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Equal Spacing and Expanding Schedules in Children's Categorization and Generalization

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Abstract

In order to understand how generalization develops across the lifespan, researchers have examined the factors of the learning environment that promote the acquisition and generalization of categories. One such factor is the timing of learning events, which recent findings suggest may play a particularly important role in children's generalization. In the current study, we build upon these findings by examining the impact of equally spaced versus expanding learning schedules on children's ability to generalize from studied exemplars of a given category to new exemplars presented on a later test. We found no significant effects of learning schedule when the generalization test was administered immediately after the learning phase, but there was a clear difference when the generalization test was delayed by 24 hours: Children in the expanding condition significantly outperformed children in the equally spaced learning condition. These results suggest forgetting and retrieval dynamics may be lower-level cognitive mechanisms promoting generalization and have several implications for broad theories of learning, cognition, and development.

Keywords

spacing effect; expanding learning schedules; forgetting; novel-noun generalization; category learning; cognitive development

Categorization and generalization are fundamental processes in cognition and development. Consequently, researchers have examined multiple factors in the learning environment that promote the acquisition and generalization of categories. A recent relevant finding is that the *timing* of learning events may be particularly important for promoting generalization:

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Distributing the presentation of category exemplars across intervals of time has been shown to promote more generalization than does massing category exemplars together in immediate succession (e.g., Birnbaum, Kornell, Bjork, & Bjork, 2013; Vlach, Sandhofer, & Kornell, 2008). To date, researchers have presented learners with category exemplars on spaced schedules with roughly equal intervals of time between presentations. The current study extends this work by examining how distributing learning events across variable amounts of time affects children's category acquisition and generalization.

The Spacing Effect in Memory and Generalization

A considerable body of research has examined the conditions under which the timing of learning events promotes and/or deters memory. The most highly replicated and robust finding of this literature is commonly termed the *spacing effect* (Ebbinghaus, 1885/1964; see Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006, for a review). The spacing effect refers to the finding that memory is enhanced on a delayed test when learning events are distributed in time, rather than massed in immediate succession. Hundreds of experiments have observed a spacing effect in a wide variety of memory tasks (Cepeda et al., 2006). In these studies, learners are presented with the same information multiple times, such as lists of words, with intervals of time filled with unrelated events between each presentation. After a delay, participants are asked to recall the exact information presented earlier in the experiment, such as the words from the list.

Only recently, however, has the spacing effect been studied in the context of categorization and generalization tasks (Birnbaum et al., 2013; Kang & Pashler, 2012; Kornell & Bjork, 2008; Kornell, Castel, Eich, & Bjork, 2010; Rohrer, 2012; Vlach et al., 2008; Vlach, Ankowski, & Sandhofer, 2012; Wahlheim, Dunlosky, & Jacoby, 2011). Categorization and generalization tasks differ from memory tasks because they require learners to aggregate exemplars, abstract relevant and irrelevant information across presentations, store information, and, at test, generalize this information to a new instance of the category. This body of research has revealed that spacing the exemplars of a given category, versus presenting exemplars in immediate succession, promotes generalization at a delayed test. Indeed, this finding has been observed across the lifespan, including in childhood (e.g., Vlach et al., 2008, 2012), in adulthood (e.g., Birnbaum et al., 2013), and in older adulthood (with interleaved learning paradigms; e.g., Kornell et al., 2010).

In studies of categorization and generalization processes in children, the children are typically presented with a series of category exemplars, often novel objects that share a common perceptual feature (e.g., shape), but also have differing perceptual features (e.g., color and texture). Each category exemplar is paired with a novel linguistic label (e.g., “wug”). In studies on the effects of spacing (Vlach et al., 2008, 2012), the exemplars have been presented on either a massed schedule, in which category exemplars are presented in immediate succession, or spaced schedule, in which category exemplars are separated in time. At test, children are shown a set of objects that includes a novel exemplar of a studied category and asked to identify the object that is, say, a “wug.” The current study uses a similar paradigm.

To date, in research on spaced learning schedules in categorization and generalization tasks, learners have been presented with exemplars of a given category with an equal, or roughly equal, temporal separation between successive exemplars. That is, information has been presented on spaced schedules with an equal amount of time between learning events (e.g., Birnbaum et al., 2013; Vlach, et al., 2008, 2012). However, research has yet to examine categorization and generalization on variable learning schedules. Thus, in the current study we examined children's generalization across both equal and variable time schedules. Given that there are an infinite number of possible variable learning schedules, we focused on a particular schedule—an expanding-interval schedule—that has often been compared to a uniform schedule in research on memory for verbal materials, such as names or vocabulary items.

