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The interaction of spaced retrieval practice and element interactivity.

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The Interaction of Spaced Retrieval Practice and Element Interactivity

By

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Lay Summary

Within undergraduate neuroanatomy education, the brain tends to be studied as a collection of individual elements as opposed to functionally interactive networks. At the same time, students will "cram" for an exam as opposed to spacing their studying out over time. Together, these factors lead to quick forgetting of neuroanatomy once an exam is over. This study explores the interaction of spacing out retrieval-based study and learning more complex and interconnected information (called relational information). Retrieval-based study is study which involves remembering information stored in long-term memory (for example, a fill in the blank question). This is in contrast to recognition–based study, which would involve recognizing the information relevant to the question (for example, a multiple-choice question). This study had participants study brain structures over a several week period. We manipulated whether the structures were spaced or crammed retrieval-based study and how low or high relation the information was. We hypothesized that the effectiveness of spaced out retrieval-based study depended on how relational the information was. We found that structures in the highly relational/spaced retrieval condition performed significantly better than highly relational/massed retrieval condition structures. This indicates highly relational information benefits more from spacing than low relational information. Future research should further investigate how relational learning can best be applied in a classroom setting for long-term memory that extends beyond a single semester.

Abstract

Our study investigates the interaction of retrieval practice and element interactivity. Spaced practice is the process of breaking up the retrieval of information into smaller chunks across a longer period of time as opposed to learning everything in one time block. Retrieval practice is the process of testing yourself on previously learned material. Spaced retrieval practice is the merger of these two ideas. This style of learning is well-suited for learning many items that must be retained indefinitely (Lyle et al., 2019). Element interactivity describes the amount of learned items (elements) that are interrelated and must be processed together in working memory to be learned effectively. We utilized a within-subjects crossing of spaced retrieval practice and element interactivity in a psychology course for undergraduate participants. This study focused on memorization of neuroanatomy structures across a semester. Practice consisted of neuroanatomy labs in which structures were reviewed six times total across three labs. After a two-month delay, assessment consisted of a final in which participants attempted to label each structure from the neuroanatomy labs. Results suggested that spaced retrieval practice was more effective with more element interactivity. Given these findings, future research should focus on further clarifying the efficacy of spaced retrieval practice when affected by other common factors in educational settings. This research is vital for further developing a nuanced and effective curriculum at all educational levels.

The interaction of spaced retrieval practice and element interactivity

Introduction

Educators often depend on students remembering the information they learned from semester to semester and academic year to academic year. Whether it's remembering addition and subtraction so students can learn multiplication and division or remembering the structures in a cell so students can learn more complex processes, almost every facet of education depends on student's retaining information well enough that they can continue to build off it for years to come.

In spite of this, educators struggle with getting students to remember long term. Students are not commonly graded for long-term retention. Amongst other things, this causes students to form study habits that are effective for short-term retention but lead to quick forgetting. They also form inaccurate assessments of good learning strategies. Blaisman et al. (2017) asked students to rate the efficacy of various study strategies. Students rated rereading the highest and retrieval practice the lowest. This is the exact opposite of how modern research views these study strategies. This disconnect means students rely on educators to teach more effective study strategies on top of having these study strategies included in the design of their classes (Blaisman et al., 2017).

Surprisingly, however, educators are also often unfamiliar with effective long-term retention strategies. Morehead et al. (2016) found that only 19% of instructors endorsed the idea that retrieval practice was more effective than rereading. This was actually lower than students of which 31% endorsed retrieval practice. While it would be easy to blame educators for this disconnect from research, there are many factors at play causing educators to be unfamiliar with more effective methods (Morehead et al., 2016).

Surma et al. (2018) found that only 6% of sampled university teacher education textbooks referenced both spaced practice and retrieval practice. Furthermore, only 5% of sampled teacher education program materials referenced spaced practice and retrieval practice. These programs and textbooks provided even less implementation information or references to primary research for these topics. It is clear current education systems do not provide teachers with the appropriate tools to learn effective study strategies (Surma et al., 2018).

Spaced Retrieval Practice

Retrieval practice is a longstanding study strategy which has only relatively recently been extensively investigated. Retrieval refers to the process of testing students. While testing typically refers to the large exams given occasionally covering substantial sections of content, in this context testing refers to activities that require students to retrieve something from memory that they have been taught. This testing can include many items like homework questions, flash cards, quizzes, or exams. In general, testing students has proven to be an effective method of learning and has shown to be more effective than studying the information another time. Testing yourself in this directed manner is called retrieval practice (Lyle et al., 2019).

