
Semaine de la
FAD
2026
Fondamentalement humain
Comprendre le cerveau pour optimiser la formation à distance
Conférence d’ouverture - Semaine de la FAD 2026 - 16 février 2026
Steve Masson, professeur à l’Université du Québec à Montréal

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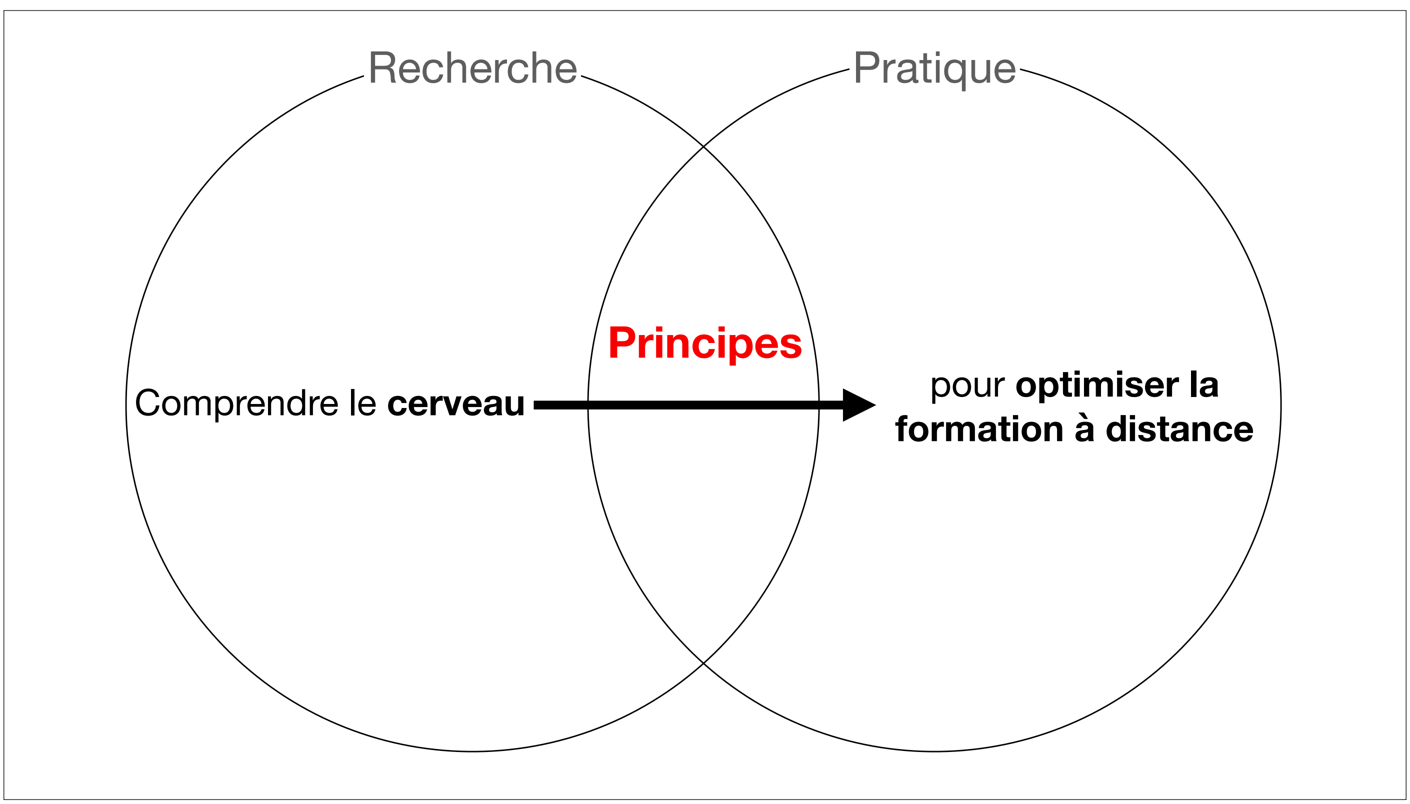
Recherche
Pratique
Principes
Comprendre le **cerveau**
pour **optimiser la formation à distance**