Expanding Learning Schedules

In expanding schedules (e.g., Landauer & Bjork, 1978), the amount of time between learning events gets larger with every presentation. That is, the spacing interval becomes increasingly longer over the course of the learning period. We focused our investigation on expanding learning schedules for a few reasons. First, as outlined below, the logic as to why an expanding schedule should enhance memory and generalization is appealing in the context of children's concept learning. Second, even though there have been demonstrations that equally spaced schedules can sometime produce better long-term recall (e.g., Karpicke & Bauernschmidt, 2011; see Balota, Duchek, & Logan, 2007, for a discussion), recent findings have demonstrated that expanding schedules are superior for individuals and/or materials subject to rapid forgetting (see Maddox, et al., 2011; Storm, Bjork, & Storm, 2010), an important consideration in research on young children (e.g., Rovee-Collier, 1997).

A third reason for examining expanding schedules is that finding benefits of such schedules would implicate memory processes as being key to children's inductive learning. Expanding schedules have been hypothesized to enhance memory to a greater degree than equally spaced schedules because expanding schedules reactivate information along the forgetting curve at more optimal time points than do equally spaced schedules (Landauer & Bjork, 1978; Maddox et al., 2011; Storm et al., 2010). There are two ways in expanding schedules optimize the reactivation of information. First, expanding learning schedules minimize the amount of forgetting between the first and second learning event—that is, such schedules still introduce forgetting between the first two learning events, but reduce the likelihood that learners will be unable to retrieve information before it is presented again. Second, such schedules gradually make retrieval more effortful, which has been shown to strengthen memory for the retrieved information and slow the subsequent forgetting rate (e.g., Whitten & Bjork, 1977). As the retrieval strength for information improves with subsequent presentations, increasing the interval between learning events introduces more forgetting, which may engender more effortful retrieval at subsequent presentations, promoting even stronger memory for information. An optimal expanding schedule would reactivate information at a key point in time at each presentation—namely, right before information is about to become inaccessible to the learner. However, there are a number of time points along the forgetting curve that would engage learners in more effortful retrieval of the past than equally spaced schedules, which would still result in a benefit of an expanding schedule.

In sum, a benefit of an expanding schedule would suggest that memory processes are central in promoting categorization and generalization. Indeed, prior research on spaced learning and generalization has suggested that forgetting may be a cognitive process that supports children's generalization by promoting memory for relevant features of categories across exemplar presentations (Vlach et al., 2008, 2012).

Current Study: Equal and Expanding Learning Schedules in Children's Generalization

In the current experiment the effects of presentation schedule were examined on generalization tests administered on two timescales: immediately or after a 24-hour delay. The immediate test was administered, in part, to ensure that children would be able to generalize information after learning. However, the benefits of spacing are typically not observed at an immediate test, but are observed at a delayed test (Cepeda et al., 2006). Consequently, there was also a test administered at a substantial delay. In sum, the two presentation conditions and the two testing conditions allowed for a direct examination of different learning schedules in children's immediate and long-term generalization.

Method

Participants

The participants were 48 3-year-old children (*M* = 41.49 months; 25 girls). All children were monolingual English speakers and recruited from local preschools. An equal number of children were randomly assigned to each presentation condition, resulting in 12 children in each condition of the study. Children at this point in development (i.e., preschool-aged children) were chosen in order to parallel previous research on spacing in generalization tasks (e.g., Vlach et al., 2008) and to characterize generalization behavior during a time period in which learners are rapidly acquiring new object categories and concepts.

Stimuli

Children were presented with eight novel object categories. Each category contained four instances that varied in color, texture, and perceptual features, but all instances had the same shape (see Figure 1, Panel B, for examples). Each novel object was randomly assigned a novel label (e.g., “blicket”). There were also eight novel distractor objects presented (see Figure 1, Panel A). The object presentation order and object-label pairing were randomly assigned for each participant.

At test, there were four objects presented (see Figure 1, Panel C). One object was a novel instance of the target category and one object was the distractor object. The third object was a novel object that differed in shape, color, texture, and perceptual features from all of the objects presented at test. The fourth object was a familiar object (e.g., a toy dinosaur).

Design

The study was a 2 (Presentation Timing) × 2 (Testing Delay) design. Both Presentation Timing (equal or expanding) and Testing Delay (immediate or 24-hour delay) were between-subjects factors.