The effect of retrieval increasing retention can be further augmented by the spacing of the retrieval practice, also called distributed practice. Spacing involves a temporal distance between each retrieval of information. For example, practice could occur in two sessions spaced three days apart or six days apart. Practice that is less spaced out is called massed practice. Previous research suggests increased spacing improves the retention of information. Research by Hopkins et al. (2016) found that increased spacing helped students retain precalculus knowledge not only during the duration of the course, but also during follow-up examination in the next semester.

This style of breaking up and spacing out retrieval practice is called spaced retrieval practice (Hopkins et al., 2016).

Element Interactivity

Educators don't typically exclusively focus on rote memorization. van Gog & Sweller describe how a lot of tasks in education involve performing complex and meaningful learning. These tasks involve complex information that is often all logically related and needs to be understood both for its parts and as a whole. Element interactivity is the number of elements that are interrelated and must be processed together in working memory, a cognitive system that can temporarily hold multiple information pieces and manipulate them. Element interactivity also considers the amount of knowledge students have prior to learning the material. For example, students who have already memorized the names of all the structures in the brain would not have to actively learn those names when learning the structure and location of those structures. This means that having previous knowledge about the topic lowers element interactivity as it leaves less elements that need to be learned together to learn effectively. (van Gog & Sweller, 2015).

Present Study

This study explored the impact that element interactivity has on spaced retrieval practice. This study pre-familiarized participants with the experimental material by showing all the brain structures and their associated label. This was to ensure that prior knowledge was relatively equal and minimized the effect prior knowledge differences had on the results of our study (as having lower familiarity would increase element interactivity) (van Gog & Sweller, 2015). This study trained participants on brain structures during an introductory neuroscience course. Participants were taught all structures, but the condition of the structure changed across participants. After training, participants learned some brain structures during massed retrieval sessions either one or seven weeks later and some brain structures over three sessions starting one week later then every two weeks.

Some of their retrieval practice provided only the label of the structure after answering (low element interactivity) while some of their retrieval practice provided several extra elements upon answering: a functional description of the neuroanatomy structure, the brain system the structure belonged to, and the rest of the structures belonging to that brain system were tested along with it (high element interactivity).

We hypothesized that the efficacy of spaced retrieval practice is dependent on element interactivity. Previous research has indicated concern about the efficacy of retrieval practice, especially when the material has high element interactivity. However, this research did not explore spaced retrieval practice. If prior research about retrieval practice holds true for spaced retrieval practice, participants are expected to perform worse on high element interactivity content (van Gog & Sweller, 2015).

Methods

Subjects

Subjects were undergraduate participants enrolled in a psychology course titled *Brain and Behavior* in Spring 2021 at University of Louisville. Initial enrollment was 121 but only 84 participants were included in the analyses as some participants did not successfully complete all the required tasks and some participants did not complete the course. Participants were not compensated. Instead, participants were required to participate in three neuroanatomy labs and a neuroanatomy lab final for a participation grade. They were also required to complete a portion of the final exam which covered material from the neuroanatomy labs and was graded for accuracy (see Appendix C for further grading details).

Course Format and Materials

A neuroanatomy study session, three neuroanatomy labs, and the neuroanatomy lab final were hosted in the application “Show Me the Brain!” abbreviated “SMtB.” SMtB is an application that has an interactive 3D model of the brain. Participants were presented brain structures and asked to provide the structure name from a list of 60 potential structures (see Figure 1). SMtB labs were virtually hosted through Microsoft Azure[1], an online cloud computing service. A neuroanatomy final used pictures and information from SMtB, but was hosted in Blackboard[2], an online course delivery system. This final provided the highlighted brain structure and asked participants to provide the label. The functional information final was hosted in TopHat[3], an active learning platform capable of hosting real-time testing. This portion also used pictures and information from SMtB and provided the highlighted brain structure, but instead asked participants to select the correct functional description from four potential functional descriptions.

The neuroanatomy practice session occurred one week before the start of the neuroanatomy labs. Participants were sequentially presented with 60 brain structures displayed on a 3D model of the brain along with their respective labels. Participants were to select the correct label for the structure from a list of all 60 structures. Participants were given twelve hours to complete this practice session and were not limited in the amount of time they could spend on each question.

