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Distributing Learning Over Time: The Spacing Effect in Children's Acquisition and Generalization of Science Concepts

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Abstract

The spacing effect describes the robust finding that long-term learning is promoted when learning events are spaced out in time, rather than presented in immediate succession. Studies of the spacing effect have focused on memory processes rather than for other types of learning, such as the acquisition and generalization of new concepts. In this study, early elementary school children (5–7 year-olds; $N = 36$) were presented with science lessons on one of three schedules: massed, clumped, and spaced. The results revealed that spacing lessons out in time resulted in higher generalization performance for both simple and complex concepts. Spaced learning schedules promote several types of learning, strengthening the implications of the spacing effect for educational practices and curriculum.

Keywords

spacing effect; distributed learning; learning and memory; generalization; cognitive development; educational curriculum and practices

In this study, we examine the spacing effect, a learning phenomenon found across the lifespan, from early infancy to later adulthood. This study was designed to inform our understanding of the spacing effect in two ways. First, we expand upon recent research by examining how spacing learning over time promotes different levels of generalization. Although recent research indicates spacing promotes generalization (e.g., Vlach, Sandhofer, & Kornell, 2008), the question of whether spacing supports varying levels of generalization remains unexamined. Second, this experiment bridges psychological and educational research by using educational materials to investigate the effects of timing on learning. By examining the spacing effect in an educationally relevant task, we expand upon a growing body of research demonstrating the benefits of applying spaced learning to educational practices.

The Spacing Effect

The spacing effect refers to the finding that long-term memory is enhanced when learning events are spaced apart in time, rather than massed in immediate succession (see Ebbinghaus, 1885/1964, for the first study on the spacing effect). The spacing effect is arguably the most replicable and robust finding from experimental psychology. Hundreds of articles, including a number of reviews (e.g., Dempster, 1988) and meta-analyses (e.g., Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006), have found a spacing effect in a wide variety of memory tasks.

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In these studies, memory is typically tested by presenting learners with lists of words on two learning schedules, massed and spaced. Massed learning schedules present participants with learning events in immediate succession (i.e., one right after the other). In contrast, spaced learning schedules distribute learning events across time (i.e., separated by an operationally defined amount of time). After a delay, participants are asked to identify or recall the words that they had been presented earlier. Results of these studies have consistently demonstrated that learners have higher long-term performance on spaced learning schedules than massed learning schedules (e.g., Cepeda et al., 2006).

Interestingly, spacing effects appear to be persistent across timescales and development. Spaced learning schedules have been tested over a matter of seconds (e.g., Russo, Mammarella, & Avons, 2002), days (e.g., Childers & Tomasello, 2002), and years (e.g., Bahrick, Bahrick, Bahrick, & Bahrick, 1993). Moreover, spacing effects appear early in infancy (e.g., Gallucio & Rovee-Collier, 2006), in childhood (e.g., Toppino, 1993), in adulthood (e.g., Glenberg, 1979), and in older adulthood (e.g., Kornell, Castel, Eich, & Bjork, 2010). In fact, several other species also demonstrate spacing effects in learning, including simple organisms such as aplysia, a genus of sea slugs (e.g., Carew, Pinsker, & Kandel, 1972). This body of work has suggested that spaced learning is an index of fundamental principles of memory.

Only within the last few years has research on spaced learning examined generalization—the ability to apply a classification, a concept, or both to a new context. This work suggests that spacing effects may not be limited to memory for specific items, but instead may be a more general learning effect (e.g., Kornell & Bjork, 2008; Vlach et al., 2008). For example, Kornell and Bjork (2008) presented participants with different paintings by relatively obscure artists on either a massed (immediate succession) or spaced schedule (18 seconds between presentations). After a 15s delay, participants were shown unfamiliar paintings by the same artists and asked to generalize an artist's style to the unfamiliar paintings. Participants that were presented with paintings on a spaced schedule were more accurate in generalizing a painter's style than participants on a massed schedule, suggesting that spaced presentations facilitated generalization more so than did massed presentations. In sum, not only do spaced learning schedules promote memory for specific items, but spaced schedules promote generalization to novel information as well.

Do Spaced Learning Schedules Promote Complex Generalization?