Procedure

The experiment was conducted by two experimenters: One experimenter coordinated the timing and the second experimenter organized the objects under a table so that they were not visible until presentation. During the presentations, the first experimenter kept the object in the child's gaze at all times. If a child began to look away during an object presentation, the first experimenter moved the object into the child's visual focus to maintain the child's attention and ensure equivalent looking times across all trials.

During the experiment, children were introduced to eight sets of stimuli, one set per trial. Each set was presented in three phases: a distractor phase, a learning phase (on an equal or expanding schedule), and a test phase.

Distractor Phase—The distractor phase was the first phase of each trial. As depicted in Figure 1 (Panel A), a distractor object was presented for 40s and was not given a linguistic label (for example, the experimenter said, "Look at this!"). The distractor object was different in shape from the objects presented in the learning phase and was a novel object in every trial. The purpose of introducing a distractor object was to have a familiar object present during testing that was not the target object. This ensured that children were not simply responding based on the familiarity of the objects during the test.

Learning Phase—The learning phase of each trial began immediately following the distractor phase. As depicted in Figure 1 (Panel B), in both presentation conditions, each of the objects was presented individually and allotted 10 seconds of viewing time. During the four object presentations, each object was labeled 3 times (e.g., "Look at this blicket!"). Thus, the total presentation time for each novel category ("blicket") was 40s, equivalent to that of the distractor object presented in the distractor phase.

The only difference between the two presentation timing conditions was the amount of time between each object presentation. In the equal spacing condition, there was 30s between each presentation. In the expanding condition, there was 10s between the first and second presentations, 30s between the second and third presentations, and 50s between the third and fourth presentations. During the spacing intervals (labeled 'Play' in Figure 1), children played with stickers and/or completed puzzles. These schedules were chosen to be consistent with prior research (e.g., Vlach et al., 2012) and to control for the overall amount of spacing between the two conditions. The equal spacing condition (30s – 30s – 30s) and expanding condition (10s – 30s – 50s) both contained a total of 90s of spacing between object presentations.

Test Phase—During the test phase of each trial, children were given one forced-choice novel-noun generalization test. For children in the immediate testing condition, the test phase immediately followed the learning phase. For children in the 24-hour delayed condition, the test phase occurred the next day. As depicted in Figure 1, Panel C, children were simultaneously presented with four objects, in random placement order, and were asked to pick out the target object ("Can you hand me the blicket?"). The target object ("blicket") was a new instance of the category that varied in color and texture from previously viewed instances. A second object was the same distractor object that had been presented during the distractor phase. A third object was an unfamiliar novel object and the fourth object was an object known by children that had not been presented during the experiment (e.g., a toy dinosaur). Children were not given feedback during the test phase.

Results

We were interested in whether the timing of presentations affected children's generalization performance at the immediate and 24-hour delayed tests. Figure 2 shows the mean percentage of correct responses in the four conditions of the study. As can be seen in the figure, there were overall differences between the two presentation timing conditions and the two testing delays, suggesting an interaction between testing delay and presentation timing. A 2 (Presentation Timing) × 2 (Testing Delay) ANOVA, with the mean percentage of correct responses as the dependent measure, revealed no main effect of presentation timing, $F(1, 44) = 1.695$, $p = .200$. However, the test also revealed a significant main effect of testing delay, $F(1, 44) = 16.856$, $p < .001$, $\eta_p^2 = .277$, and a significant interaction of presentation timing and testing delay, $F(1, 44) = 6.267$, $p = .016$, $\eta_p^2 = .125$.

We had predicted that any differential effects of presentation schedule would show up on the 24-hour delayed test, rather than on the immediate test. We computed two planned comparisons using t-tests with Bonferroni corrections (corrected to an alpha of .05) to determine the nature of the differences between the two presentation timing conditions within each testing delay condition. Because we were interested in examining the effects of the two presentation schedules on children's immediate and long-term generalization, it was important to determine how performance differed between the presentation timing conditions within each level of delay (immediate or 24-hour delay). These tests revealed no significant difference at the immediate test, $p = .395$, but a significant difference at the 24-hour delayed test, $p = .015$. Thus, although there was not a significant difference in performance between the two presentation conditions at the immediate test, children in the expanding learning condition demonstrated significantly higher performance at the 24-hour delayed test. We also examined whether there were differences in children's errors across test lures (distractor, novel, and known objects) and conditions; we did not find any significant differences across lures or conditions, *p*s > .05.