The three neuroanatomy labs occurred throughout the semester. Participants were not informed about the spaced retrieval practice or element interactivity manipulations. Participants could opt out of including their scores as part of the dataset. No participant opted out.

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[1] Further information can be found at “https://azure.microsoft.com/en-us/”
[2] Further information can be found at “https://blackboard.com”
[3] Further information can be found at “https://tophat.com”

The amount of spacing and element interactivity was only manipulated during the three labs. The labs were hosted throughout the semester approximately once every two weeks. Each lab was available during a twelve hour window. Participants were not limited in the amount of time they could spend on each question. All questions required participants to observe a highlighted structure on a 3D model of a brain and identify the structure from a list of 60 potential structures.

Participants studied 60 brain structures as part of the course. 26 of the brain structures studied were included in the analyses. We created eight versions of each lab and rotated each structure across groups through all four conditions (see Table 1 for condition breakdown). The class was split into eight groups of roughly equal size (range of group size by end of course = 8-13) and each group received a different version of the lab. Each of the three consisted of l0 sections. Each section reviewed all structures of a particular condition which would necessitate twelve trials. Each trial reviewed one brain structure according to the condition of the section. Each condition contained 4-8 target structures depending on the condition and group[4]. Each structure appeared no more than once in each section. Across all three labs, each structure was shown six times.

A 60 question neuroanatomy lab final occurred two months after the third lab which was the day before the final exam. It covered all included structures as well as discluded structures. Each structure had one question associated with it. The questions were presented in the same way as they were presented in the labs.

A 60 question functional information final covered all included structures as well as discluded structures. Each structure had one question associated with it. The questions asked

[4] This discrepancy was due to an implementation error. In order to account for improper stimuli exposure, some structures were removed.

about the structure's associated function. The questions were four option multiple choice and used pictures from SMtB. This functional information final was a secondary measure as a manipulation check.

Design

In the element interactivity condition, there was a label condition and a function condition. In the label condition, upon answering the question, a label for the correct structure was shown with no additional information provided (see the top two pictures of Figure 1). Structures within label conditions were composed of two intermixed brain systems. For example, for one group, their label condition was an intermixing of the auditory and limbic system brain structures. The spaced label condition would receive half of these intermixed structures while the massed label condition received the other half.

The function condition utilized three different manipulations to increase the interrelated complexity of the content. First, structures had a functional description shown upon answering (along with the label). Second, all structures shared functional similarity and/or were part of the same brain system. Third, structures belonging to the same brain system were shown successively (see the bottom two pictures of Figure 1).

Four different brain systems were used: visual system, auditory and linguistic system, motor system, and limbic and paralimbic system. As an example of a structure's functional information, the visual system included the inferior occipital gyrus with the functional information: "Part of the ventral visual stream which processes information about object shape" (see Appendix A). Retrieval practice for a particular structure either occurred six times in one lab (massed condition) or twice per lab for all three labs (spaced condition).

Participants were randomly broken up into eight groups. The condition assignment changed in two ways across each group. First, the contents of each condition changed between groups. For example, for some groups, the visual system was in the spaced function condition. For other groups, the visual system was intermixed with another brain system and divided between the massed label and spaced label conditions. Second, the placement of conditions changed between groups. For half of the groups, the first lab contained the massed label condition. For the other half, the third lab contained the massed label condition. The miscellaneous structures were always shown during the second lab (see Table 2 and/or Appendix B for further detail).

Results

Stimuli creation, data aggregation, data cleaning, data formatting, data analysis, and data visualization was all handled with MATLAB (see Appendix C and D for further details and the scripts we developed for this experiment). Degrees of freedom (n-1) was 83 for all of our analyses. P-values less than or equal to an alpha of 0.05 were considered significant. T-scores (ex: $t(83) = ##$) show how many standard deviations a mean of the alternative hypothesis is from the mean of the null hypothesis. F-scores (ex: $F(83) = ##$) is a ratio of the variance between conditions and the variance within conditions.

Lab Performance

We calculated each participant's mean score per section. We then averaged across sections calculating the mean score per condition. All conditions showed significant improvement between the first trial and the sixth trial of training, t-scores for function spaced $t(83) = 11$, function massed $t(83) = 10$, label spaced $t(83) = 18$, label massed $t(83) = 8.6$, all $p < 0.001$ (see Figure 2).