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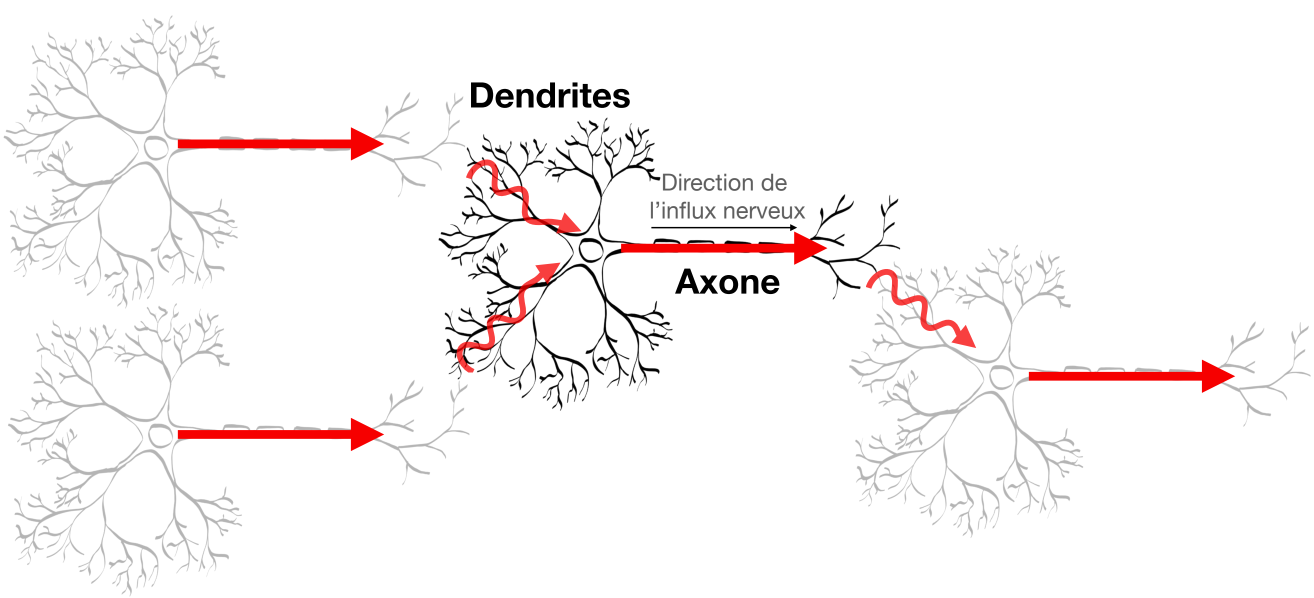
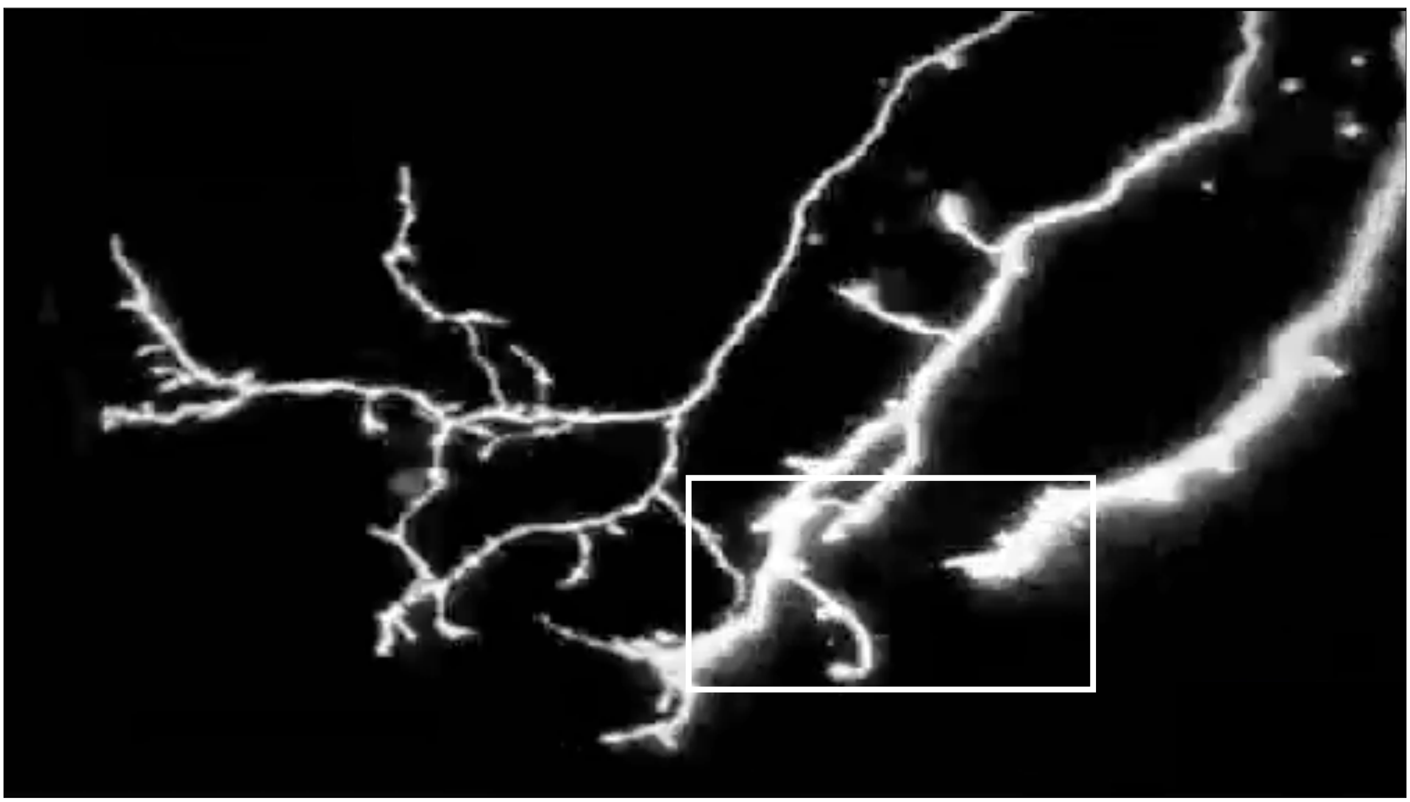
Principe 1

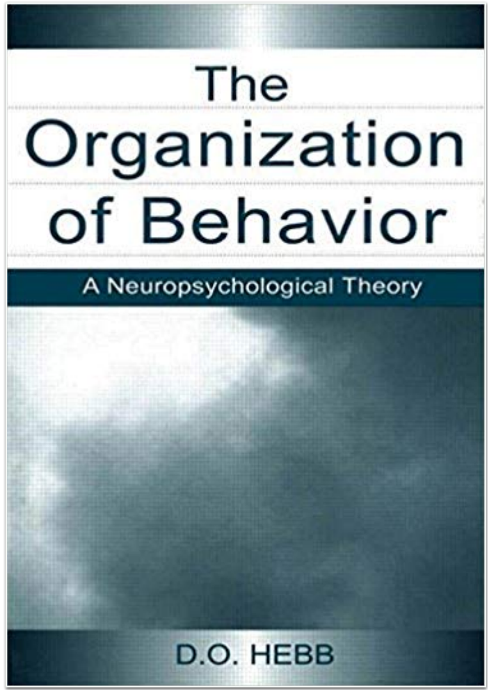


Apprendre, c'est changer
ses **connexions** neuronales.