Discussion

In this study, we examined whether the timing of learning events affected children's categorization and generalization. Specifically, we examined whether an expanding learning schedule would promote generalization to a greater degree than would an equally spaced learning schedule. We found that, on an immediate generalization test, there was no significant difference in performance between the two presentation conditions. However, at the 24-hour delayed generalization test, we observed a significant difference between the two conditions: Children in the expanding learning condition significantly outperformed children in the equal spacing condition. To our knowledge, this study is the first to demonstrate that expanding learning schedules can promote generalization to a greater degree than non-expanding spaced learning schedules. These findings suggest that the benefits of expanding schedules are not constrained to memory tasks, but that these learning schedules can promote multiple types of learning, such as the acquisition and generalization of information.

Why did we observe that an expanding learning schedule promoted children's generalization to a greater degree than an equally spaced schedule? We suggest that the same cognitive processes that promote memory are also affecting categorization and generalization. In the sections below, we outline (1) the memory processes that could be contributing to enhanced generalization in expanding schedules, (2) the value of a developmental approach to understanding the efficacy of expanding learning schedules, and (3) the implications of these findings for the curriculum design and educational practices.

Memory Processes in Children's Categorization and Generalization

Historically, there have been four classes of theories that have been developed to explain spacing effects in memory tasks: (1) study-phase retrieval theories (e.g., Thios & D'Agostino, 1976; also see Benjamin & Tullis, 2010), (2) deficient processing theories (e.g., Hintzman, 1974), (3) encoding variability theories (e.g., Glenberg, 1979), and, (4) consolidation theories (e.g., Landauer, 1969). Consolidation accounts have proposed that spacing effects emerge because the interval between learning events allows time for consolidation. Indeed, in most studies on the spacing effect, spaced learning schedules are typically longer in overall duration than massed learning schedules, allowing more time for consolidation during the learning period. However, the current paradigm does not have this confound; there was an equal amount of time between the learning events (90s) and the learning trials were the same duration (130s), but we still observed performance differences at the delayed test. Another possibility is that the longer interval between the last two presentations in the expanding schedule resulted in more time for consolidation at the end of learning, which could result in higher performance in the expanding condition. However, based on consolidation theories (Landauer, 1969), there should be differences in performance between the spaced and expanding schedule at both the immediate and delayed test, which is inconsistent with our finding a significant difference in performance only at the 24-hour delayed test.

What about the other theoretical accounts? The current results are consistent with previous research demonstrating that forgetting and retrieval difficulty may be a mechanism promoting children's categorization and generalization (a study-phase retrieval account; e.g., Vlach et al., 2008, 2012). However, the current research does not rule out the possibility that there were differences in contextual encoding and/or attention across the equally spaced and expanding learning conditions. Consequently, an important direction for future research is to examine these processes in children's categorization and generalization. Indeed, spaced learning has only been investigated in the context of categorization and generalization tasks within the last few years; much research is needed to connect the process of generalization to classic theories of spaced learning.

Looking Ahead: Developmental Theories and Educational Contexts

We observe accelerated rates of forgetting in early childhood and older adulthood (e.g., Maddox et al., 2011; Rovee-Collier, 1997). Consequently, there may be an even larger benefit of expanding learning schedules, which minimize the likelihood of failing to retrieve information between the first two learning events, over equally spaced schedules for young children and older adults. Recent studies with young and older adults suggest that the benefits of expanding learning for memory performance may be directly related to an individual's forgetting rates and developmental state (Maddox et al., 2011). Examining expanding schedules early in development may reveal how memory development affects the efficacy of expanding schedules and how this in turn affects children's categorization and generalization. In sum, it is highly likely that a developmental theory across the lifespan is necessary for (a) resolving conflicting findings on the efficacy of expanding schedules with adult learners and (b) understanding how expanding schedules promote multiple forms of learning, such as memory and generalization.

On a final note, it is important to highlight that this study represents a convergence of several bodies of research. Both early experimental psychological science (e.g., Ebbinghaus, 1885/1964) and broad theoretical frameworks of development and education (e.g., Bruner, 1960) have emphasized the importance of the timing of learning. For example, a central tenant of spiral curriculum is to gradually increase the amount of time between lessons to optimize educational curriculum (Bruner, 1960). The current work supports a common idea across these bodies of work—children should initially be presented with learning events close together in time to reduce the difficulty of learning, but then further apart in time as learning becomes easier. Indeed, it may be that the lower-level cognitive processes identified by experimental psychology are the same processes that promote memory and generalization across broad timescales, development, and in educational contexts.

