & Hoeffner, 2002; Wainer, 1980, 1992). However, less is known about how variations in format affect young elementary students' basic graph reading ability, namely their ability to link a correct *y*-axis value with a specific *x*-axis value. In particular, how will children integrate and weigh task-relevant relational information and task-irrelevant (or extraneous) perceptual information?

Previous research suggests that children often have difficulty attending to relations and instead focus on superficial features (Gentner, 1988; Rattermann & Gentner, 1998). With development, they become increasingly capable of acquiring complex relational knowledge, such as basic arithmetic. Improvements in relational reasoning are largely driven by increases in domain knowledge (Goswami, 1992, 2001; Goswami & Brown, 1990) and in working memory capacity (Andrews & Halford, 2002; Halford, 1993; Richland, Morrison, & Holyoak, 2006). However, development per se does not guarantee successful relational reasoning. When relations are more complex than those involved in simple analogies or metaphors (which is often the case with mathematical concepts), even adults can fail to recognize and transfer learned relations to novel contexts (Gick & Holyoak, 1980, 1983; Goswami, 1991; Kaminski, Sloutsky, & Heckler, 2008; Novick, 1988; Reed, Dempster, & Ettinger, 1985; Reed, Ernst, & Banerji, 1974).

Although complex relational knowledge is generally difficult to transfer, the format of the learning material can affect the likelihood of successful transfer. Undergraduate students who learned a novel mathematical concept from a generic, perceptually sparse learning format demonstrated better transfer than students who learned from a perceptually rich format (Sloutsky, Kaminski, & Heckler, 2005). There is also evidence that perceptually rich learning formats can hinder transfer of the nonmathematical relations (Goldstone & Sakamoto, 2003) as well as problem solving (McNeil, Uttal, Jarvin, & Sternberg, 2009). As we argued above, this is because examples used in this format communicate considerable extraneous information to the learner (see Kaminski & Sloutsky, 2011, for discussion), and this irrelevant information may be difficult for the learner to inhibit and filter.

The inclusion of extraneous information in learning of mathematics may be particularly detrimental for young children. First, mathematical knowledge is often relational in nature, and relations are less salient than objects (e.g., Gentner, 1988). Adding extraneous superficial information increases the disparity in salience between the relevant relations and the superficial features. Second, filtering of irrelevant, potentially distracting information is particularly difficult for preschool and even elementary school children (Kemler, 1982; Shepp & Swartz, 1976; Smith & Kemler, 1978; see also Hanania & Smith, 2010). For example, Shepp and Swartz (1976) instructed 6- and 9-year-olds to sort items according to shape, with color being an irrelevant dimension. It was found that 6-year-olds (but not 9-year-olds) were slower when color varied independently of shape than when color covaried with shape or did not vary at all. Therefore, the task-irrelevant dimension affected performance of younger, but not older participants. Similarly, Napolitano and Sloutsky (2004) demonstrated that 4-year-olds have difficulty performing same–different discrimination with serially presented visual stimuli, when sounds accompanying these visual stimuli varied independently (see also Robinson & Sloutsky, 2004).

In addition, young children often experience difficulty inhibiting a previously learned response when a new response is needed (see Hanania & Smith, 2010; Plude, Enns, & Brodeur, 1994, for reviews). Although this ability improves with development (Davidson, Amso, Anderson, & Diamond, 2006), even adults are not immune to negative effects of such conflicts (Diamond & Kirkham, 2005; MacLleod, 1991). A variant of the difficulty to inhibit a well-learned response also transpires in the learning of mathematics. Children often apply well-learned, highly practiced procedures instead of to-be-learned ones. For example, children were found to apply familiar, yet inappropriate, arithmetic strategies to solve mathematical equivalence problems (McNeil, 2007; McNeil & Alibali, 2005) and whole number addition procedures to add fractions (Resnick & Ford, 1981).

In sum, in the context of extraneous information, successful learning (including learning of many mathematical concepts and procedures) may require attentional filtering and inhibitory control that may not be sufficiently developed in children. As a result, extraneous pictures that are intended to make learning material visually more appealing may actually hinder learning by either distracting from relational information or by prompting a well-learned, yet potentially inappropriate, strategy. Furthermore, given that the ability to filter irrelevant information and inhibit prepotent responses develops between preschool and late elementary school (Shepp & Swartz, 1976; see also Hanania & Smith, 2010; Plude et al., 1994, for reviews), we expect that these effects should reduce with age. Both hypotheses were tested in the four reported experiments.

Experiment 1

Method

Participants. Participants were 122 students recruited from public and private schools in suburbs of Columbus, Ohio, on the basis of returned parental consent forms. The majority of participants were Caucasian from middle-class families. Students were in kindergarten (20 girls, 20 boys; $M = 6.26$ years, $SD = 0.32$), first grade (18 girls, 24 boys; $M = 7.16$ years, $SD = 0.40$), and second grade (20 girls, 20 boys; $M = 8.24$ years, $SD = 0.38$).

Materials and design. Participants were randomly assigned to one of two between-subjects conditions (extraneous information or no extraneous information), which differed in the appearance of the graphs. The experiment consisted of three phases: Training, Condition-Specific Testing, and Novel Testing. Novel Testing was identical for both conditions. In all phases, participants were shown bar graphs representing quantities of different objects at different times, with quantities either increasing or decreasing with time. Time was always indicated on the *x*-axis, and quantity was always indicated on the *y*-axis.

Training. The Training phase consisted of the presentation of one example graph and one test graph. The appearance of the Training graphs differed across condition. In the no extraneous information condition, the bars were monochromatic (see Figure 1B), whereas in the extraneous information condition, the bars were filled with pictures of the objects whose quantities they represented (see Figure 1A). In the extraneous information condition, the number of objects in each of the bars was equal to the corresponding *y*-value (e.g., in Week 1, the number of shoes is five, and there are five shoes inside the corresponding bar). The experimenter demonstrated four separate readings of the Training example graph, and the participants were asked to make four readings (one for each bar) of the Training test graph.

