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Review article

The effect of distributed practice: Neuroscience, cognition, and education

Emilie Gerbier [a,*], Thomas C. Toppino [b,1]

[a] *Laboratoire d'Etudes des Mécanismes Cognitifs – EA 3082, Université de Lyon , Université Lumière Lyon 2, 5 Avenue Pierre Mendès France, 69500 Bron, France*
[b] *Villanova University, 800 Lancaster Avenue, Villanova, PA 19087, USA*

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ABSTRACT

Education ideally should induce learning that lasts for years and more. A wealth of research indicates that, to achieve long-lasting retention, information must be practiced and/or tested repeatedly, with repeated practice well distributed over time. In this paper we discuss the behavioral, neuroimaging and neurophysiological findings related to the effect of distributed practice and testing as well as the resulting theoretical accounts. Distributed practice and testing appear to be powerful learning tools. We consider implications of these learning principles for educational practice.

Contents

1. Introduction

Say you need to learn a lesson about the French Revolution for your history class and you only have a limited time to prepare for an exam that will take place in one week. What is the best strategy for scheduling your study sessions during the next seven days? Should you wait until the day before the exam to study? Should

* Corresponding author. Tel.: +334 76 82 71 45.
E-mail addresses: emilie.gerbier@univ-lyon2.fr (E. Gerbier), thomas.toppino@villanova.edu (T.C. Toppino).
[1] Tel.: +1 610 519 4722.

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you start today and study a different part of your lesson each day? Or, should you organize your studying so that every part of the lesson is studied and reviewed in two or three sessions, separated by one to several days?

Obviously, one way to boost learning and memory is to increase the number of study opportunities with to-be-learned materials. Unfortunately, learning time is necessarily limited because of the enormous amount of information to be acquired by students in the different disciplines, both in and outside school. In addition, we generally want knowledge to be as durable as possible. In this article, we will discuss how to arrange study time efficiently by scheduling study sessions in a way that maximizes learning and memory. As we will develop it further in this article, it is most beneficial to engage in "distributed practice." That is, it is best to study something by scheduling relatively short study sessions that can be repeated after an appropriate period of time rather than by devoting the same total amount of time to a single study session or to a number of repeated study sessions that occur in immediate succession. The distribution of practice is under-used in real life settings [1], perhaps because it is counter-intuitive [2]. However, it is easy to implement and potentially useful in a large number of contexts and disciplines (see [3]). It is important for the educational community to become more aware of the benefits of distributed practice. We will focus on the cognitive and neuroscientific research on distributed practice effects, and conclude with implications for education.

2. Massed versus spaced practice

Re-studying a piece of information immediately after the first study episode is not an efficient way to proceed in order to learn effectively and retain information over a long period of time. More than 100 years of psychological research have consistently demonstrated that spacing the repetitions of the same piece of information over time favors later retention of the material compared to massing the repetitions in immediate succession. Classic experiments typically involve either of two basic designs. Researchers may present to-be-learned items (e.g., words) one by one in a single session and vary how many other items are interspersed between two presentations of a repeated item Alternatively, they may present the same items in two different sessions and vary the interval between sessions (see Fig. 1 for a schematic view of such studies). Two spaced presentations can be twice as effective as two massed presentations. Research has also shown that this effect is valid for virtually all types of to-be-learned materials: words (e.g., [4]), word pairs (e.g., [5]), faces (e.g., [6]), pictures (e.g., [7]), texts (e.g., [8]), and so on. The phenomenon also has been observed for the practice of motor skills (e.g., [9]) as well as for cognitive skills like grammar in a foreign language [10] or solving mathematics

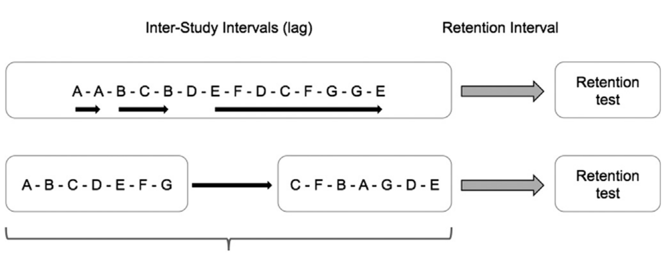

Fig. 1. Schematic representation of experimental studies of the effect distributed practice. The upper panel represents studies manipulating spacing within a learning session, and the dark arrows highlight the spacing interval separating some of the repeated items. The lower panel describes studies using two distinct learning sessions involving the same material. The dark arrow represents the interval between sessions which can be manipulated to vary the degree of spacing.

problems [11]. And, very different learning tasks appear to yield similar effects across an extended range of spacings [12]. (For reviews of the distributed practice effect, see [2,13–15]).

It is noteworthy that the effect is valid with tasks that are experienced in real school settings. For example, Bloom and Shuell [16] had high-school students learn foreign language vocabulary either in a single, 30-min long session or with three 10-min sessions over 3 days. Retention after four days was 35% better in the spaced than in the massed condition. The benefit of spaced practice seems to be even more powerful when multiple repetitions are used. Work from Bahrick and colleagues showed that the more the study sessions were spaced, the better the result (e.g., [17,18]), although there are limits to this generalization as we will see later.

Although most of the research on distributed practice has been conducted with young, college-age adults, the benefit of distributed practice has been observed throughout the lifespan. Children display this effect. It has been demonstrated in infancy (e.g., 5 months in [19]), in preschool children (e.g., [20]), as well as in elementary-school (e.g., [21]), and middle-school (e.g., [22]) children. At the other extreme, distributed practice effects have been demonstrated in the elderly (e.g., [23,24]).

The generality of the spacing effect also extends to other species. Very basic organisms, from drosophila [25], aplysia [26] and bees [27], to vertebrates like rodents [28] display the spacing effect in simple learning paradigms like conditioning, habituation or sensitization. For instance, when drosophila learned to avoid a given odor that was associated with electric shocks through multiple exposures, they retained the avoiding behavior over a longer period when they experienced 15-min spaced exposures to this association rather than massed exposures [25].

The uncommon ubiquity of the spacing effect suggests that it reflects a fundamental principle of the memory system, shaped by evolution (e.g., [29]). It calls for an explanation in terms of a very general mechanism or set of mechanisms.

2.1. Deficient processing

One general mechanism that may contribute to the spacing effect is described by the *deficient processing hypothesis*. According to this view, the second occurrence of an immediately repeated item receives less processing compared to a spaced repetition, resulting in less efficient encoding and poorer memory. Supporting evidence comes from both psychological and brain imaging studies, some of which are reviewed below [for a more complete review, see [2]]. Magliero [30] found that pupil dilation, an indicator of processing effort, is smaller for the second presentation of a massed item compared to the second presentation of a spaced item. Johnston and Uhl [31] showed that reaction times to a tone are shorter during repeated occurrences of an item when the repetitions are massed rather than spaced, indicating that less attentional processing is devoted to the massed repetitions. Deficient processing may be partially influenced by voluntary strategies used by the learner. For example, a sense of familiarity may arise when the same information is re-presented immediately, creating the impression that the information is already learned and that no further processing is necessary. Indeed, when participants could choose how long to study each item, they spent less time on the second presentation of a massed item than a spaced item [32]. However, involuntary processes also seem to play an important role. The spacing effect is undiminished even when incentives are provided to motivate people to study massed repetitions to a greater extent [33]. It also is obtained when learning occurs incidentally (unintentionally) (e.g., [34]), and when learners are very young children who typically do not engage in strategic study behavior [20].

Several researchers (e.g., [6,35]) have proposed that deficient processing may be related to a priming mechanism. Short-term