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Highlights

- We examined equal and variable learning schedules in children's categorization
- At the immediate test, there was no difference across conditions
- At 24-hour delayed test, children in expanding condition had higher performance
- Results suggest that efficacy of expanding schedules is not limited to memory tasks
- Results suggest that forgetting and retrieval dynamics support categorization

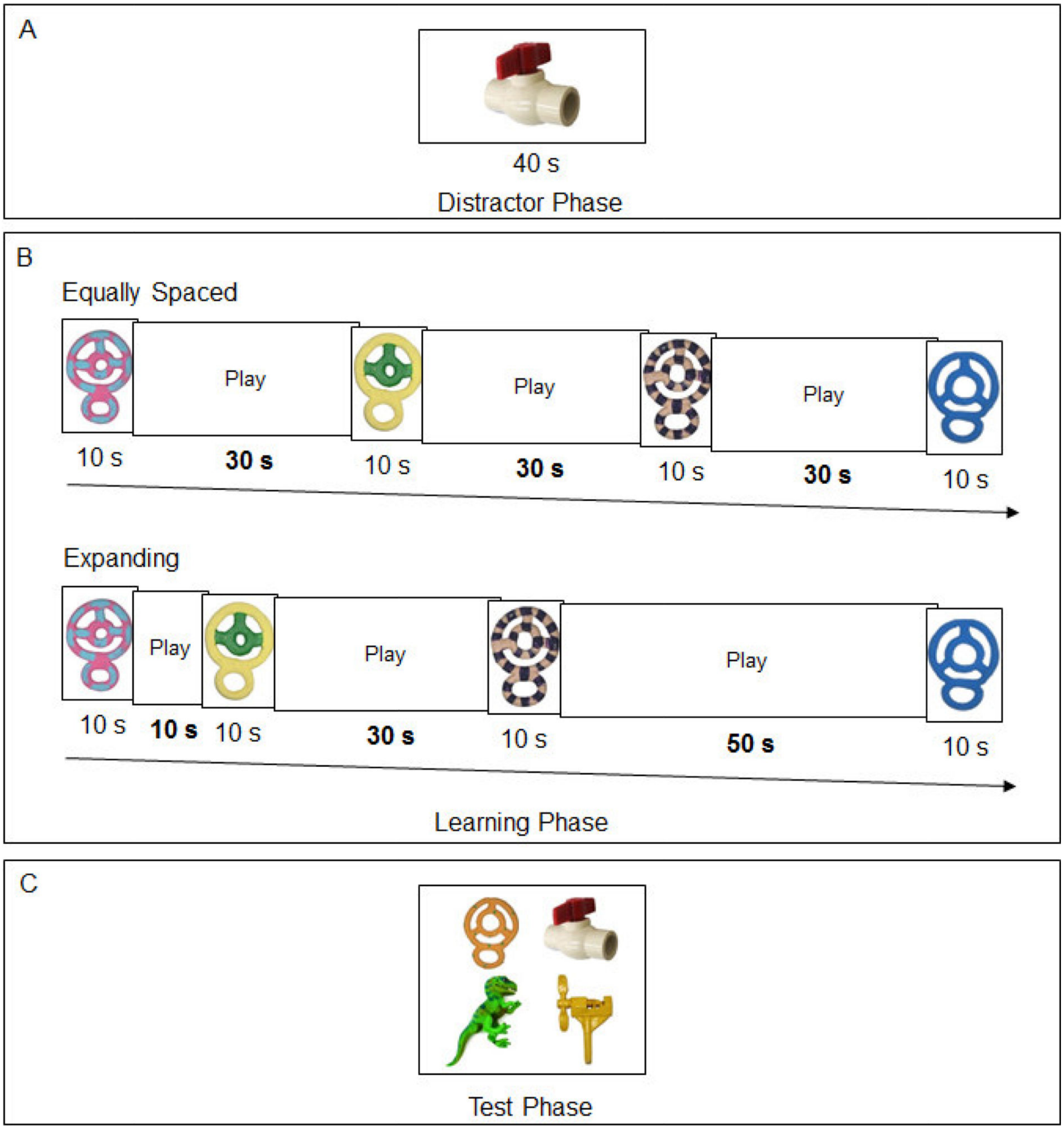

Figure 1.