Neuroplasticité



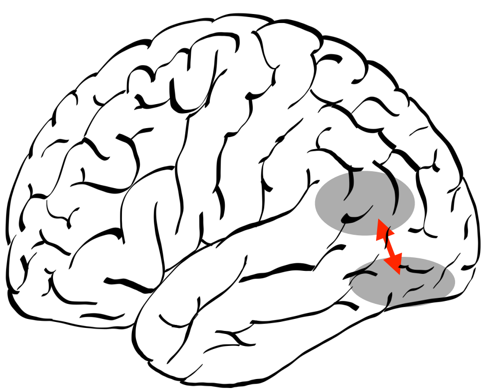
Livre de **Hebb**



Mécanisme de modification de connexions

Les neurones qui s'**activent** ensemble
se **connectent** ensemble.

Analogie de la forêt



Principe 1
Activer les neurones à plusieurs reprises

Comment ?

Stratégie 1
Planifier plusieurs moments d'activation


PNAS RESEARCH ARTICLE | PSYCHOLOGICAL AND COGNITIVE SCIENCES OPEN ACCESS

An astonishing regularity in student learning rate

Kenneth R. Koedinger[a,1], Paulo F. Carvalho[a], Ran Liu[b], and Elizabeth A. McLaughlin[a]

Edited by Douglas Medin, Northwestern University, Evanston, IL; received December 25, 2022; accepted February 10, 2023

Leveraging a scientific infrastructure for exploring how students learn, we have developed cognitive and statistical models of skill acquisition and used them to understand fundamental similarities and differences across learners. Our primary question was why do some students learn faster than others? Or, do they? We model data from student performance on groups of tasks that assess the same skill component and that provide follow-up instruction on student errors. Our models estimate, for both students and skills, initial correctness and learning rate, that is, the increase in correctness after each practice opportunity. We applied our models to 1.3 million observations across 27 datasets of student interactions with online practice systems in the context of elementary to college courses in math, science, and language. Despite the availability of up-front verbal instruction, like lectures and readings, students demonstrate modest initial prepractice performance, at about 65% accuracy. Despite being in the same course, students' initial performance varies substantially from about 55% correct for those in the lower half to 75% for those in the upper half. In contrast, and much to our surprise, we found students to be astonishingly similar in estimated learning rate, typically increasing by about 0.1 log odds or 2.5% in accuracy per opportunity. These findings pose a challenge for theories of learning to explain the odd combination of large variation in student initial performance and striking regularity in student learning rate.

learning rate | learning curves | deliberate practice | logistic regression growth modeling; educational equity

Significance

Prior research, often using self-report data, hypothesizes that the path to expertise requires extensive practice and that different learners acquire competence at different rates. Fitting cognitive and statistical growth models to 27 datasets involving observations of learning and performance in academic settings, we find evidence for the first hypothesis and against the second. Students do need extensive practice, about seven opportunities per component of knowledge. Students do not show substantial differences in their rate of learning. These results provide a challenge for learning theory to explain this striking similarity in student learning rate. They also suggest that educational achievement gaps come from differences in learning opportunities and that better access to such opportunities can help close those gaps.

Humans are capable of a wide and flexible variety of learning adaptation. This adaptability is particularly apparent in the development of expertise associated with high-profile careers, like technology innovation or music composition, but also in the wide variety of academic subject matter, reading, writing, math, science, second language, etc., humans master. Better understanding of how human learning works in the context of academic courses is of scientific interest because academic learning is particularly distinct to the human species. It is also of practical interest because such understanding can be used to develop more effective education. New technologies have often made better science possible. Such is the case for educational technologies which, in this century, have been increasingly providing unprecedented volumes of detailed data on academic learning. With center-level funding from the National Science Foundation to LearnLab (learnlab.org), we developed a social–technical infrastructure to systematically acquire such data and use it both to optimize interactive learning technologies and to pursue scientific questions about student learning.

LearnLab's early goals were to identify the mental units of learning in academic courses, to use these insights to design and demonstrate improved instruction in randomized controlled experiments embedded in courses, and to build models of learners that may reveal significant similarities and differences across learners. Past research produced methods for discovering and validating improved cognitive models of the mental units students acquire in academic courses (e.g., ref. 1). These improved cognitive models were used to redesign course units, and random assignment field experiments comparing student use of the redesign (treatment) with the original design (control) demonstrated enhanced learning outcomes (e.g., refs. 2 and 3). A key theoretical hypothesis of these cognitive models is that a decomposition of learning into discrete units, or knowledge components, produces predictions that can be tested against student performance data across different contexts and at different times. Investigations across multiple datasets support this knowledge component hypothesis (e.g., refs. 1 and 4).

In this paper, we combine these cognitive models with statistical growth models to explore significant similarities and differences across academic learners. Our research questions are:

1. Practice needed: How many practice opportunities do students need to reach a mastery level of 80% correctness?
2. Initial performance variation: How much do students vary in their initial performance?
3. Learning-rate variation: How much do students vary in their learning rate?

Author affiliations: [a]Human-Computer Interaction Institute, Carnegie Mellon University, Pittsburgh, PA 15213; and [b]Engineering, Amira Learning, Seattle, WA 98101

Author contributions: K.R.K., P.F.C, and R.L. designed research; K.R.K., P.F.C., and R.L. performed research; K.R.K., P.F.C., and R.L. analyzed data; and K.R.K., P.F.C., and E.A.M. wrote the paper.

The authors declare no competing interest.

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[1]To whom correspondence may be addressed. Email: koedinger@cmu.edu.