Final Performance

Mean condition scores were put in a 2 (spacing of retrieval practice: spaced or massed) x 2 (element interactivity: label or function) within-subjects ANOVA. The spaced versus massed main effect was significant, f-score $F(1,83) = 8.1$, $p < 0.01$. There was also a marginally significant interaction between spacing of practice and element interactivity, f-score $F(1,83) = 3.8$ $p = 0.056$. Performance on spaced questions was significantly better than massed questions in the functional condition, t-score $t(83) = 3.4$, $p < 0.01$, while the label condition was nonsignificant, t-score $t(83) = 0.87$, $p > 0.3$ (see Figure 3).

Top Hat Performance

The spaced versus massed main effect was nonsignificant, f-score $F(1,83) = 0.012$, $p > 0.9$. The interaction was also nonsignificant, f-score $F(1,83) = 0.31$, $p > 0.5$. Participants did not perform significantly better on spaced or massed questions in both the function and label conditions, function t-score $t(83) = 0.44$, $p > 0.6$, label t-score $t(83) = 0.38$, $p > 0.7$ (see Figure 4).

Discussion

The purpose of this research was to gain better insight into how introducing element interactivity impacts learning neuroanatomy in an educational setting. The design of the function versus label condition was not able to fully control for encoding effects. The function condition introduced a sentence of extra information along with each structure label (see Appendix A for included functional information). However, the label condition did not have any control for this extra information as it only provided the label. While intentional as such extraneous information would be difficult to seamlessly include in an educational setting, this means that the difference between function and label conditions could be attributed to an encoding effect as opposed to the difference between conditions. As such, the difference between spaced label condition versus the spaced function condition and the massed label condition versus the massed function condition was not analyzed.

We found that for the high element interactivity condition (the function condition), massed practice had significantly worse retention than spaced practice. This supported that extra element interactivity was detrimental during massed learning, but had no significant impact on spaced learning. This tempers previous research which has found that for high complexity content, retrieval practice effectiveness is diminished or even the same as restudying. It is possible that while massed retrieval practice is worse for more complex material, spaced retrieval practice is better for more complex material. The lower element interactivity condition (label condition) found no significant difference between massed practice and spaced practice. This indicates that for lower complexity learning, the spacing of retrieval practice does not play as significant of a role (van Gog & Sweller, 2015).

Functional Information Manipulation Check

The testing of retention of functional information did not have significant differences between all conditions. This testing was intended to see if participants learned the functional information even without pressure to do so. All conditions showed that they learned the functional information well above chance (25%). However, participants showed no significant difference in learning across conditions which suggested three different possibilities. First, the participants treated the information as extraneous information and did not bother to effectively engage with it. Second, the participants read the functional information, but forgot about it. Third, the participants did not appropriately connect the functional information with its associated structure.

Future Studies

While this experiment explored the interaction of spaced retrieval practice and element interactivity, there are still many parts of this interaction that could be explored. This experiment focused on a relatively small change in element complexity. This level of element interactivity is highly relevant to most of what is learned during education as most curriculums do not involve a lot of element interactivity. However, it is not uncommon for a topic to become significantly more complex than what is explored here. Future experimentation could explore several levels of element interactivity and identify how this interaction impacts especially complex content.

Future studies could also expand on this research by having participants retrieve the functional information and/or the brain system along with the functional information during retrieval practice. This would help monitor whether or not the participants are fully engaging with the material and would explore a dimension this study does not: the impact of changing the difficulty of retrieval practice.

Conclusion

Our research explored the interaction of element interactivity and spaced retrieval practice in an educational setting. We hypothesized that there would be an interaction between spaced-retrieval practice and element interactivity. Results indicated that spaced retrieval practice was more effective for high element interactivity content. However, there was no significant difference between spaced and massed retrieval practice for low element interactivity content. This lower complexity content could possibly start to see a significant difference were there to be a more significant gap between training and testing. Future research aimed at exploring this interaction will help elucidate how these two ideas interact in both a laboratory and educational setting.