Condition-Specific Testing. The Condition-Specific Testing phase followed the Training phase and consisted of three test graphs, for which participants made a total of 11 readings (four readings on each of the first and second graphs and three readings on the third graph). Critically, unlike in the Training phase, for the extraneous information condition, the number of objects in the bars did not equal the *y*-value; instead, the numbers of objects that appeared on each graph were proportionally related to the *y*-value as one third, one half, and one fourth of the *y*-values for the first, second, and third graphs, respectively (see Figure 1C). Therefore, responses clearly differentiated the children who correctly read the graph according to the *y*-axis from those who relied instead on the number of objects present. In the no extraneous information condition, the test graphs had monochromatic bars (see Figure 1D).

Novel Testing. The Novel Testing phase was condition-independent and consisted of two test graphs of a novel appearance. Participants in both conditions were presented with the same test graphs for which the bars were patterned with diagonal lines or small polka dots (see Figure 2). Participants were asked to make four separate readings of each test graph.

Procedure. Participants were tested individually at their schools by a female experimenter. All graphs were presented on a 15.6-in. laptop computer, and the experimenter recorded children's responses on paper. For each of the graphs, participants were read a situation involving quantities that were shown in the graph. In the Training phase, when presenting the example graph, the experimenter explicitly told the child that time was represented on the *x*-axis and stated each of the *x*-axis values. The experimenter also explicitly stated the *y*-axis values for this graph. For each of the four individual readings of the example graph, the experimenter pointed to the appropriate value on the *x*-axis, moved her finger upward over the bar of the graph, and then horizontally leftward to the *y*-axis to determine the corresponding *y*-value. The following is an excerpt from the script.

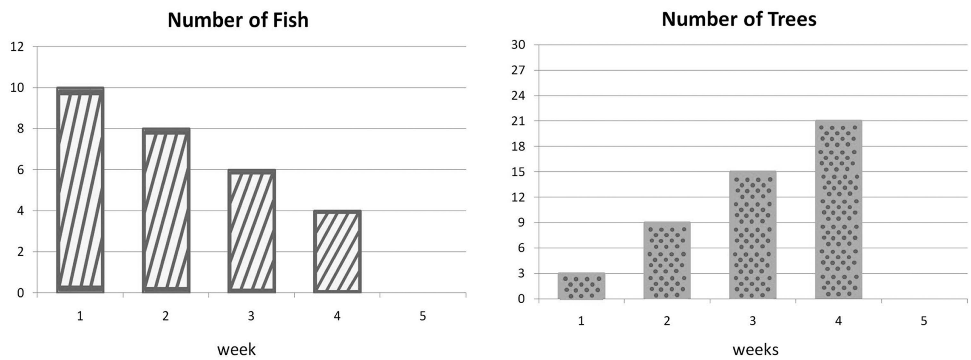

Figure 2. Novel Test Stimuli: Condition-independent Testing phase test graphs used in both the extraneous information and no extraneous information conditions.

> These bottom numbers (the experimenter gestured across the bottom) stand for the week number. . . 1 for the 1st week, 2 for the 2nd week, 3rd week and 4th week (the experimenter pointed to each individually as she spoke). These numbers here (the experimenter gestured to the *y*-axis) stand for the number of shoes in the lost and found. So, for the 1st week (the experimenter pointed to the 1 on the *x*-axis*)* there were (the experimenter gestured upward over the bar then left to the *y*-axis) five shoes in the lost and found.

For each test graph in the Training phase, Condition-Specific Testing phase, and the Novel Testing phase, the experimenter read the scenario and explicitly told the participant what quantities the graph was showing (e.g., the number of flowers over several weeks). Then participants were asked to state the quantity for each indicated time point. No corrective feedback was given during training or testing.

Results

Responses within one unit of the correct *y*-value were considered to be correct, in order to credit participants who were using a correct graph reading strategy but made small errors in reading the value on the *y*-axis. Note that in this and other experiments reported here, the overall patterns remain the same and reported effects remain significant with or without this adjustment.

Training phase. In both the extraneous information and no-extraneous information conditions, participants in all age groups did well reading the Training phase test graph (M = 100.0%, SD = 0.0% for second graders; M = 95.0%, SD = 22.4% for first graders; and M = 75.0%, SD = 37.2% for kindergarteners in the no extraneous information condition; and M = 95.0%, SD = 17.4% for second graders; M = 98.9%, SD = 5.33% for first graders; and M = 86.3%, SD = 25.0% for kindergarteners in the extraneous information condition). An analysis of variance with condition and grade level as factors revealed a significant effect of grade level, $F(2, 116) = 7.96$, $p < .002$, with first and second graders being more accurate than kindergarteners (post hoc Tukey's, $ps < .003$). There was no significant effect of condition or interaction ($ps > .24$).

Note that for the Training phase test graph, the number of objects inside each bar in the extraneous information condition was equal to the *y*-value. Therefore, participants in the extraneous information condition could respond accurately either by counting the objects in the appropriate bars or by reading the *y*-axis corresponding to the appropriate bars.

Condition-Specific Test phase. There were striking differences in accuracy between conditions on the Condition-Specific Test. For these graphs, the number of countable objects in the bars for the extraneous information condition was not equal to the *y*-value, resulting in incorrect responses from participants who counted these objects. Data across conditions and grade levels were not normally distributed. Therefore, we categorized participants on the basis of their predominant type of responses into one of three graph-reading strategies: correct, counting, or other. If greater than 50% of a participant's responses were correct, then he or she was categorized as a *correct* strategy user. The mean accuracy in this group for all ages and conditions was high, exceeding 89% (the same is true for the Novel Tests). Otherwise, if at least 50% of responses were based on the cardinality of the extraneous objects present in the bars, then the participant was categorized as a *counting* strategy user. Participants who did not fall into correct or counting categories were categorized as using *other* strategies. Responses from children in the *other* group appeared arbitrary. The mean accuracy for all ages and conditions in the latter two groups did not exceed 25% (the same is true for the Novel Tests).