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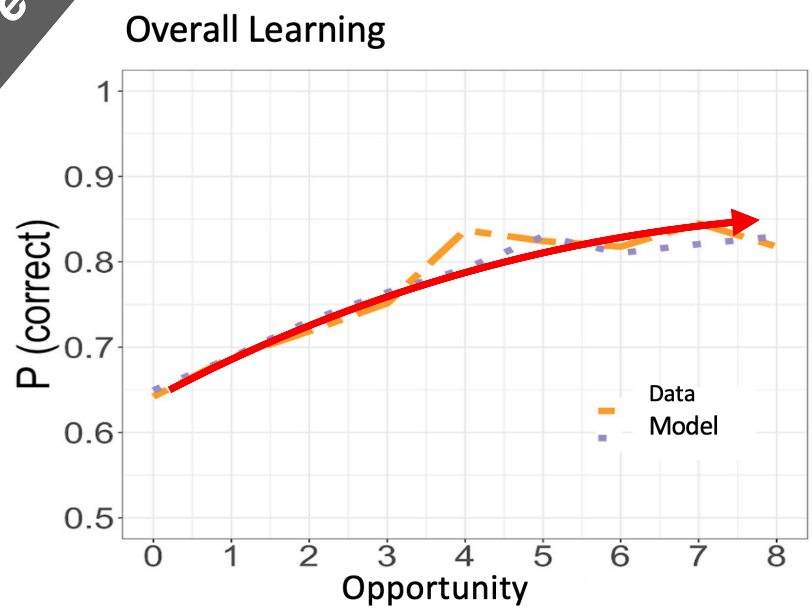
Taux d'apprentissage en fonction du **nombre d'activations**

Étude de Koedinger et al.



+ 2,5 % par activation

~7 activations

Principe 1
Activer les neurones à plusieurs reprises

Comment ?

Stratégie 1
Planifier plusieurs moments d'activation

Stratégie 2
Entraîner la récupération en mémoire

Étude de Zaromb et al.

Memory & Cognition
2010, 38 (8), 995-1008
doi:10.3758/MC.38.8.995

The testing effect in free recall is associated with enhanced organizational processes

Franklin M. Zaromb and Henry L. Roediger III
Washington University, St. Louis, Missouri

In two experiments with categorized lists, we asked whether the testing effect in free recall is related to enhancements in organizational processing. During a first phase in Experiment 1, subjects studied one list over eight consecutive trials, they studied another list six times while taking two interspersed recall tests, and they learned a third list in four alternating study and test trials. On a test 2 days later, recall was directly related to the number of tests and inversely related to the number of study trials. In addition, increased testing enhanced both the number of categories accessed and the number of items recalled from within those categories. One measure of organization also increased with the number of tests. In a second experiment, different groups of subjects studied a list either once or twice before a final criterial test, or they studied the list once and took an initial recall test before the final test. Prior testing again enhanced recall, relative to studying on the final test a day later, and also improved category clustering. The results suggest that the benefit of testing in free recall learning arises because testing creates retrieval schemas that guide recall.

A robust finding is that testing a person's memory for previously learned material enhances long-term retention, relative to restudying the material for an equivalent amount of time (e.g., Carrier & Pashler, 1992; for a review, see Roediger & Karpicke, 2006a). This finding, known as the *testing effect*, has been demonstrated using a wide range of study materials and types of tests, in both laboratory and classroom settings and in various subject populations (e.g., Butler & Roediger, 2007; Gates, 1917; Kang, McDermott, & Roediger, 2007; McDaniel, Anderson, Derbish, & Morrisette, 2007; Roediger & Karpicke, 2006b; Spitzer, 1939; Tse, Balota, & Roediger, in press). Recent years have seen renewed interest among researchers investigating the potential benefits of testing for learning as a means to improving learning in educational settings (McDaniel, Roediger, & McDermott, 2007; Pashler, Rohrer, Cepeda, & Carpenter, 2007).

One limitation with this work is that testing effects typically report improvements in learners' retention of discrete facts (e.g., foreign vocabulary words) without necessarily demonstrating a better understanding of the subject matter through testing (Daniel & Poole, 2009). However, a growing body of research has shown that testing can serve as a versatile learning tool by enhancing the long-term retention of nontested information that is conceptually related to previously retrieved information (Chan, 2009; Chan, McDermott, & Roediger, 2006), by stimulating the subsequent learning of new information (Izawa, 1970; Karpicke, 2009; Szpunar, McDermott, & Roediger, 2008; Tulving & Watkins, 1974) and by permitting better transfer to new questions (Butler, 2010; Johnson & Mayer, 2009; Rohrer, Taylor, & Sholar, 2010). In the present research, we further examine the potential benefits of testing by asking whether testing can improve individuals' learning and retention of the conceptual organization of study materials, relative to studying the materials alone—a question not yet addressed in the literature.

Psychologists have long grappled with questions of how the processes involved in mentally organizing information influence learning and retention (e.g., Ausubel, 1963; Bartlett, 1932; Katona, 1940). One theoretical assumption that has guided much of the cognitive research examining organization and learning was Miller's (1956) conception of recoding, or *chunking*, in which he argued that the key to learning and retaining large quantities of information was to mentally repackage, or *chunk*, the study materials into smaller units. Evidence for chunking has come primarily from studies using serial recall and free recall paradigms in which subjects often study and attempt to recall verbal materials such as lists of words over multiple alternating study and test trials (e.g., Bower & Springston, 1970; Tulving, 1962), but it has also come from other techniques (e.g., Mandler, 1967).