The few studies that have investigated spaced learning and generalization have required learners to make simple generalizations. In these studies, participants are required to recognize common perceptual features of learning events, such as the visual characteristics of a painter's style (Kornell & Bjork, 2008) or the common shape of a set of novel objects (Vlach et al., 2008), in order to generalize to novel exemplars. However, the question of whether spacing promotes more complex generalizations, which are based upon more abstract structures than perceptual features, has remained unexamined.

By one account, spaced learning should promote complex generalization. Recent research has proposed that spaced learning promotes generalization by supporting the abstraction of relevant and irrelevant features (Vlach et al., 2008). Spaced learning provides time in between learning presentations for learners to forget irrelevant information. However, relevant features are likely to be present on subsequent learning presentations, reactivated in memory, and thus be forgotten to a lesser degree. Consequently, when the learner is required to make a generalization at a later point in time, the learner will remember relevant features and thus generalize based upon these characteristics. In the case of complex generalization,

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perceptual features are likely to be forgotten, whereas the abstract structure is likely to be remembered to a greater degree.

Alternatively, spaced learning may deter complex generalization. It may be the case that the spacing of learning events across time promotes simple generalizations, but not complex generalizations. In order to abstract a common underlying relational structure, learners may need to compare two learning events close together in time, which has long been suggested by research on comparison and analogy (e.g., Gentner, Loewenstein, & Thompson, 2003). Indeed, for many years memory researchers speculated that spaced learning would deter any form of generalization for this very reason (see Kornell & Bjork, 2008, for a discussion).

Target Domain: Science Concept Learning

We contextualized our investigation of spaced learning and generalization within the domain of science concept learning. Specifically, we examined the effects of spacing in children's acquisition and generalization of food chains. Food chains are the ways in which energy is transferred from one living thing to another within a particular biome.

We chose food chains for two reasons. First, lesson plans for food chains typically emphasize generalization and concept learning. For example, teachers commonly teach food chains in multiple biomes (i.e., swamp, desert, etc) and aim to have children abstract across the biomes to acquire and generalize concepts (e.g., Amaral & Garrison, 2007; Eilam, 2002). Second, food chains afford different levels of generalization. Children must abstract across biomes to form concepts used for both simple and complex generalizations.

An example of a simple generalization from a food chain curriculum is the concept that bigger animals typically eat smaller animals. Children must rely on perceptual features of the animals (i.e., size) in order to form and generalize this concept. An example of a complex generalization is the concept of interdependency. In each biome, there is an underlying structure that characterizes the different relations between living things. These relationships exist because living things are dependent upon each other for food and survival. If something happens to one living creature, it often affects all of the other creatures, because of the interdependent nature of these relationships. These structures are often termed 'food webs' and share commonalities across biomes. We examined both simple and complex generalizations in the current study.

Current Study

The current study investigated the role of the spacing effect in children's simple and complex generalizations about food chains. Children were assigned to one of three learning schedules: massed, clumped, or spaced. In the massed condition, children were given four lessons in immediate succession, on the same day. In the clumped condition, children were given two lessons, in immediate succession, on one day, and two lessons, in immediate succession, on the next day. Children in the spaced condition were given one lesson per day for four consecutive days. Children in all conditions were given a pre-test before the experiment and a post-test one week after the last lesson.

The different learning schedules allowed for a direct examination of the effects of lesson timing on children's simple and complex generalizations of science concepts. In sum, this study expands upon existing psychological research by examining the role of spacing in multiple levels of generalization. Moreover, we contextualize our examination with educationally relevant materials, broadening a growing body of literature demonstrating the implications of spaced learning for educational practices.

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Method

Participants

The participants were 36 early elementary school aged children (M = 6.43 years, range: 5.4 – 7.7 years; 1st and 2nd graders) who were recruited from the university laboratory school. Children were randomly assigned to one of three conditions: 12 children were assigned to the massed condition (M = 6.41 years, 6 girls, 6 boys), 12 children were assigned to the clumped condition (M = 6.48 years, 5 girls, 7 boys), and 12 were assigned to the spaced condition (M = 6.39 years, 6 girls, 6 boys). An additional four children were not included in the final sample because they were absent from school and unable to complete all sessions of the study. Children had not received prior instruction on food chains in school.