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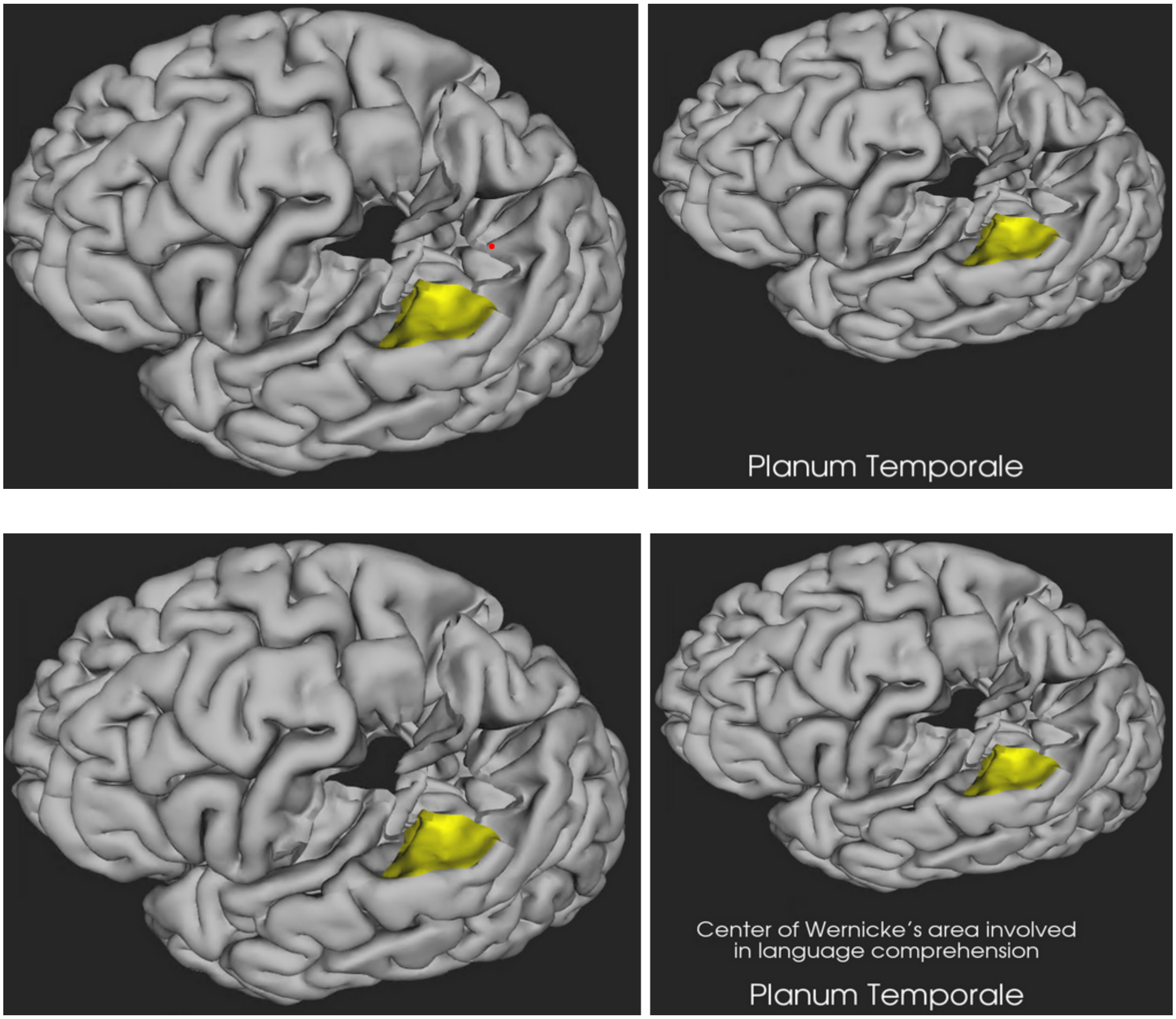

Figure 1

Picture of label condition structure before answering (top left) and after answering (top right), and picture of function condition structure before answering (bottom left) and after answering (bottom right)