Figure 3 presents the percentage of participants who used each of the strategy types and also the mean accuracy for all participants on the Condition-Specific Test. All first- and second-grade participants and 75% of kindergarten participants in the no extraneous information condition appropriately read the graphs. However, this was not true for the extraneous information condition in which 90% of kindergarteners and 72% of first graders responded by counting the objects. Differences in the number of correct strategy users were analyzed using an asymmetric log-linear analysis (Kennedy, 1992), with strategy type (correct or incorrect) as the dependent variable and condition and grade level as factors. Both condition and grade level were significant, $\chi^2(1, N = 122) > 55.3$, $p < .01$; and, $\chi^2(2, N = 122) > 26.4$, $p < .01$, respectively (.05 was added to cells with zero frequency). Older children were more accurate than younger children, $\chi^2(1, N = 82) > 3.09$, $p < .05$, one-tailed test between kindergarteners and first graders; and, $\chi^2(1, N = 82) > 5.56$, $p < .01$, one-tailed test between first graders and second graders.

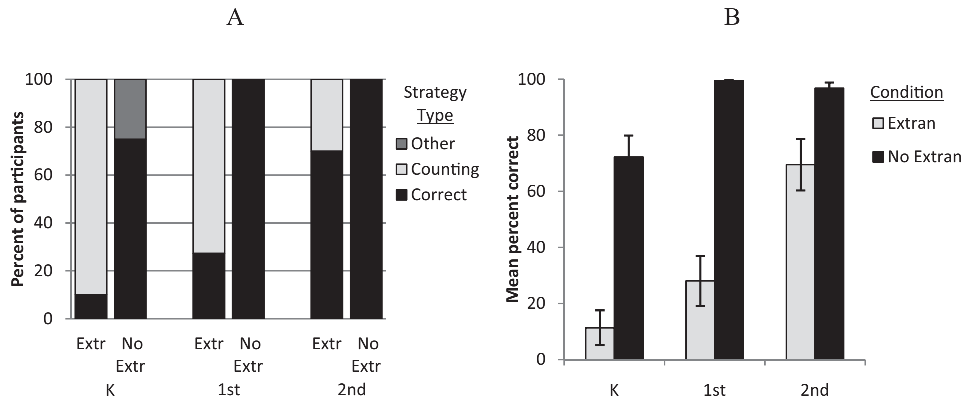

Figure 3. Performance on Condition-Specific Test in Experiment 1 split by condition and grade level. Panel A shows the percentage of participants performing each graph-reading strategy type. Panel B shows mean percent correct for all participants. Bars represent standard error of the mean. K = Kindergarten; 1st = first grade; 2nd = second grade; Extr = Extraneous; No Extr = No Extraneous; Extran = Extraneous; No Extran = No Extraneous.

Novel Test phase. Not only did many participants in the extraneous information condition count the discrete objects when present, but many of these participants also failed to appropriately read the Novel Test graphs (i.e., patterned bars). Figure 4 presents the percentage of participants who used each of the strategy types and also the mean accuracy for all participants on the Novel Test. To our surprise, many participants attempted to count the small stripes or polka dots on the bars, or they counted the horizontal lines present on the graph without considering the corresponding value on the *y*-axis. The remainder of participants who did not read the graphs accurately made arbitrary responses. However, in the no extraneous information condition, all first and second graders and 75% of kindergarteners accurately read these graphs. An asymmetric log-linear analysis with strategy type (correct or incorrect) as the dependent variable and condition and grade level as factors revealed differences across condition to be significant, $\chi^2(1, N = 122) > 11.1$, $p < .01$. Grade level was also a significant factor, $\chi^2(2, N = 122) > 25.6$, $p < .01$. First graders were more accurate than kindergarteners, $\chi^2(1, N = 82) > 9.76$, $p < .01$, and second graders were marginally more accurate than first graders, $\chi^2(1, N = 82) = 2.67$, $p = .051$.

These results suggest that task-irrelevant, extraneous information interferes with learning, and these interference effects decrease with development. The presence of the discrete objects encouraged many kindergarten and first graders to count the objects instead of appropriately reading the graphs using the *y*-axis. Not only did these participants fail to use an appropriate strategy in the presence of these objects, many of them attempted to use counting strategies on the Novel Test graphs with the patterned bars. Others responded with arbitrary answers when there was no countable information present, suggesting that they failed to learn. Although it appears that the presence of these objects alone distracted participants from learning and using an appropriate graph-reading strategy, one could argue that the presence of the objects themselves is not harmful per se; rather, it is the conflict between the number of objects and the corresponding *y*-value that hindered

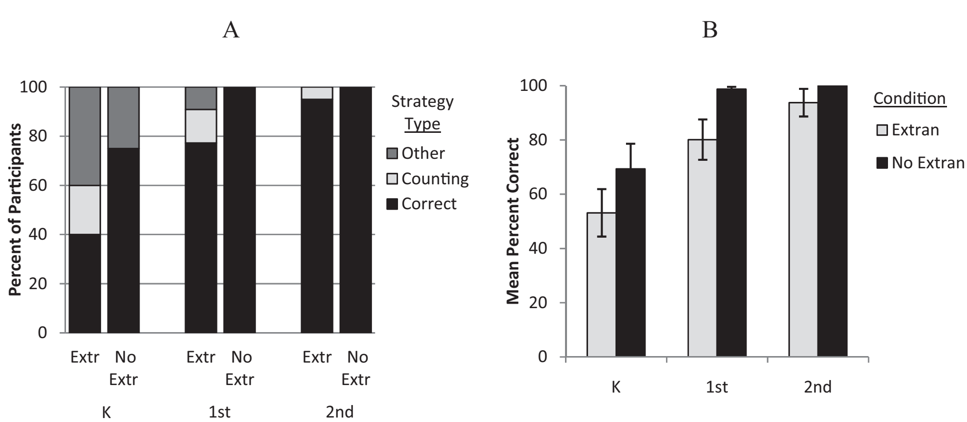

Figure 4. Performance on the Novel Test in Experiment 1 split by condition and grade level. Panel A shows the percentage of participants performing each graph-reading strategy type. Panel B shows mean percent correct for all participants. Bars represent standard error of the mean. K = Kindergarten; 1st = first grade; 2nd = second grade; Extr = Extraneous; No Extr = No Extraneous; Extran = Extraneous; No Extran = No Extraneous.

performance. Perhaps when these two pieces of information are in agreement, the objects may not hinder learning and may even facilitate learning by underscoring the fact that the bars represent quantities.

