Proceedings of the International Conference on Global Politics and Socio-Humanities
DOI: 10.54254/2753-7048/46/20230625

The Role of Memory Enhancing Techniques in Learning

--Examining the Effects of Item-level Brain Training Techniques on Learning

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Abstract: Brain training techniques are commonly used to enhance an individual's learning and memory, especially in classroom teaching and self-directed learning contexts. Among a range of techniques, the item-level methods that focus on boosting memory for a specific item are the most well-known and widely applied ones. In this work, the mechanisms underlying two item-level brain training techniques, spaced repetition and retrieval practice, are investigated. Studies have proved that learners who are trained according to a spaced repetition schedule are prone to show better acquisition of language and science concepts compared to those who learn under mass conditions. Yet, the method currently relies on somehow primitive algorithms. Therefore, the optimal time interval for the second exposure to a learnt content could vary primarily among individuals. Reviewing pieces of information through retrieval practice, based on the testing effect, also leads to better performance in final assessments in most cases. Frequent testing with relatively few questions each time seems to produce the best results. However, most of the research on these two techniques up to now is in semantic learning scenarios such as language acquisition, so the evidence for determining the effectiveness of either method on other types of learning is somehow few.

Keywords: memory consolidation, brain training, spaced repetition, retrieval practice

1. Introduction

Generally, brain training refers to activities that are believed to help with improving cognitive functions, which people purposely do. Due to their non-invasive nature, brain training techniques has been the most widely utilized approach to aid learning and memory consolidation in non-clinical scenarios. For instance, students are often encouraged to use these techniques to help to consolidate their memory of knowledge and skills, which they will be assessed on, in order to achieve high scores in upcoming exams.

As proposed by Ullman and Lovelett, ways to enhance memory consolidation could be divided into two types: learner-level techniques, which are approaches to improve the learner's overall memorizing ability and item-level techniques that only boost the learner's memory of a particular skill or knowledge [1]. The aim of the paper is to give a brief introduction of some of the item-level techniques and determine whether they are fact or fiction with respect to data from others' research up to the present.

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2. Mechanism of Memory Formation and Consolidation

The formation of memory can be divided into three stages: encoding, consolidation, and retrieval. To begin with, encoding is the stage of initial learning, during which sensory information is integrated into a form that can be stored as memory. This integration process relies heavily on the thalamus, where almost all types of sensory inputs pass through.

After that, memories that are significant in some aspects are consolidated. Consolidation is the selective process in which some of short-term memories are transferred into long-term memories. The consolidation process happens mainly in the hippocampus and neocortex when repeated stimuli cause changes in membrane potential and thus trigger a molecular cascade that results in increased strength of synapses. To be more specific, when the axons of neuron A contribute to repeated and sustained excitation of neuron B, A's efficiency as a cell that excites B will increase [2]. "synaptic plasticity" is the term to describe such capability of alterations in synaptic strength which functions as the foundation of long-term memories.

Since the capacity of memory is biologically limited, the memory system has developed adaptive features to get rid of monotone stimuli and to prioritize significant, goal-relevant information. According to Cowan, a number of criteria of goal relevance have been identified, including the association of the stimulus with reward or punishment, as well as the intensity of the stimulus. Memories of stimuli that are dull or are not related to an outcome are probably less likely to be consolidated [3]. In other words, a piece of information related to an emotionally stimulating factor would possibly be recognized as an important one and is, therefore, more likely to be consolidated.

Eventually, retrieval is the action of remembering and replaying stored information. Its interaction with other cognitive processes can also hint on the enhancement and modification of memories [4]. The method of retrieval practice, which will be discussed later in this paper, is based on this property of memory.

3. Spaced Repetition: Effects of Time on Memory

In most cases, the repeated presence of a stimulus is crucial for memory consolidation, and the time interval between exposures to the stimulus also plays a substantial role. Studies of the link between forgetting and time began with Ebbinghaus's study of the "Forgetting Curve" model in 1885, which has been replicated and interpreted by many other researchers [5]. In a book he published in the same year, Ebbinghaus brought forward the idea that retention and forgetting are both functions of time. With this relationship in mind, psychologists and educationalists have extensively examined the spacing effect in learning, and the spaced repetition technique is developed as an attempt to utilize this effect.

Spaced repetition is a brain training technique using a special review schedule based on a spaced repetition algorithm [6]. In spaced repetition training schemes, the time between each two review sessions is deliberately controlled in order to maximize the time span of retention, and this has been proved to be useful in many learning scenarios [1,7,8].

There is a variety of theories about the spacing effect that can possibly explain the enhancement in learning and memory. Foremost, the theory of "encoding variability" proposes that variation of context over time leads to a more diverse representation of the content that a person learns. People usually memorize environmental cues when they are learning and would thus associate some aspects of the context with the content to be learnt [1]. This widens the range of "familiar context," in which learners yield better results when tested. Moreover, spaced repetition could make learning less stressful or demanding, as it does not require long focusing time in comparison to massed study. In addition, being reminded of content after a relatively large time lapse causes people to expect that the

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content will be needed in a more distant future, and this might also be a reason for extending the time of retention.

The effectiveness of spaced repetition has been supported by studies in different contexts. Language learning is one of the examples: in the vocabulary learning experiment designed by Kornel, 90% of the participants learned more GRE-type vocabulary in spaced repetition training than in massed conditions, which is dramatically higher than the percentage of participants that exhibited a reversed pattern (6%) [7]. Vlach and Sandhofer's research on Children's acquisition of science concepts also revealed notable progress in both simple and complex generalization of content [9]. In most of the experiments, the number of words that are correctly recalled in a final test is recorded as the representation for the effectiveness of learning since successfully retrieved items must have properly undergone all three steps of memory properly.