In support of the chunking hypothesis, researchers have pointed to the finding that when people study lists of words coming from different conceptual categories in a randomized order, they tend to recall them in an organized fashion by clustering conceptually related responses together (W. A. Bousfield, 1953; W. A. Bousfield, Cohen, & Whitmarsh, 1958). Furthermore, response clustering is often associated with greater retention (Mulligan, 2005; Puff, 1979). Similarly, Tulving (1962) found that when students learned

F. M. Zaromb, fzaromb@ets.org

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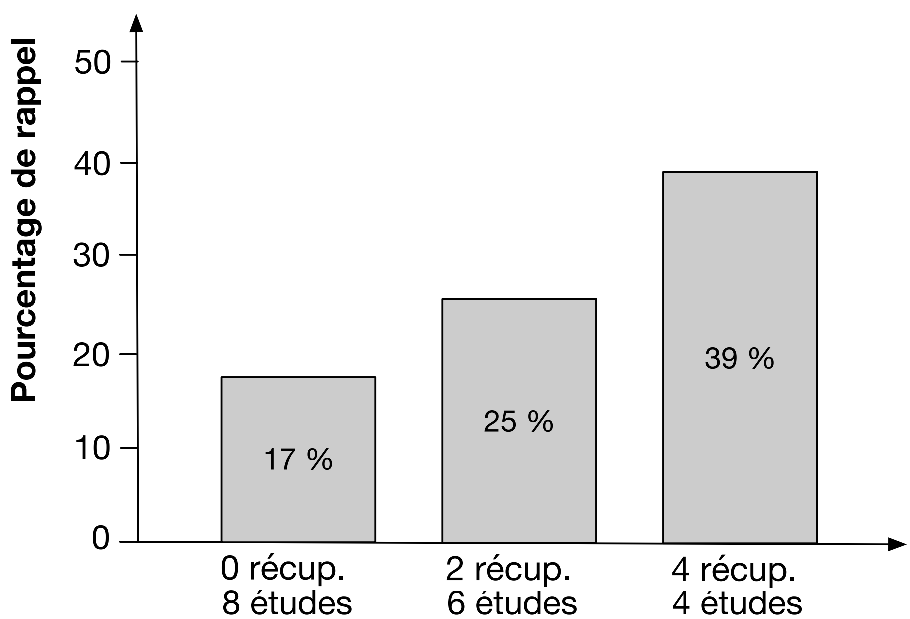
Effets de l'entraînement à la **récupération** en mémoire vs **étude**

Étude de Zaromb et al.



Principe 1
Activer les neurones à plusieurs reprises

Comment ?

Stratégie 1
Planifier plusieurs moments d'activation

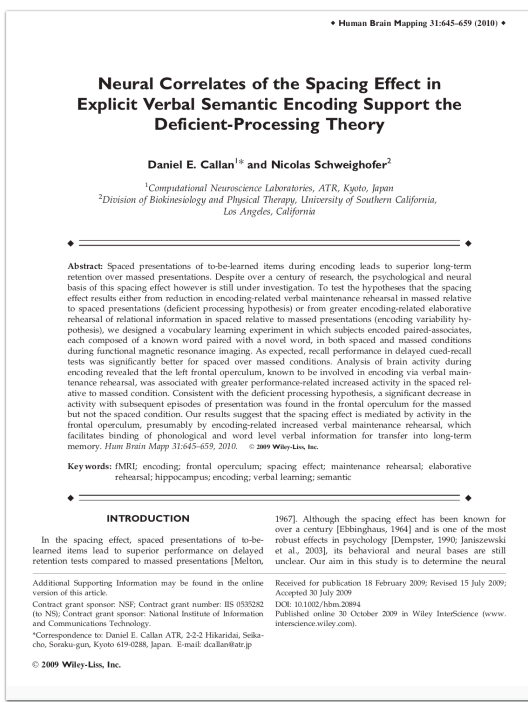
Stratégie 2
Entraîner la récupération en mémoire

Stratégie 3
Élaborer des explications

Principe 2

Activation 1 | Activation 2 | Activation 3

Étude de Callan et al.


◆ Human Brain Mapping 31:645–659 (2010) ◆

Neural Correlates of the Spacing Effect in Explicit Verbal Semantic Encoding Support the Deficient-Processing Theory

Daniel E. Callan[1]* and Nicolas Schweighofer[2]

[1]*Computational Neuroscience Laboratories, ATR, Kyoto, Japan*
[2]*Division of Biokinesiology and Physical Therapy, University of Southern California, Los Angeles, California*

Abstract: Spaced presentations of to-be-learned items during encoding leads to superior long-term retention over massed presentations. Despite over a century of research, the psychological and neural basis of this spacing effect however is still under investigation. To test the hypotheses that the spacing effect results either from reduction in encoding-related verbal maintenance rehearsal in massed relative to spaced presentations (deficient processing hypothesis) or from greater encoding-related elaborative rehearsal of relational information in spaced relative to massed presentations (encoding variability hypothesis), we designed a vocabulary learning experiment in which subjects encoded paired-associates, each composed of a known word paired with a novel word, in both spaced and massed conditions during functional magnetic resonance imaging. As expected, recall performance in delayed cued-recall tests was significantly better for spaced over massed conditions. Analysis of brain activity during encoding revealed that the left frontal operculum, known to be involved in encoding via verbal maintenance rehearsal, was associated with greater performance-related increased activity in the spaced relative to massed condition. Consistent with the deficient processing hypothesis, a significant decrease in activity with subsequent episodes of presentation was found in the frontal operculum for the massed but not the spaced condition. Our results suggest that the spacing effect is mediated by activity in the frontal operculum, presumably by encoding-related increased verbal maintenance rehearsal, which facilitates binding of phonological and word level verbal information for transfer into long-term memory. *Hum Brain Mapp 31:645–659, 2010.* © 2009 Wiley-Liss, Inc.