The purpose of Experiment 2 was to consider this possibility. In this experiment, the number of countable objects in a graph never conflicted with the corresponding *y*-value during the Training phase and the Condition-Specific Testing phase. Also, we only considered kindergarteners and first graders because the effect of the extraneous information was most pronounced for these two age groups.

Experiment 2

Method

Participants. Eighty-six students participated in the study. Students were in kindergarten (19 girls, 23 boys; $M = 6.14$ years, $SD = 0.32$) and first grade (26 girls, 18 boys; $M = 7.10$ years, $SD = 0.37$).

Materials and design. The material, design, and procedure were similar to those of Experiment 1, with one critical difference: Unlike Experiment 1, for the Condition-Specific Test in the extraneous information condition, the number of objects in each bar of the graphs equaled the corresponding *y*-value. Therefore, in the extraneous information condition, the cardinality of the extraneous objects never conflicted with the *y*-value. The actual numbers of the objects shown were the same as those in Experiment 1, but the *y*-values were set equal to these cardinalities. The same *y*-axis scale was used for both the extraneous information condition and the no extraneous information condition.

Results

Because the number of extraneous objects was equal to the *y*-value for the test graphs in the Training phase as well as the Condition-Specific Test phase, responses to these questions were not separated as in Experiment 1, but were analyzed together as the Condition-Specific Test responses.

Condition-Specific Test. In both the extraneous information and no extraneous information conditions, participants in both age groups did well reading the Condition-Specific graphs ($M = 98.8\%$, $SD = 2.63\%$ for first graders, and $M = 94.5\%$, $SD = 20.0\%$ for kindergarteners in the no extraneous information condition; and $M = 97.6\%$, $SD = 5.26\%$ for first graders, and $M = 92.7\%$, $SD = 8.35\%$ for kindergarteners in the extraneous information condition). An analysis of variance with condition and grade level as factors revealed no significant effect of condition and no significant interaction (*p*s $> .052$). There was a marginal effect of grade level, $F(1, 82) = 3.52$, $p = .064$, with first graders appearing slightly more accurate than kindergarteners. Therefore, similar to results with the Training Test graphs in Experiment 1, when the extraneous information does not conflict with the relevant *y*-values, participants accurately interpreted the graphs.

Novel Test. Although participants in both conditions were equally accurate reading the Condition-Specific Test graphs, the same was not true for reading the Novel Test graphs. The data were not normally distributed; therefore, participants were categorized on the basis of their predominant graph-reading strategy as correct, counting, or other (see Figure 5). The mean accuracy of correct strategy uses for both ages and conditions exceeded 95%. The mean accuracy for participants using the other two strategy types did not exceed 50%. In the no extraneous information condition, 100% of first graders and 91% of kindergarteners used a correct strategy to accurately read these graphs. However, in the extraneous information condition, only 77% of first graders and 45% of kindergarteners did so. The difference in the number of correct strategy users across condition was significant, asymmetric log-linear analysis, $\chi^2(1, N = 86) = 17.5$, $p < .01$. Additionally, first graders were more accurate than kindergarteners, $\chi^2(1, N = 86) = 6.62$, $p < .02$.

The results of Experiment 2 demonstrated that the hindering effects of the extraneous objects are not limited to situations when the cardinality information conflicts with the *y*-values. When cardinality is equal to the *y*-value, children were able to determine the correct values on the graphs. However, in the absence of such overt countable information (i.e., the patterned graphs), many

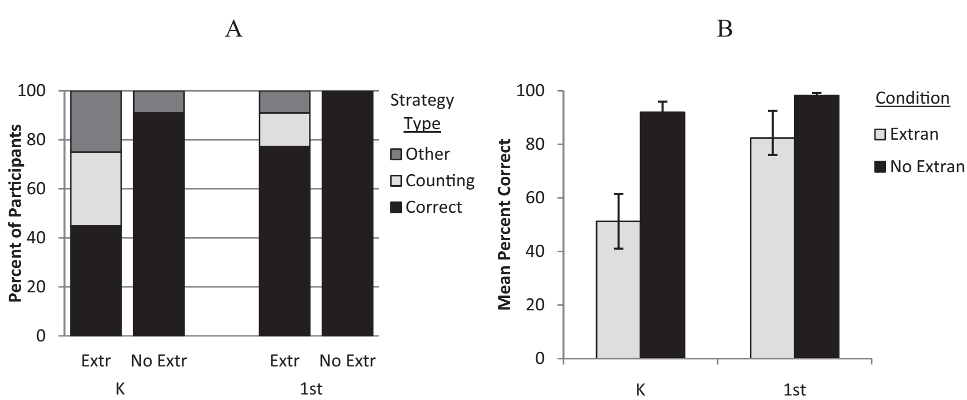

Figure 5. Performance on the Novel Test in Experiment 2 split by condition and grade level. Panel A shows the percentage of participants performing each graph-reading strategy type. Panel B shows mean percent correct for all participants. Bars represent standard error of the mean. K = Kindergarten; 1st = first grade; Extr = Extraneous; No Extr = No Extraneous; Extran = Extraneous; No Extran = No Extraneous.

children appear unable to correctly interpret the graphs. It seems that many children merely counted the objects they saw and failed to learn a correct graph-reading procedure.