Design

Children were randomly assigned to one of three between-subjects conditions: massed, clumped, or spaced. The only difference between these conditions was the timing in which children received four lessons. Children in the massed condition received all four lessons in immediate succession on a Monday. Children in the clumped conditions received two lessons in immediate succession on a Monday and two lessons in immediate succession on the next day, Tuesday, providing a combination of massing and spacing. Children in the spaced conditions received one lesson per day, for four days. Thus, children in the spaced condition had one lesson on a Monday, one lesson on a Tuesday, one lesson on a Wednesday, and one lesson on a Thursday. All lessons and tests occurred at the same time of day. These learning schedules were chosen to parallel actual classroom practices.

Materials and Procedure

The experiment began on a Monday with a pre-test. After the pre-test, children received four lessons, the timing of which was determined according to the condition to which the children were randomly assigned. Finally, children were given a post-test exactly one week after the last lesson. All children received lessons and tests individually.

Pre-test—The pre-test consisted of two types of questions: forced-choice simple generalization questions and forced-choice complex generalization questions. Examples of these questions are presented in Figure 1. The entire pre-test was conducted within the context of one particular biome: either the arctic, desert, grasslands, ocean, or swamp. The biome in which children were pre-tested was randomly assigned. The test was approximately five minutes in length. It is important to note that, because this was a pre-test, children did not receive instruction before taking the test nor did they receive feedback during the test.

In the first half of the pre-test, children were asked four simple generalization questions. These questions tested whether children could apply the rule that bigger animals eat smaller living things. As an example, in the desert biome, children were first shown a card with a picture on it and the experimenter said, “This is a scorpion.” The experimenter then laid out four cards with pictures of other living things in that particular biome (e.g., a fox, lizard, beetle, and cactus). The experimenter asked the children, “Which of these living things does the scorpion eat?” Children then pointed to the answer they thought was correct. This process was then repeated three more times for different living things. The order of the questions was randomly assigned for each child (see Figure 1, for an additional example in the grasslands biome).

In the second half of the pre-test, children were asked four complex generalization questions. The complex generalization questions tested children’s ability to generalize the

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structure of the relationships within biomes to a novel biome. Specifically, children needed to induce the concept of interdependency: a food chain is a dynamic structure in which animals depend on each other for food and survival.

To test this, children were first told a story about an event that happened in the biome. As an example, in the desert biome, children were told that tarantulas moved into the desert and that scorpions really liked eating the tarantulas, in addition to eating beetles. The experimenter then asked four questions about how the food chain would change based upon the scenario. For example, children would be asked, “If there is more for the scorpions to eat, what do you think happens to the number of scorpions in the desert? Does it go up, go down, or stay the same?” The experiment placed three cards on the table, one with an arrow pointing up, one with an arrow pointing down, and one with an equal sign. Children then pointed to the answer they thought was correct. The experimenter proceeded to the next complex generalization question until all questions were complete. The order of the questions was randomly assigned for each child (see Figure 1, for an additional example in the grasslands biome).

Lessons—Children received a total of four lessons. In all conditions, the first lesson immediately followed the pre-test. All lessons were equivalent in length and were brief (~5 minutes long). Each lesson was in the context of a particular biome: either the arctic, desert, grasslands, ocean, or swamp. The biome in which children had been pre-tested was not included in the lessons. For examples of materials and lesson scripts, please contact the first author.

At the beginning of each lesson, the experimenter told children information that applied to all food chains and biomes. Next, the experimenter told children that they were going to talk about the food chain in a particular biome. For that biome, the experimenter introduced five living things, each of which was represented with a toy figurine. The figurines were small, but varied in size relative to the actual size of the creature (i.e., toy figurines for larger animals were bigger than toy figurines for smaller animals). After introducing the living things and what they ate, the experimenter removed the figurine and asked children to recall what the various animals ate.