Key words: fMRI; encoding; frontal operculum; spacing effect; maintenance rehearsal; elaborative rehearsal; hippocampus; encoding; verbal learning; semantic

INTRODUCTION

In the spacing effect, spaced presentations of to-be-learned items lead to superior performance on delayed retention tests compared to massed presentations [Melton, 1967]. Although the spacing effect has been known for over a century [Ebbinghaus, 1964] and is one of the most robust effects in psychology [Dempster, 1990; Janiszewski et al., 2003], its behavioral and neural bases are still unclear. Our aim in this study is to determine the neural

Additional Supporting Information may be found in the online version of this article.

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*Correspondence to: Daniel E. Callan ATR, 2-2-2 Hikaridai, Seika-cho, Soraku-gun, Kyoto 619-0288, Japan. E-mail: dcallan@atr.jp

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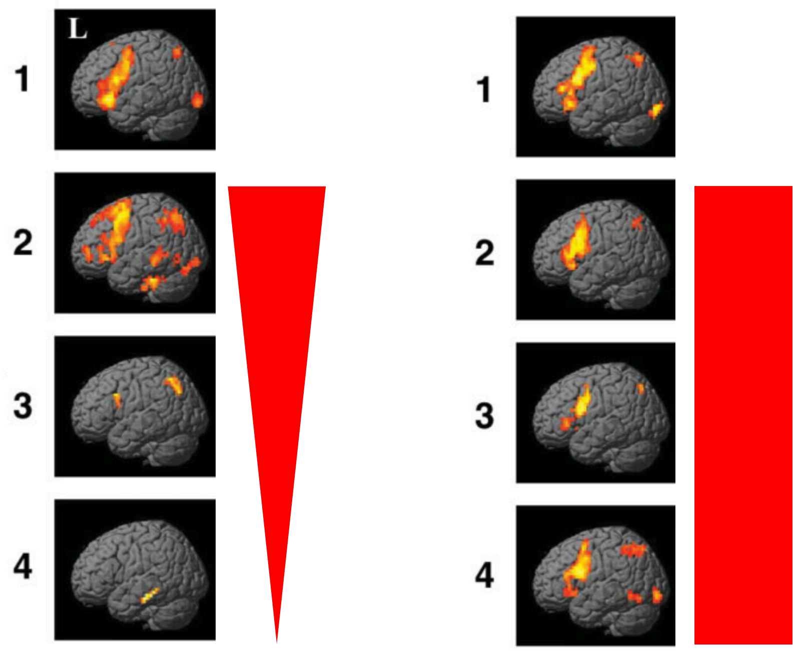
Effets de l’**espacement** sur l’activité cérébrale

Étude de Callan et al.

Regroupé	Espacé



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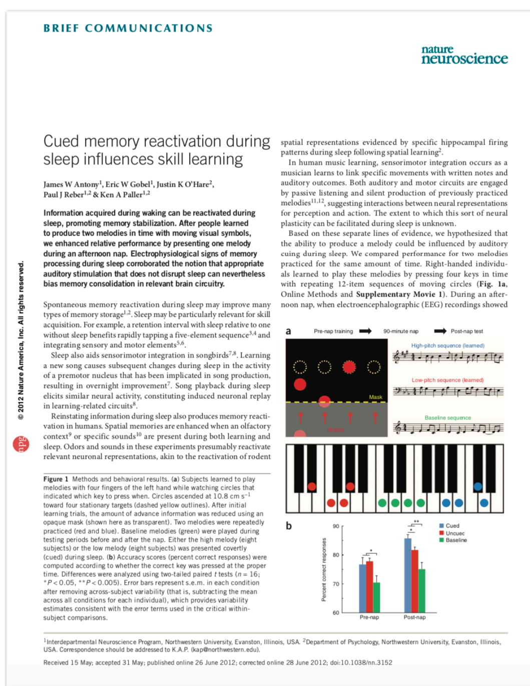
Étude de Antony et al.



BRIEF COMMUNICATIONS

nature neuroscience

Cued memory reactivation during sleep influences skill learning

James W Antony[1], Eric W Gobel[1], Justin K O'Hare[2], Paul J Reber[1,2] & Ken A Paller[1,2]

Information acquired during waking can be reactivated during sleep, promoting memory stabilization. After people learned to produce two melodies in time with moving visual symbols, we enhanced relative performance by presenting one melody during an afternoon nap. Electrophysiological signs of memory processing during sleep corroborated the notion that appropriate auditory stimulation that does not disrupt sleep can nevertheless bias memory consolidation in relevant brain circuitry.

Spontaneous memory reactivation during sleep may improve many types of memory storage[1,2]. Sleep may be particularly relevant for skill acquisition. For example, a retention interval with sleep relative to one without sleep benefits rapidly tapping a five-element sequence[3,4] and integrating sensory and motor elements[5,6].

Sleep also aids sensorimotor integration in songbirds[7,8]. Learning a new song causes subsequent changes during sleep in the activity of a premotor nucleus that has been implicated in song production, resulting in overnight improvement[7]. Song playback during sleep elicits similar neural activity, constituting induced neuronal replay in learning-related circuits[8].

Reinstating information during sleep also produces memory reactivation in humans. Spatial memories are enhanced when an olfactory context[9] or specific sounds[10] are present during both learning and sleep. Odors and sounds in these experiments presumably reactivate relevant neuronal representations, akin to the reactivation of rodent spatial representations evidenced by specific hippocampal firing patterns during sleep following spatial learning[2].

In human music learning, sensorimotor integration occurs as a musician learns to link specific movements with written notes and auditory outcomes. Both auditory and motor circuits are engaged by passive listening and silent production of previously practiced melodies[11,12], suggesting interactions between neural representations for perception and action. The extent to which this sort of neural plasticity can be facilitated during sleep is unknown.