The results of both Experiments 1 and 2 suggest that participants in the extraneous conditions did not learn to correctly read bar graphs. However, it may be that these participants actually did learn a correct graph-reading strategy, but noticed the equivalence of the *y*-values and the number of objects present on the example graph during the training phase and subsequently relied on a counting strategy in the presence of countable objects. They may also have overgeneralized this strategy to the novel test graphs, leading many to attempt to count aspects of the patterns (i.e., the strips or the dots). If this possibility is true, then the extraneous information may not have hindered learning; it may only have hindered performance by encouraging participants to count when countable objects or features were present. Furthermore, if participants in the extraneous information condition actually did learn how to read graphs correctly, then asking them to read graphs with monochromatic bars would be the optimal condition for them to do so. Graphs with monochromatic bars lack salient countable objects and features and therefore would eliminate or minimize the temptation to count.

The goal of Experiment 3 was to parse out the effect of the extraneous information on participants' performance and on participants' learning by testing all participants on graphs with monochromatic bars, patterned bars (i.e., stripes and dots as in the previous experiments), and bars with extraneous information (i.e., countable objects for which the number of objects conflicts with the *y*-value). If the extraneous information hinders only performance and not learning, then scores on the monochromatic graphs and countable object graphs should be comparable for participants in the extraneous information condition and participants in the no extraneous information condition. The absence of overtly countable extraneous objects on the monochromatic bars should encourage participants in either condition to use a proper graph-reading strategy if one had been learned. Alternatively, if the extraneous information hinders learning of the correct graph-reading strategy, scores on the monochromatic graphs should be lower for participants in the extraneous information condition than for those in the no extraneous information condition. Also, the presence of these objects on the graphs with extraneous information may encourage participants in the no extraneous information condition to use a counting strategy even though they have learned the appropriate graph-reading strategy. If this is the case, then it suggests that the extraneous information hinders performance even when a correct strategy was learned. Experiment 3 considered only kindergarteners as the effect of the extraneous information was most pronounced for this group of children.

Experiment 3

Method

Participants. Forty-four kindergarten students (21 girls, 23 boys; $M = 6.29$ years, $SD = 0.39$) participated in the study.

Materials and design. As in the previous experiments, there were two between-subject conditions, extraneous information and no extraneous information, which specified the appearance of the graphs that participants saw. In the extraneous information condition, the bars of the graphs had countable objects. In the no-extraneous information condition, the bars were monochromatic.

The experiment consisted of three phases: Training, Condition-Specific Testing, and General Testing. Training and Condition-Specific Testing were identical to Experiment 2. The General Testing was identical for the extraneous information condition and the no extraneous information condition and consisted of six test graphs with four readings each. Two of the six graphs presented patterned bars (i.e., the novel test graphs used in the previous experiments), two other graphs presented monochromatic bars, and the remaining two graphs presented bars filled with pictures of countable objects where the number of objects was not equal to the corresponding *y*-value. These six graphs were presented to participants in a random order.

Results

Responses within one unit of the correct *y*-value were considered to be correct, in order to credit participants who were using a correct graph-reading strategy but made small errors in reading the value on the *y*-axis.

Condition-Specific Test. In both the extraneous information and no extraneous information conditions, participants in both age groups did well reading the Condition-Specific graphs ($M = 92.7\%$, $SD = 12.7\%$ in the no extraneous information condition; and $M = 91.5\%$, $SD = 14.7\%$ in the extraneous information condition). There were no significant differences in accuracy between conditions (independent-samples *t* test), $t(42) = .293$, $p = .771$. As in the previous experiment, the extraneous information did not conflict with the *y*-values; therefore, participants in the extraneous information condition could arrive at the correct responses either through a correct graph-reading strategy or though counting the objects present.

General Test. The data for performance on the monochromatic graphs, patterned graphs, and countable object graphs was not normally distributed. Therefore, participants were categorized on the basis of their predominant graph-reading strategy as correct, counting, or other as done in the previous experiments. In both conditions and for all test graphs, the mean accuracy for participants categorized as correct strategy users exceeded 87%; the mean accuracy for participants in the other categories was below 50%.

Mean scores and frequency of strategies are presented in Figure 6. A repeated measures binary logistic regression was conducted to examine effects of training condition and test graph type on correct strategy use. There was a significant effect of condition, Wald $\chi^2(1, N = 44) = 12.5$, $p < .001$. For all three types of graphs, a higher percentage of participants in the no extraneous information condition than in the extraneous information condition used a correct graph-reading strategy, Pearson's $\chi^2(1, N = 44) > 5.93$, $ps < .02$. Test graph type also had a significant effect on strategy use, Wald $\chi^2(2, N = 44) = 15.8$, $p < .001$. Participants were more likely to use a correct strategy on the monochromatic than on the countable graphs, Wald $\chi^2(1, N = 44) = 15.3$, $p < .001$, and they were more likely to use a correct strategy on the patterned than on the countable graphs, Wald $\chi^2(1, N = 44) = 11.6$, $p < .002$.

When asked to read monochromatic graphs, many participants in the extraneous information condition failed to do so. Even in the absence of salient countable objects, 14% of participants re-

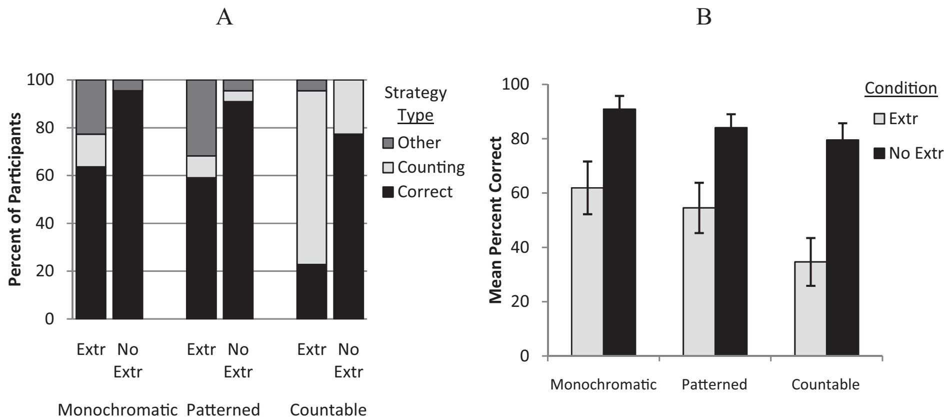

Figure 6. Performance on the General Test in Experiment 3 split by condition and graph type. Panel A shows the percentage of participants performing each graph-reading strategy type. Panel B shows mean percent correct for all participants. Bars represent standard error of the mean. Extr = Extraneous; No Extr = No Extraneous.

sponded by counting the horizontal lines through the graphs. Another 23% made arbitrary responses to these graphs. These results support the argument that the extraneous information hindered learning; it appears that 37% of participants in the extraneous information condition failed to learn a correct graph-reading strategy, whereas only 5% of participants in the no extraneous information condition did not learn. This difference was significant (Fisher's exact test, $p < .02$).