However, the method of designing spaced repetition schedules is currently coarse, and the algorithms behind it are, according to Tabibian, somehow primitive heuristics based on parameters that are assigned values [6]. The "optimal" time interval could vary largely among individuals due to differences in their ability of consolidate and retrieve.

4. Retrieval Practice: Effects of Tests on Memory

In 1969, Allen G. reported that taking part in a test after learning can make an individual five times as efficient as when they simply learn the same content five times [10]. In terms of learning, testing is much more than a tool to quantify progress that has been made. Instead, testing also plays the role of a memory-enhancing approach, and the "testing effect" is the name of such direct benefits [11]. Since the last century, the testing effect has been extensively studied and widely applied.

Retrieval practice is a brain training technique that uses tests to enhance memory consolidation. A typical process of retrieval practice experiment involves three stages: first, a study phase in which the contents are initially learned, then a preexposure phase for about 50% of the items to undergo retrieval tests, and finally, a test phase in which all items are assessed [12].

A few theories are believed to account for the testing effect. Bjork's framework for "desirable difficulties" supports the idea that difficulties in tests can be desirable as they trigger encoding and retrieval processes, provided that the candidate has a certain level of background knowledge [13]. The elaborative retrieval hypothesis is also a widely accepted explanation: Tests could induce activation of elaborative memory associated with the target content. Thus, when a related cue is present and activates the memory of the corresponding piece of information, the likelihood of successful retrieval of the target information could be boosted [14].

Biological evidence which could presumably prove the effectiveness of retrieval practice has been noticed. Increased activity in the posterior hippocampus has been detected after retrieval practice, and this increase in brain activity appears to be a linear function of the number of successful retrievals [15]. Up to now, experiments that compare results of learning with and without spaced repetition training have also revealed that trained individuals are prone to perform better in memory tasks (e.g., recall more idea units [16]) than those who did not undergo training [16, 17].

Nevertheless, this method shares a similar drawback with spaced repetition: The optimal level of difficulty for enhancing memory consolidation depends heavily on an individual's initial learning [18]. As a result, it is often hard to determine. Also, as some researchers pointed out, sometimes a decrease in the utility of training as the number of tests increases is found in learners. Moreover, even though "learning from mistakes" could result in improved memory consolidation, there is another problem that is often overlooked: students who make mistakes in initial tests are more likely to express lower confidence in the final test [1].

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5. Practical Applications of Brain Training Projects

Brain training techniques are now commonly used by students, educators and lifelong learners. Its future prospect is promising with respect to its convenience and non-invasive characteristics, and it actually exists in many forms in daily life scenarios, sometimes without even being noticed.

Apparently, quizzes and exams, which existed long before any study of retrieval practice, have exploited the testing effect to some extent, yet making any further improvement by integrating algorithms into academic tests would require a lot of effort. More scientific and well-organized usage of either retrieval practice or spaced repetition (e.g.: setting up a specific schedule based on spaced repetition algorithms) in class is hardly possible since the learning ability of individuals varies largely, and, what makes the situation worse, the attention each student pays to classes is also a factor that is unlikely to be controlled.

In spite of these restrictions on level of preciseness, a change in number of tests and questions on a given item may still help to optimize students' capability of memory consolidation and retrieval. Bangert-Drowns research shows that students' grades improved more significantly (0.57 standard deviation) after taking a large number of tests with fewer questions, compared to those who took a small number of tests that included too many questions [17]. Despite the short-term positive impacts on classroom performance, frequent tests could be misleading in the long run. It is often the case that when teachers overemphasize tests and quizzes, students tend to focus only on cramming to get high scores but not on learning. Therefore, it is important to balance between tests and routine teaching.

Online platforms for memory training are also emerging as the study of memory-enhancing techniques proceeds, and they are becoming increasingly popular among lifelong learners. In attempting to attract users, many memory training websites and applications like Art of Memory, Lumosity, and Very well Mind incorporate scientific training methods with games.

A few of these platforms were supported by data and statistics, although most of them are still ambiguous. For instance, experiments showed that in a 10-week randomized study that involved 4715 participants, learners in the experiment group who used Lumosity generally appeared to have further improved memory and other cognitive functions than those in the control group [19], yet no more convincing data (e.g., the difference in memory retrieval efficiency in terms of standard deviations) or experimental methods (e.g., how scientists designed the test to measure improvements in cognitive skills) can be found on the homepage, making their advertisement less compelling. Besides, a lot of the so-called brain training projects do not provide users with quantified scientific evidence at all, and nor do these projects explain any recognized mechanism underlying the games. Regarding this vagueness, it is necessary for individual learners to be critical and doubtful when choosing an application or website to assist them.

6. Conclusion

Up to now, the two brain training techniques, retrieval practice and spaced repetition have both been verified to enhance memory skills by experiments. Generally, their positive effects on memory are on the "item level", which means that they could only improve a learner's memory for a specific item but not the overall cognitive function of an individual. It is believed that the consolidation process and the retrieval process are specifically reinforced, and most of these inferences are derived from the fact that time span of retention is prolonged after training sessions, and more contents are successfully recalled in a final test. Relevant studies often use tests that involve recalling or associating items as criteria of memory enhancement, which are measurable and relatively easy to quantify, yet in these tests. It could be hard to distinguish among the effects on memory encoding, consolidation, and retrieval separately.

Research has provided insight into the application of retrieval practice and spaced repetition to education as well as self-directed learning. Still, most of the research in these fields is about the acquisition of a first language or second language, bringing about the suspicion that memory-enhancing techniques only work steadily for a narrow range of semantic learning and associative learning. Educational services and life-long learners are currently in need of further investigations into the effects of brain training techniques on other types of memory and learning, such as episodic memory and motor skills.

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