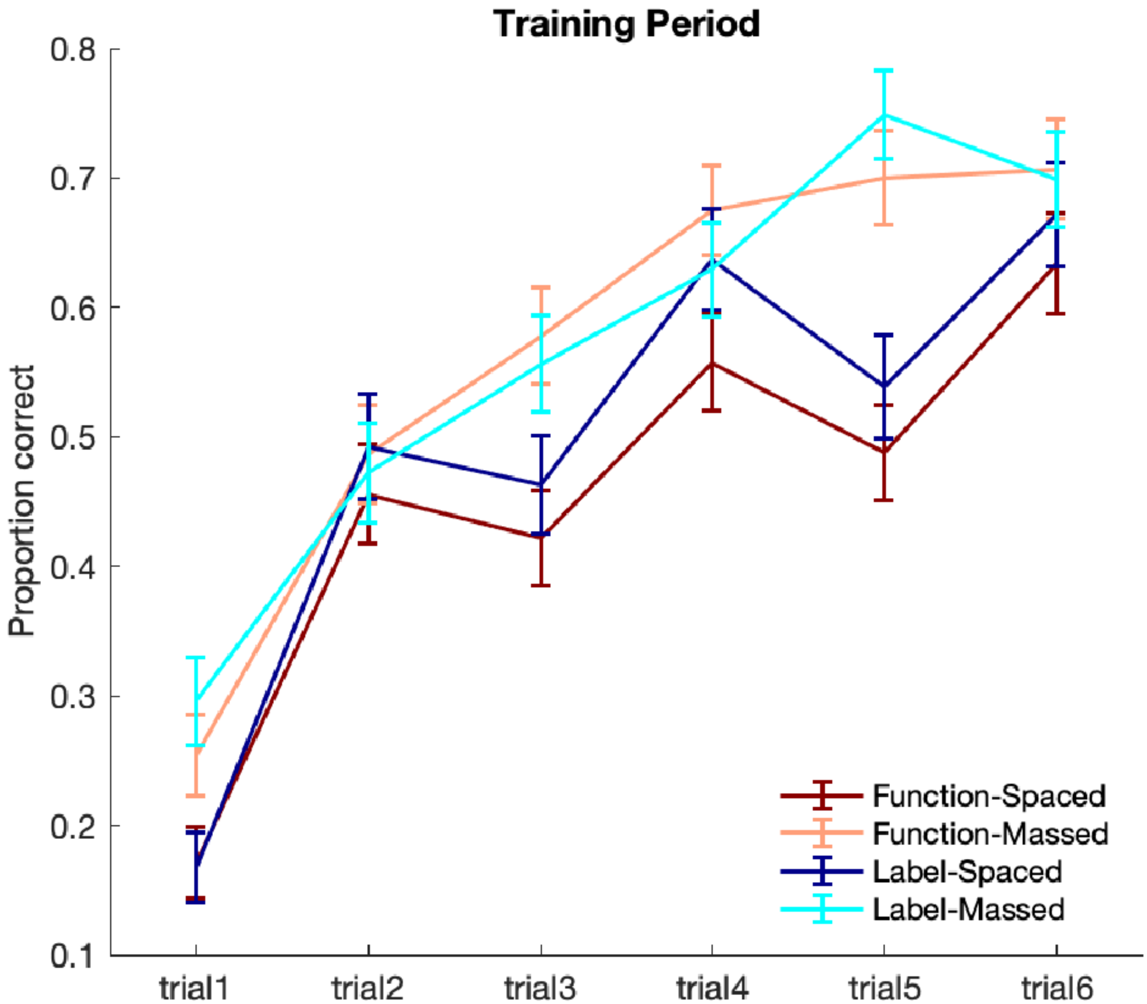

Figure 2

Lab performance across conditions. Figure shows the performance on first through sixth trial. Participants were given a brain structure highlighted on an interactive 3D model of a brain and asked to provide the label. Improvement from trial 1 to trial 6 was significant across all conditions, $p < 0.0001$.