Although a majority of participants in the no extraneous information condition accurately read the monochromatic and patterned graphs, they were not all immune to the distraction of the countable objects; 22% responded to countable object graphs by counting the objects. The number of participants in the no extraneous information condition who counted was significantly fewer than the number in the extraneous information condition (77% counted), Pearson's $\chi^2(1, N = 44) = 11.0, p < .002$. These results suggest that although the presence of countable objects does encourage children to perform an incorrect strategy, they are less likely to do so if they initially learned a graph with monochromatic bars than if they initially learned a graph with extraneous objects on the bars.

The results of Experiment 3 suggest that the extraneous information hinders both learning and performance. On the monochromatic graphs, the percentage of participants in the extraneous information condition who accurately read the graphs was 32 points less than the percentage of participants in the no extraneous information condition (64% vs. 96%), suggesting that the extraneous information hindered learning. When comparing performance on monochromatic graphs with performance on countable object graphs for participants in the no extraneous information condition, there was a 19-point drop in percentage of participants responding correctly (96% vs. 77%), suggesting that the presence of the extraneous objects hindered performance, even for participants who acquired an accurate graph-reading strategy.

Although these results provide further evidence that the presence of the extraneous information distracted children from learning the relevant relational knowledge, there is an alternative explanation for the poor accuracy of participants in the extraneous information condition. It may be that these participants attended to the relation between the *x*- and *y*-values on the example graph and noticed the equivalence of the *y*-values and the number of objects present. Because the number of objects always agreed with the experimenter's reported values, participants may have learned to rely on a counting strategy to read graphs and not on the appropriate relation between the *x*- and *y*-values. Therefore, it may be that the presence of the extraneous objects may not have hindered learning if participants did not observe that the number of objects corresponded with the correct readings on the example they were shown.

The purpose of Experiment 4 was to test this possibility. The design of this experiment was identical to that of Experiment 3 with one critical exception. The numbers of objects shown on the columns of the example graph did not equal the corresponding *y*-values. If performance was hindered not by the presence of the objects themselves but by the fact that the number of objects concurred with the correct readings on the example graphs, then performance in the extraneous information condition should be comparable to that of the no extraneous information condition.

Experiment 4

Method

Participants. Forty kindergarten students (20 girls, 20 boys; $M = 6.23$ years, $SD = 0.33$) participated in the study.

Materials and design. As in the previous experiments, there were two between-subject conditions, extraneous information and no extraneous information, which specified the appearance of the graphs that participants saw. The experiment consisted of three phases: Training, Condition-Specific Testing, and General Testing. Training and Condition-Specific Testing were similar to those of Experiments 2 and 3. However, the number of objects that appeared on the bars of the graphs in the Training and Condition-Specific Testing phases for the extraneous information condition was never equal to that of the corresponding *y*-values. The numbers of objects on the example graph were half of the corresponding *y*-values. The numbers of objects on the Condition-Specific Test graphs were one half, one third, one half, and one fourth of the *y*-values for the first, second, third, and fourth graphs, respectively. The General Testing was the same for participants in both the extraneous information condition and the no extraneous information condition and identical to that of Experiment 3.

Results

Responses within one unit of the correct *y*-value were considered to be correct, in order to credit participants who were using a correct graph-reading strategy but made small errors in reading the value on the *y*-axis.

The data for performance on the condition-specific, monochromatic, patterned, and countable object graphs were not normally distributed. As in the previous experiments, participants were categorized on the basis of their predominant graph-reading strategy as correct, counting, or other for each test graph. In both conditions and for all test graphs, the mean accuracy for participants categorized as correct strategy users was high, exceeding 93%; the mean accuracy for participants in the other categories was below 50%. Figure 7 presents the frequencies of strategy types and the mean percent correct collapsed across all strategy types.

Unlike the previous experiment, there was a marked difference between the extraneous information and no extraneous information conditions in accuracy on the Condition-Specific graphs. Significantly more participants in the no extraneous information condition used a correct strategy than those in the extraneous information condition (Fisher's exact test, $p < .03$).

For the monochromatic graphs, patterned graphs, and countable object graphs, a repeated measures binary logistic regression was conducted to examine the effects of training condition and test graph type on correct strategy use. The results reveal a significant effect of training condition, $\chi^2(1, N = 44) = 3.87$, $p < .05$, with no significant effect of test graph type, Wald $\chi^2(2, N = 44) = 3.31$, $p = .191$. The former effect indicated that across the test graph types, a higher number of participants in the no extraneous information condition than in the extraneous information condition used a correct strategy.

As in Experiment 3, the presence of the countable objects encouraged a small number of participants (10%) in the no-extraneous information condition to respond by counting the objects as opposed to correctly reading the graphs. However, 30% of participants in the extraneous information condition responded to these graphs by counting. The difference in frequency of correct strategy use between the two conditions approached significance (Fisher's exact test, $p = .06$).