Experimental procedure for one trial. (A) Distractor phase. A novel object was presented without a label (e.g., ‘‘Look at this!”). (B) Learning phase. Four novel objects were presented and given a label (e.g., ‘‘Look at this blicket!”) on an equal spacing or expanding learning schedule. (C) Test phase. Four objects were presented and the child was asked to identify the target (e.g., ‘‘Can you hand me the blicket?”). For children in the immediate condition, testing occurred immediately after the learning phase. For children in the delayed testing condition, testing occurred the next day.

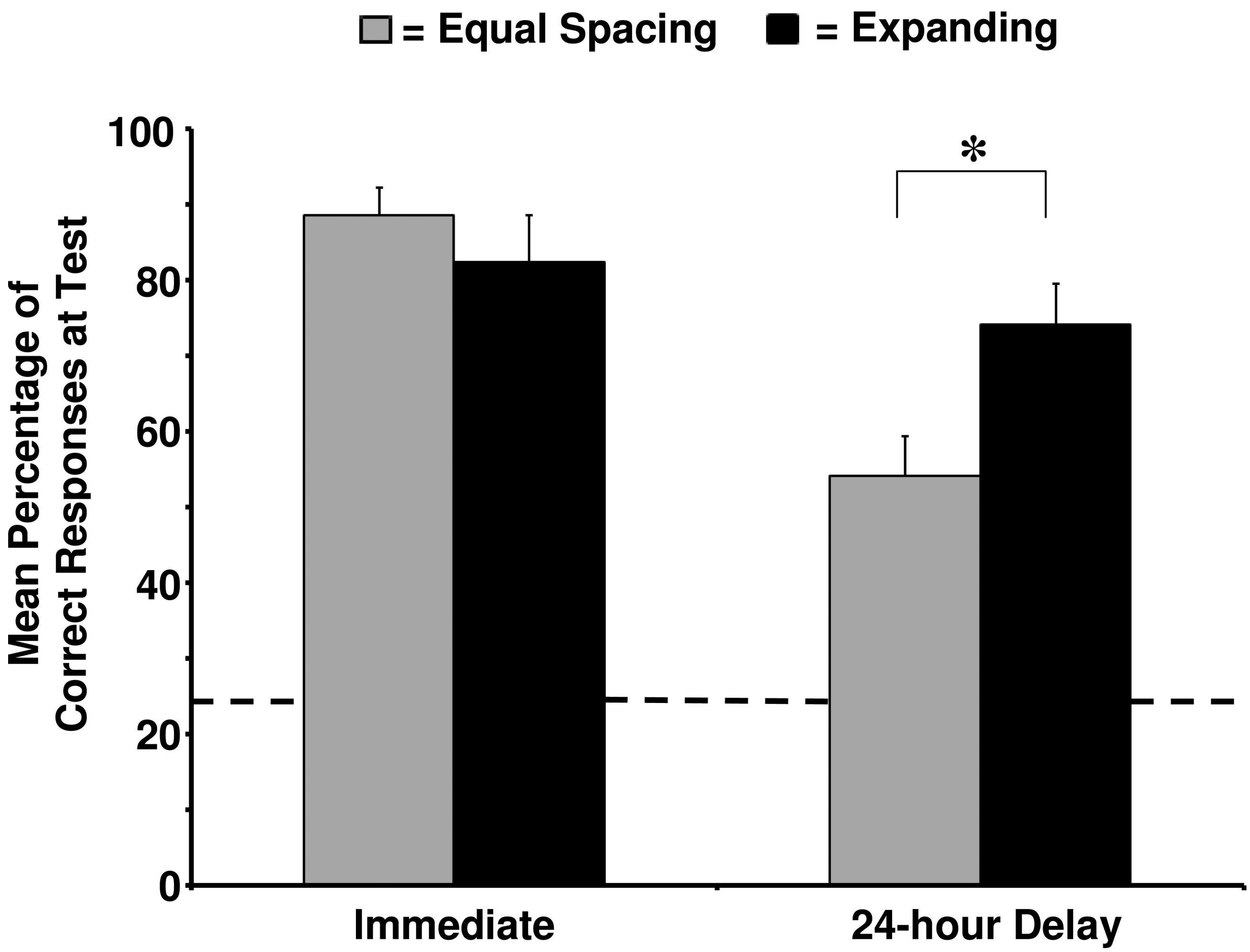

Figure 2.

Mean percentage of correct responses by presentation timing condition (equal spacing or expanding) and testing delay (immediate or 24-hour delay). Error bars represent one standard error. The dashed line represents chance performance; children in all conditions performed significantly above chance performance. A * represents a significant difference, $p < .05$.