In the second part of the lesson, children were presented with five tubes, one for each of the animals in the biome. An example set for the grassland biome is depicted in Figure 1. Each tube varied in size relative to the actual size of the creature (i.e., tubes for larger animals were bigger than tubes for smaller animals) and smaller tubes fit inside the larger tubes to demonstrate the interdependence of the animals in that biome. As an example, for the grasslands biome, children were told that a farmer sprayed some poison on the grass. As the experimenter told children this story, the experimenter placed a poison sticker on top of the grass tube. The experimenter would then say, “The cricket comes along and eats the grass. What do you think happens to the cricket?” The experimenter placed the cricket tube on top of the grass tube, so that the grass tube was no longer visible. The experimenter would then lean the tube over and demonstrate that the poison sticker was inside the tube.

Post-test—The post-test was identical to the pre-test. The pre-test and post-tests tested the same biome and children did not receive instruction in this biome during the lessons. For example, for one child, the protocol might have been that the pre-test and post-test were in the desert biome and the lessons were in the grasslands, arctic, swamp, and ocean biomes. All post-tests occurred exactly one week following children’s last lesson.

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Results

In this study, we asked whether lesson timing would affect children's simple and complex generalization of science concepts. We were particularly interested in whether or not spacing would promote children's complex generalizations. In order to determine if lesson timing affected children's learning, we examined children's pre-test scores, post-test scores, and difference scores from pre-test to post-test, which are summarized in Table 1 and Figure 2.

Children's pre-test and post-test scores were calculated using two sub-scores, one for simple generalization questions and one for complex generalization questions. For the simple generalization sub-score, children received one point for each correct response, with a possible total of four points. For the complex generalization sub-score, children received one point for each correct response, with a possible total of four points (see Table 1).

In order to determine whether there were changes in performance from the pre-test to the post-test on the generalization sub-scores, we calculated difference scores. The difference scores were calculated by subtracting the pre-test sub-score from the post-test sub-score. We then conducted two univariate ANOVAs, with difference score as the outcome variable.

For the simple generalization sub-score, results revealed a main effect of lesson timing on the simple generalization difference score, $F(2, 33) = 3.271$, $p = .05$, $\eta_p^2 = .165$. To further examine the differences in performance on simple generalization difference scores, we computed three planned comparisons using t-tests with Bonferroni corrections ($p < .05$). As Figure 2 demonstrates, children's change in performance from the pre-test to the post-test for the spaced condition was significantly higher than for the massed condition, $p = .05$. Children's change in performance from the pre-test to the post-test for the clumped condition was not significantly different from the massed condition, $p > .05$, or the spaced condition, $p > .05$. In sum, children in the spaced condition had a greater increase in performance on the simple generalization task than children in the massed condition.

For the complex generalization sub-score, results revealed a main effect of lesson timing on the complex generalization difference score, $F(2, 33) = 15.097$, $p < .001$, $\eta_p^2 = .478$. To further examine the differences in performance on the complex generalization difference score, we computed three planned comparisons using t-tests with Bonferroni corrections. As Figure 2 demonstrates, children's change in performance from the pre-test to the post-test for the spaced condition was significantly higher than for the clumped condition, $p = .004$, and for the massed condition, $p < .001$. There was no difference in performance between the clumped and massed conditions, $p > .05$. In sum, children in the spaced condition had a greater increase in performance on the complex generalization task than children in the massed and clumped conditions.

Discussion

The results of this study revealed that spacing educational lessons apart in time promoted both simple and complex generalization. Moreover, the results indicated that the benefits of spacing lessons apart in time were present one week after the last lesson. To our knowledge, this is the first study to demonstrate that spaced learning promotes complex generalization. Thus, these results have several implications for theory and research, which are discussed below.

The Spacing Effect in Development and Education

This study contributes to a growing body of literature empirically demonstrating the benefits of spaced learning for educational materials and practices (e.g., Bjork, 1994; Dempster,

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1988; Pashler, Rohrer, Cepeda, & Carpenter, 2007; Rohrer, 2009; Smith & Rothkopf, 1984). One of this study's unique contributions to this literature is the finding that the benefits of spaced learning are not constrained to memory for specific information, such as facts or lists of words. Instead, spaced learning also promotes the acquisition and generalization of educational concepts. This is important because a primary goal of education is to foster the generalization of knowledge outside of the context in which it is learned (e.g., Bransford & Schwartz, 1999).