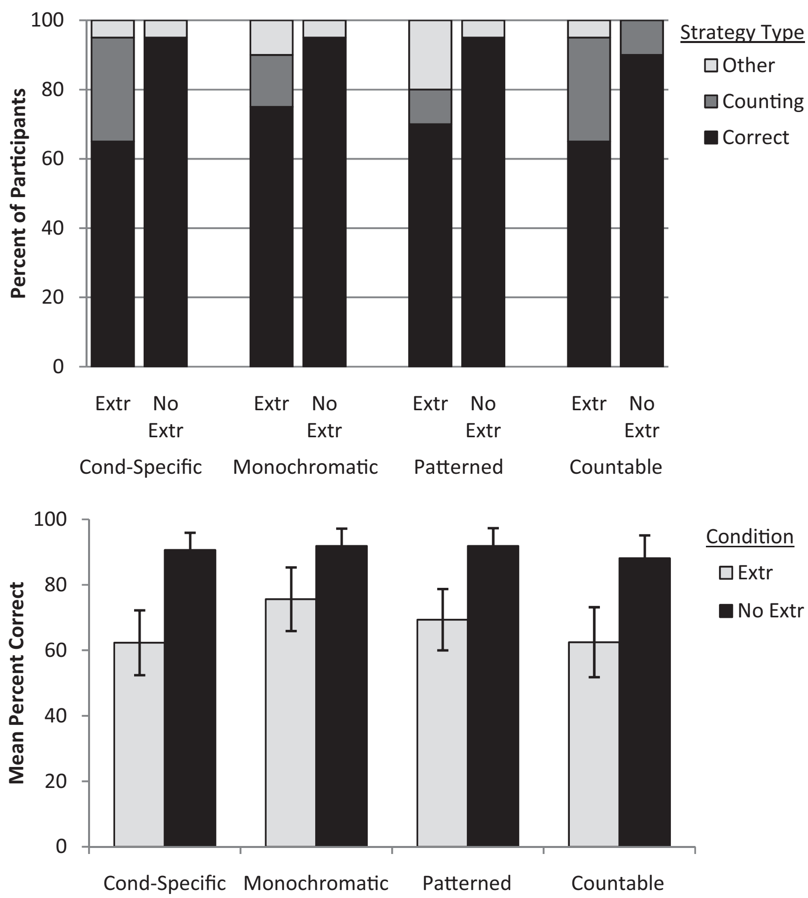

Figure 7. Performance on the Condition-Specific (Cond-Specific) Test and General Test in Experiment 4 split by training condition and test graph type. The top panel shows the percentage of participants performing each graph-reading strategy type. The bottom panel shows mean percent correct for all participants. Bars represent standard error of the mean. Extr = Extraneous; No Extr = No Extraneous.

Also similar to the previous experiment, many participants in the extraneous information condition failed to correctly read the monochromatic graphs; 15% responded by counting the horizontal lines through the graphs, and another 10% made arbitrary responses to these graphs. These results suggest that 25% of participants in the extraneous information condition failed to learn to correctly read bar graphs. In the no extraneous information condition, only 5% of participants did not read the graphs correctly. The difference in number of correct graph readers between the two conditions also approached significance (Fisher's exact test, $p = .09$).

Compared with the results of Experiment 3, more participants in the extraneous information condition of Experiment 4 learned to read the graphs correctly. To compare failure rates across the two experiments, the risk difference of failing to learn in the extraneous information condition versus failing to learn in the no extraneous information condition was used as a measure of effect size (see Ferguson, 2009). The risk difference in Experiment 3 was 32% (37% failure rate in the extraneous information condition vs. 5% in the no extraneous information condition), whereas the risk difference of Experiment 4 is 20% (25% failure rate in the extraneous information condition vs. 5% in the no extraneous information condition). The reduction in failure rate suggest that presenting graphs in which the number of objects did not equal the corresponding *y*-values enabled more children to learn than when the number of objects equaled the *y*-values.

General Discussion

The goal of the present research was to examine how extraneous perceptual information affects acquisition of simple mathematical knowledge by children. The results of Experiments 1 and 2 demonstrate that when discrete objects were depicted on the bars of a graph, the majority of children failed to read the graphs accurately and instead based their responses on the number of objects present. Not only did many participants respond by counting the objects when present, many of these children continued to use a counting strategy when shown the subsequent patterned graphs, basing their responses on extraneous features of the graph such as the number of stripes or dots. However, children who initially saw monochromatic bars accurately read these graphs.

The results also reveal a developmental trend with first and second graders (i.e., 7- and 8-year-olds) more accurately reading the graphs than kindergarteners (i.e., 6-year-olds), suggesting that older children are more capable of learning and using an appropriate procedure in the face of extraneous information. The better performance of the older participants is likely to stem from two factors. First, development leads to improvements in inhibitory control (Hanania & Smith, 2010; Plude et al., 1994; Shepp & Swartz, 1976), which is likely to increase children's ability to filter extraneous information and focus on relevant information. Second, the older children (i.e., first and second graders) may have had experience with bar graphs in school.

The results of Experiment 2 demonstrate that the difficulty introduced by the extraneous pictures is not limited to test situations when the extraneous and relevant information are in conflict. These findings suggest that it is not necessarily the conflict between information during testing that hindered children, but the conflict that arose during learning between possible procedures: the to-be-learned graph-reading procedure and the well-learned counting procedure activated by the presence of the discrete objects.

Experiments 3 and 4 eliminate two alternative explanations for the poor performance of participants in the extraneous information conditions. Experiment 3 considered the possibility that the extraneous objects did not hinder learning, but hindered performance by encouraging a counting strategy when salient countable objects or features were present. Participants were tested on graphs with simple monochromatic bars as well as graphs with countable objects. The results were that performance in both the extraneous information and the no extraneous information conditions was better on graphs with monochromatic bars than on the graphs with countable objects; this suggests that the presence of the objects can hinder performance even for those in the no extraneous information condition who demonstrated correct graph reading. In addition, performance on the graphs with monochromatic bars was significantly lower in the extraneous information condition than in the no extraneous information condition, suggesting that the presence of the objects does hinder learning.