Based on these separate lines of evidence, we hypothesized that the ability to produce a melody could be influenced by auditory cuing during sleep. We compared performance for two melodies practiced for the same amount of time. Right-handed individuals learned to play these melodies by pressing four keys in time with repeating 12-item sequences of moving circles (**Fig. 1a**, Online Methods and **Supplementary Movie 1**). During an afternoon nap, when electroencephalographic (EEG) recordings showed

Figure 1 Methods and behavioral results. (**a**) Subjects learned to play melodies with four fingers of the left hand while watching circles that indicated which key to press when. Circles ascended at 10.8 cm s^{-1} toward four stationary targets (dashed yellow outlines). After initial learning trials, the amount of advance information was reduced using an opaque mask (shown here as transparent). Two melodies were repeatedly practiced (red and blue). Baseline melodies (green) were played during testing periods before and after the nap. Either the high melody (eight subjects) or the low melody (eight subjects) was presented covertly (cued) during sleep. (**b**) Accuracy scores (percent correct responses) were computed according to whether the correct key was pressed at the proper time. Differences were analyzed using two-tailed paired *t* tests ($n = 16$; $*P < 0.05$, $**P < 0.005$). Error bars represent s.e.m. in each condition after removing across-subject variability (that is, subtracting the mean across all conditions for each individual), which provides variability estimates consistent with the error terms used in the critical within-subject comparisons.

[1]Interdepartmental Neuroscience Program, Northwestern University, Evanston, Illinois, USA. [2]Department of Psychology, Northwestern University, Evanston, Illinois, USA. Correspondence should be addressed to K.A.P. (kap@northwestern.edu).

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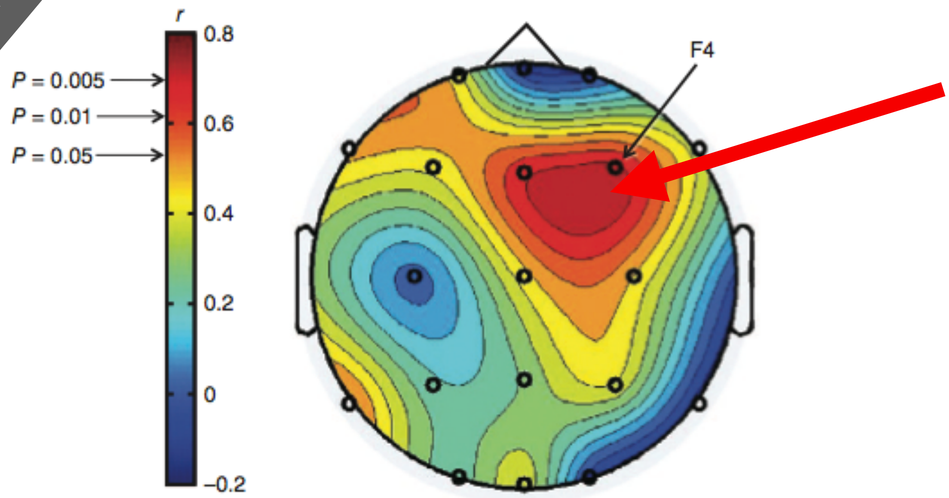
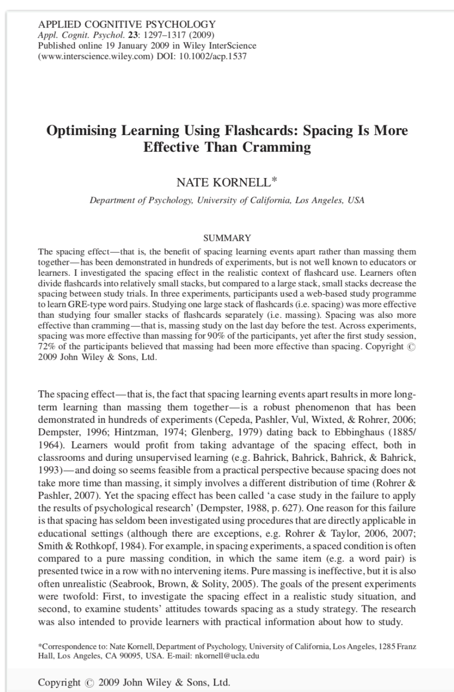
Effets du **sommeil** sur l'apprentissage et l'activité cérébrale

Étude de Antony et al.



Cortex prémoteur lié à la main utilisée

Étude de Kornell et al.



APPLIED COGNITIVE PSYCHOLOGY
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(www.interscience.wiley.com) DOI: 10.1002/acp.1537

Optimising Learning Using Flashcards: Spacing Is More Effective Than Cramming

NATE KORNELL*

Department of Psychology, University of California, Los Angeles, USA

SUMMARY

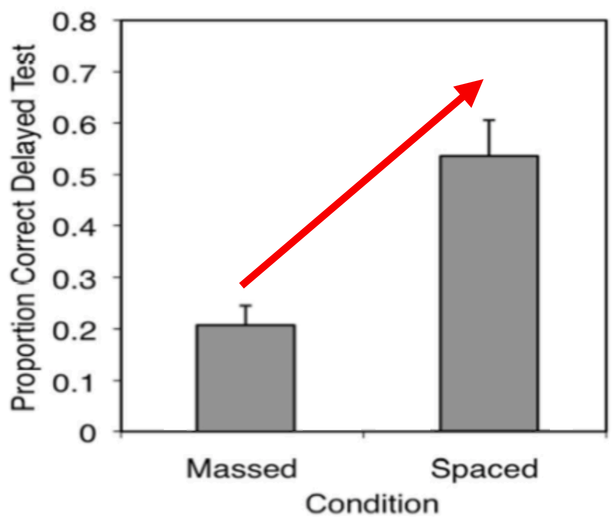
The spacing effect—that is, the benefit of spacing learning events apart rather than massing them together—has been demonstrated in hundreds of experiments, but is not well known to educators or learners. I investigated the spacing effect in the realistic context of flashcard use. Learners often divide flashcards into relatively small stacks, but compared to a large stack, small stacks decrease the spacing between study trials. In three experiments, participants used a web-based study programme to learn GRE-type word pairs. Studying one large stack of flashcards (i.e. spacing) was more effective than studying four smaller stacks of flashcards separately (i.e. massing). Spacing was also more effective than cramming—that is, massing study on the last day before the test. Across experiments, spacing was more effective than massing for 90% of the participants, yet after the first study session, 72% of the participants believed that massing had been more effective than spacing. Copyright © 2009 John Wiley & Sons, Ltd.