Moreover, the spacing effect may be one contributing factor to the success of other educational interventions that have demonstrated success in promoting learning and generalization. For example, research on iterative learning in mathematics suggests that alternating repetitions (i.e., interleaved presentations) of procedural and concept lessons facilitates more learning than presenting each lesson type in immediate succession (e.g., Rittle-Johnson & Koedinger, 2008; Rittle-Johnson, Siegler, & Alibali, 2001). One possibility is that iterative learning facilitates more learning in part because iterations space lessons of the same type over time. A non-iterative learning schedule, such as a procedures-first or concepts-first approach, often masses lessons together and may not provide spacing (e.g., Rittle-Johnson & Koedinger, 2008).

Theories of Learning: The Spacing Effect and Generalization

Historically, there have been four classes of theories used to explain spacing effects: 1) deficient processing theories (e.g., Hintzman, 1974), 2) encoding variability theories (e.g., Glenberg, 1979), 3) consolidation theories (e.g., Landauer, 1969), and 4) study phase retrieval theories (e.g., Thios & D'Agostino, 1976). To date, the most parsimonious and predominate collection of theories are study-phase retrieval theories (see Delaney, Verkoeijen, & Spirgel, 2010, for a discussion). However, one limitation of spacing effect theories is that they have primarily been constructed to explain memory processes, not generalization processes.

For example, many deficient processing theories are based on the idea that massed presentations are encoded to a lesser degree than spaced presentations (e.g., Hintzman, 1974). Massed presentations are encoded to a lesser degree because, when presenting the exact same stimulus over and over again, learners habituate to the stimulus. However, in the case of generalization tasks, presentations are likely to be quite variable and, consequently, learners are less likely to habituate to massed presentations. In short, this work demonstrates that spaced learning promotes several levels of generalization, and thus current theories of the spacing effect must be revised in order to account for these findings.

Why do spaced learning schedules promote both simple and complex generalization? This is an open question and definitely an area for future research. One possibility is that spaced learning provides opportunities for forgetting between learning presentations. Relevant features are likely to be present on subsequent learning presentations, reactivated in memory, and thus be forgotten to a lesser degree than irrelevant features. Consequently, when the learner is required to generalize at a later point in time, the learner will remember relevant features and thus generalize based upon these characteristics (Vlach et al., 2008). In the case of complex generalization, perceptual features are likely to be forgotten, whereas the underlying abstract structure is likely to be remembered to a greater degree. Indeed, the most basic mechanisms of memory (i.e., forgetting) may be the same mechanisms that support our most sophisticated forms of learning (i.e., complex generalization).

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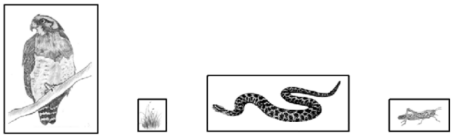
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<table>
<tr><td>Stimuli: Lessons</td><td colspan="2">Tube Set</td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td>Stimuli: Tests</td><td>Simple Generalization</td><td>Complex Generalization</td></tr>
<tr><td></td><td>Question: “What does the rat eat?”

Child Selects:
</td><td>Scenario: “The Grass gets sprayed with a poison that makes animals die when they eat it.”

Question: “What happens to the number of Crickets? Does it go up, down, or stay the same?”

Child Selects:
</td></tr>
</table>

Figure 1.
Examples of stimuli used during lessons and tests. These materials were used for lessons and tests in which the biome was the grasslands. Picture of tubes courtesy of Nature-Watch, www.nature-watch.com.