The goal of Experiment 4 was to examine the possibility that learning was not hindered by the presence of the objects per se but rather by the fact that the numbers of objects shown on the example graph always equaled the corresponding *y*-values. It may be that participants in the extraneous information condition did initially attend to the relation between the *x*- and *y*-values, but relied instead on a counting strategy because they observed that such a strategy led to correct readings of the example graph. The results demonstrate that when participants were shown an example graph for which they could not rely on counting the numbers of objects to arrive at a correct reading, subsequent performance was still lower in comparison to participants who were shown an example graph with monochromatic bars. These results provide further support for the argument that the extraneous information hindered learning.

Although graph-reading performance in Experiment 4 was lower for participants in the extraneous information condition than those in the no extraneous information condition, a comparison of risk differences (i.e., a measure of failure rate attributable to the extraneous information) between Experiments 3 and 4 suggests that the negative effect of the extraneous information is attenuated when this information is in conflict with the alternative strategy (i.e., counting). It may be that participants who noticed the conflict between the number of objects and the corresponding *y*-value redirected their attention to the relevant relation between the *x*-values and the *y*-values. These findings are perhaps counterintuitive because they suggest that in some situations, extraneous information that aligns with to-be-learned relational information may have a greater negative effect on learning than extraneous information that conflicts with to-be-learned relational information. Although creating a conflict between the relevant and extraneous information produced successful learning for many participants, this type of learning material does not appear to be widely used by teachers. In our informal survey of teachers who we mentioned earlier, only four of the 16 teachers indicated that they would use such graphs in their teaching.

Taken together, the results of all four experiments suggest that successful learning of mathematical procedures requires sufficient attention be allocated to the relevant underlying relations. Extraneous information included in the learning material can capture the learner's attention and divert it from these relations during learning. Not only can extraneous information hinder learning, it can also hinder subsequent performance. However, children who learned in the absence of extraneous information were more resistant to the hindering effects of extraneous information during testing than those who learned in the presence of extraneous information. In the present experiments, extraneous information came in the form of discrete, countable objects, which might intuitively seem to support learning because the number of these objects corresponded with the to-be-learned responses (in Experiments 1–3). However, it appears that that the extraneous information activated a well-learned counting procedure that children used instead of learning a new procedure.

By elementary school, children are very familiar with the process of counting to determine cardinality. Understanding of the relationship between counting and cardinality emerges gradually over the preschool years (Baroody & Price, 1983; Briars & Siegler, 1984; Fuson, 1988; Gelman & Gallistel, 1978; Mix, 2002; Wynn, 1990, 1992). In school, instruction on arithmetic concepts often involves enumeration and counting of sets of discrete objects (see Van De Walle, 2007, for examples). Therefore, the process of counting to determine cardinality is very well practiced. This process can promote important mathematical understanding. At the same time, there may be instances, such as those of the present study, when counting and cardinality conflict with correct mathematical knowledge and procedures. This possibility has also been noted by other researchers who have suggested that well-learned counting knowledge may interfere with children's proportional reasoning (Boyer, Levine, & Huttenlocher, 2008). More generally, in the course of acquiring mathematical knowledge, children sometimes apply well-learned, highly practiced, but inappropriate procedures instead of to-be-learned ones (e.g., when solving equivalence problems and when performing fraction arithmetic; see McNeil, 2007; McNeil & Alibali, 2005; Resnick & Ford, 1981). However, unlike the situations with equivalence problems and fraction arithmetic, the temptation to apply a familiar but inappropriate strategy to bar graph reading can be easily avoided by removing the source of this temptation.

It could be argued that in the case of teaching children to read bar graphs, the inclusion of columns of objects is intended to scaffold learning with students initially instructed to read pictograms for which the number of objects present intentionally represents the relevant quantities. The present study suggests two points. First, if such objects are included in instructional material, explicit measures need to be taken to direct children's attention to the relevant relation between the x and y variables. Such measures may come in the form of creating a conflict between possible responses, as in Experiment 4, or possibly in the form of phasing the extraneous information out the learning material. Progressive fading of perceptual details has been shown to facilitate transfer of knowledge (Goldstone & Son, 2005). Second, the high level of accuracy in the no extraneous information conditions suggests that such a scaffold is not necessary for successful learning.

The present study revealed that extraneous perceptual information hinders learning of reading graphs, especially in kindergarten (i.e., 6- to 7-year-old) children. However, several related issues remain unknown. First, in the present study we examined children's most basic understanding of bar graphs, namely, how to associate a particular independent variable with the appropriate dependent variable. The effects of extraneous information on other aspects of bar graph reading, such as noticing trends in the data or interpreting contextual significance, would need further experimental consideration. In addition, the extent to which the extraneous information may affect participants' generalizability of the learned graph-reading procedure is not known. For example, can participants generalize the learned procedure to appreciably different bar graphs, such as graphs with horizontal bars? Second, the extraneous information examined in this study was both countable and perceptually rich. To know the extent to which the demonstrated effect is attributed to each of these factors independently would need further research. Clearly, the effect is attributed in part to the presence of discrete objects; otherwise, there would be nothing to count. We also expect that the perceptual richness of the objects also contributes to the effect by making the objects very salient, as opposed to less salient countable circles for example.

The present results have important implications for the design of educational material. These findings underscore the importance of considering children's limited attentional capacities when designing and introducing learning material. Those who design material need to consider the possibility that inclusion of extraneous perceptual information may divert attention from the to-be-learned information. The consequence of children not acquiring the new knowledge may not be immediately recognizable by teachers in situations when the extraneous information is not in conflict with to-be-learned procedures (e.g., in the present study, when cardinality equaled the y-value). Instead, failure in learning can appear later when children are presented with material from which they cannot rely on another procedure. Therefore, it is important that the designers of instructional material, including textbooks and lesson plans, not simply rely on intuition as to what features may seem desirable or visually pleasing. They should recognize a priori the potential pitfalls of including such extraneous information in learning material intended for children whose ability to inhibit extraneous information is still developing.

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Received July 3, 2012
Revision received October 25, 2012
Accepted November 1, 2012 ■