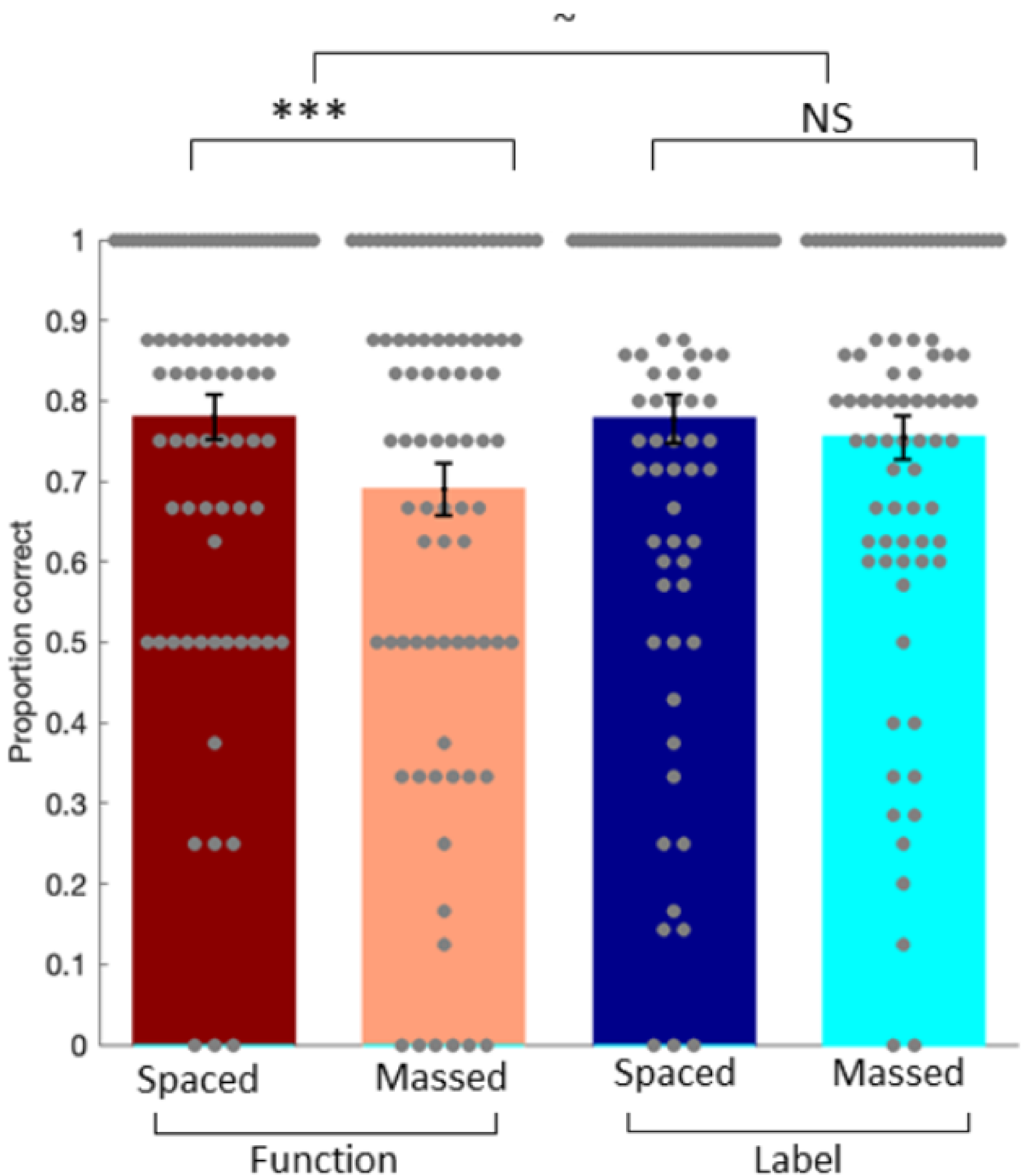

Figure 3

Neuroanatomy final performance by condition. The questions highlighted the structure on a 3D model of the brain in Show Me the Brain and asked for the label from a list of 60 potential structures. The main effect condition was p < 0.01. The Interaction was p = 0.056. Error bars *depict the standard of the mean. Legend: NS = nonsig nificant, ~ = marginally significant, *** = significant.*