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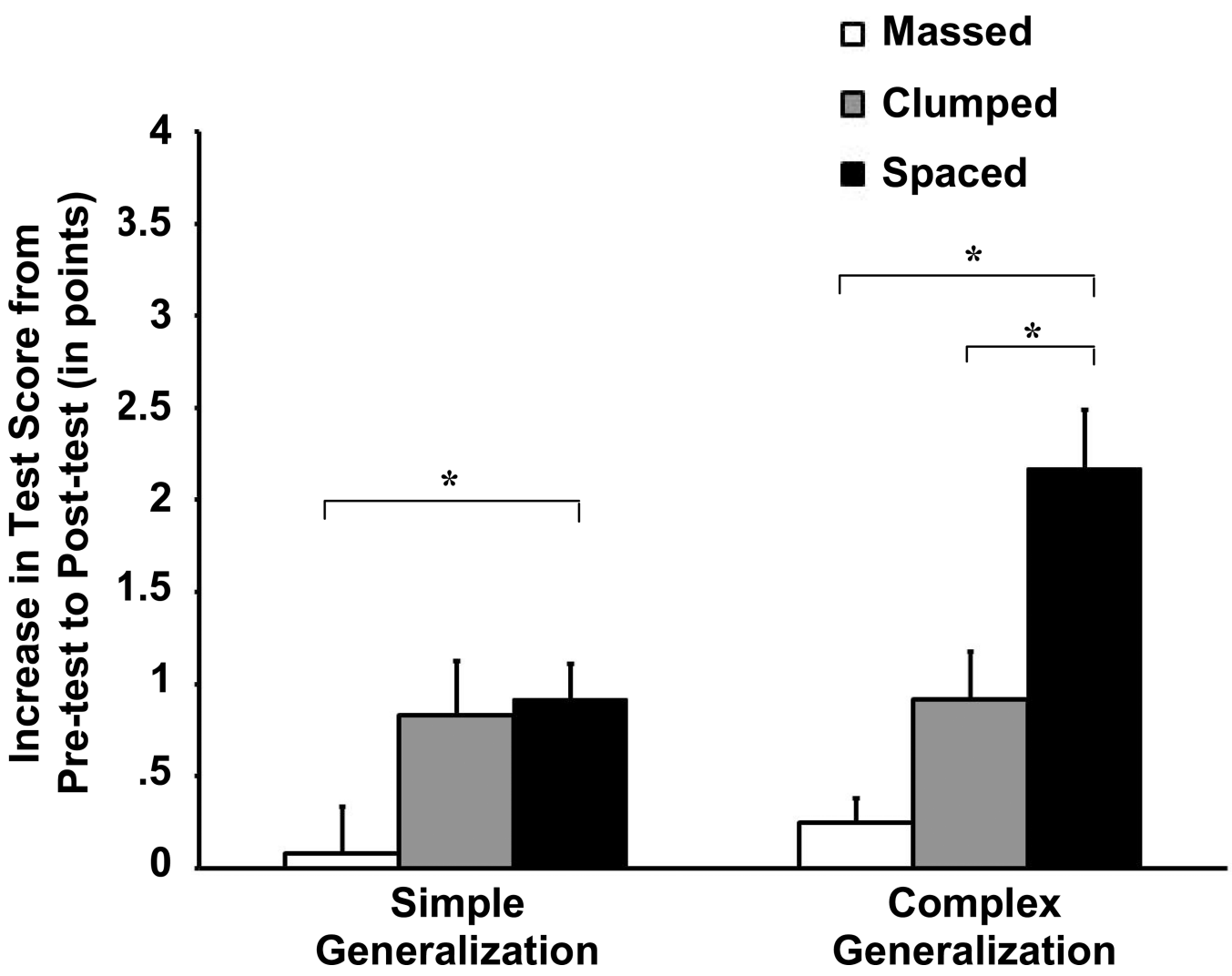


Figure 2.
Increase in the number of points from pre-test to post-test for simple generalization questions and complex generalization questions. Error bars represent one standard error. * = significant at $p < .05$.

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Table 1

Average Pre-test and Post-test Scores by Level of Generalization

	Simple Generalization Score		Complex Generalization Score	
Learning Schedule	**Pre-test** ***M (SD)***	**Post-test** ***M (SD)***	**Pre-test** ***M (SD)***	**Post-test** ***M (SD)***
Massed	2.17 (1.19)	2.25 (.87)	1.50 (1.45)	1.75 (1.55)
Clumped	2.17 (.72)	3.00 (1.04)	1.17 (.94)	2.08 (1.17)
Spaced	2.42 (.52)	3.33 (.65)	.92 (.79)	3.08 (1.00)

Note. Pre-test scores for the massed, clumped, and spaced conditions did not significantly differ from each other, for both simple and complex generalization scores. However, the simple generalization pre-test scores were significantly higher than the complex generalization pre-test scores, $t(35) = 2.870$, $p = .007$.