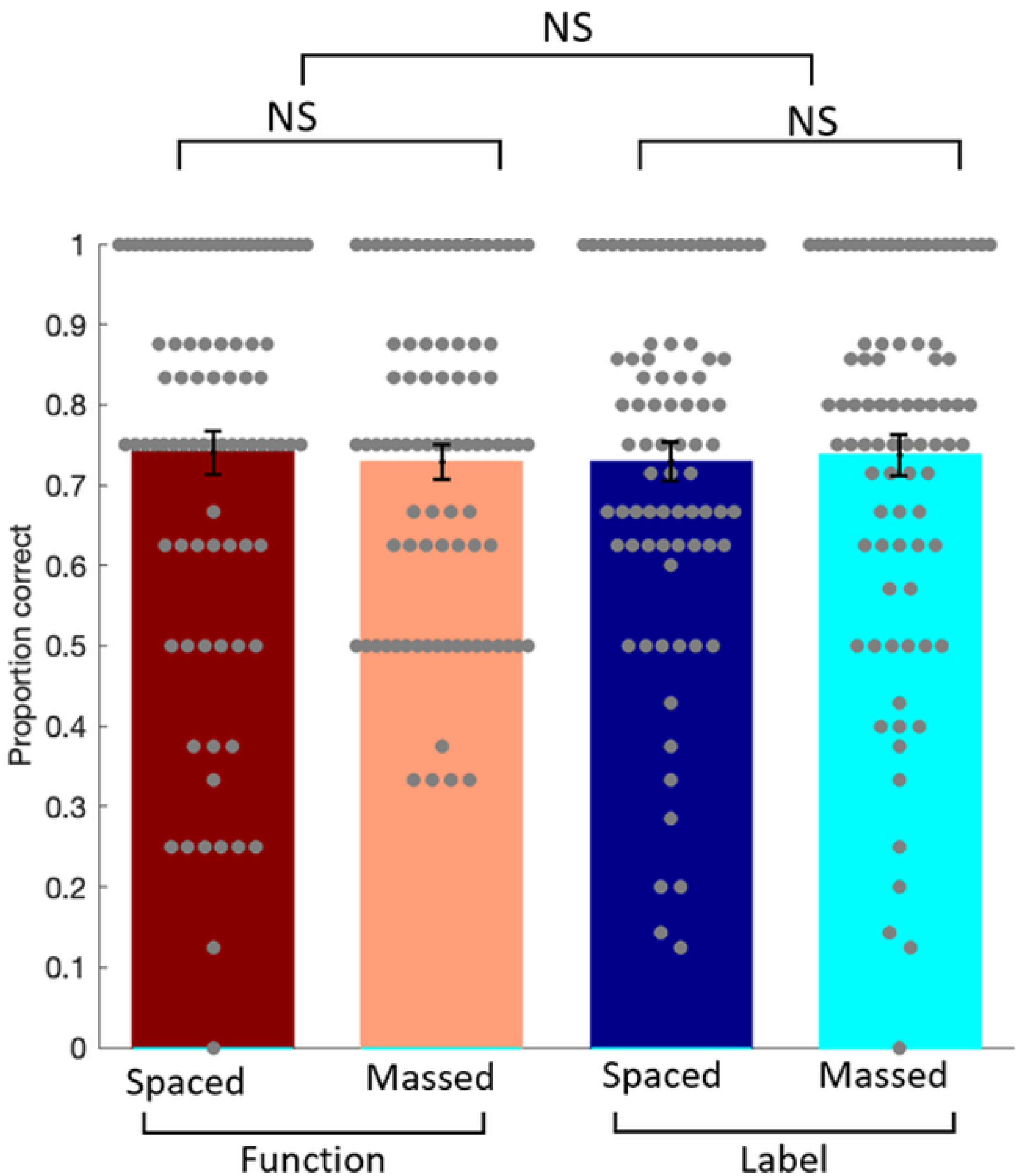

Figure 4

*Final exam functional information questions performance by condition. The questions provided an image of a 3D image of a brain with the structure highlighted. The question then provided four potential functional information answers (see Appendix A). The main effect, conditions, and interaction were nonsignificant, all p > 0.5. Legend: NS = nonsignificant, ~ = marginally significant, *** = significant.*

	Label (label only, no schema)	**Function (label+function, schema)**
Massed Practice	"Label/Massed" 12 structures 6 sections in 1 of the 3 labs	"Function/Massed" 12 structures 6 sections in 1 of the 3 labs
Spaced Practice	"Label/Spaced" 12 structures 2 section in each of the 3 labs	"Function/Spaced" 12 structures 2 section in each of the 3 labs

Table 1

Condition breakdown

# of structures	Lab 1		Lab 2		Lab 3
24	Spaced Label Mixed System	24	Spaced Label Mixed System	24	Spaced Label Mixed System
24	Spaced Function System	24	Spaced Function System	24	Spaced Function System
72	Massed Label Mixed System or Massed Function System	72	Miscellaneous Structures	72	Massed Function System or Massed Label Mixed System*

Table 2

Lab structure breakdown by condition

Note: for a version of this broken down by group, see Appendix B.

*Whichever condition was not used in Lab 1.