The spacing effect—that is, the fact that spacing learning events apart results in more long-term learning than massing them together—is a robust phenomenon that has been demonstrated in hundreds of experiments (Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006; Dempster, 1996; Hintzman, 1974; Glenberg, 1979) dating back to Ebbinghaus (1885/1964). Learners would profit from taking advantage of the spacing effect, both in classrooms and during unsupervised learning (e.g. Bahrick, Bahrick, Bahrick, & Bahrick, 1993)—and doing so seems feasible from a practical perspective because spacing does not take more time than massing, it simply involves a different distribution of time (Rohrer & Pashler, 2007). Yet the spacing effect has been called 'a case study in the failure to apply the results of psychological research' (Dempster, 1988, p. 627). One reason for this failure is that spacing has seldom been investigated using procedures that are directly applicable in educational settings (although there are exceptions, e.g. Rohrer & Taylor, 2006, 2007; Smith & Rothkopf, 1984). For example, in spacing experiments, a spaced condition is often compared to a pure massing condition, in which the same item (e.g. a word pair) is presented twice in a row with no intervening items. Pure massing is ineffective, but it is also often unrealistic (Seabrook, Brown, & Solity, 2005). The goals of the present experiments were twofold: First, to investigate the spacing effect in a realistic study situation, and second, to examine students' attitudes towards spacing as a study strategy. The research was also intended to provide learners with practical information about how to study.

*Correspondence to: Nate Kornell, Department of Psychology, University of California, Los Angeles, 1285 Franz Hall, Los Angeles, CA 90095, USA. E-mail: nkornell@ucla.edu

Effets de l'**espacement** sur l'apprentissage

Étude de Kornell



Principe 2
Espacer les activités d'apprentissage

Comment ?

Stratégie 1
Distribuer l'apprentissage

Regroupé

Activation 1 | Activation 2 | Activation 3

Distribué

Activation 1 Activation 2 Activation 3

Souvent mais pas trop longtemps

Principe 2

Espacer les activités d'apprentissage

Comment ?

Stratégie 1
Distribuer l'apprentissage

Stratégie 2
Entrelacer les apprentissages

Regroupé

1 1 1 2 2 2 3 3 3

Entrelacé

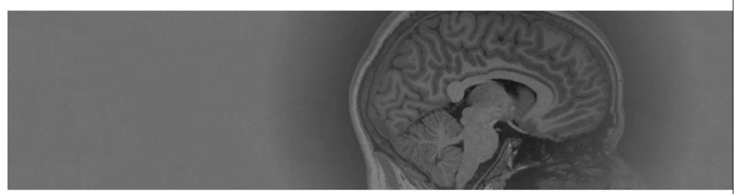
1 2 3 3 1 2 2 3 1

Bloc 1	Bloc 2
Objectif 1	**Objectif 1**
Objectif 1	Objectif 2
Objectif 1	Objectif 2
Objectif 1	Objectif 2
Objectif 2	Objectif 2

Regroupé	$\frac{3}{7} \times \frac{2}{3} = ?$	$\frac{2}{4} \times \frac{1}{2} = ?$	$\frac{5}{9} \times \frac{3}{6} = ?$	$\frac{1}{5} \times \frac{3}{8} = ?$
Entrelacé	$\frac{3}{7} \times \frac{2}{3} = ?$	$\frac{1}{2} + \frac{3}{5} = ?$	$\frac{5}{9} \times \frac{3}{6} = ?$	$\frac{5}{6} + \frac{2}{3} = ?$

Comment entrelacer ?

- Faire des **retours** sur des éléments vus plus tôt (capsule de révision)
- **Ajouter aux exercices** existants des questions portant sur du contenu antérieur
- **Conserver** une partie des exercices pour plus tard



Principe 3

Rétroaction =
retour d'information survenant à la suite d'une **action**

Rétroaction négative =
retour d'**information** indiquant qu'une **erreur** a été commise

Étude de Monchi et al.


The Journal of Neuroscience, October 1, 2001, 21(19):7733–7741

Wisconsin Card Sorting Revisited: Distinct Neural Circuits Participating in Different Stages of the Task Identified by Event-Related Functional Magnetic Resonance Imaging

Oury Monchi,[1,2] Michael Petrides,[2] Valentina Petre,[1] Keith Worsley,[1,3] and Alain Dagher[1]

[1]McConnell Brain Imaging Centre and [2]Cognitive Neuroscience Unit, Montreal Neurological Institute, and [3]Department of Mathematics and Statistics, McGill University, Montréal, Québec, H3A 2B4 Canada

The Wisconsin Card Sorting Task (WCST) has been used to assess dysfunction of the prefrontal cortex and basal ganglia. Previous brain imaging studies have focused on identifying activity related to the set-shifting requirement of the WCST. The present study used event-related functional magnetic resonance imaging (fMRI) to study the pattern of activation during four distinct stages in the performance of this task. Eleven subjects were scanned while performing the WCST and a control task involving matching two identical cards. The results demonstrated specific involvement of different prefrontal areas during different stages of task performance. The mid-dorsolateral prefrontal cortex (area 9/46) increased activity while subjects received either positive or negative feedback, that is at the point when the current information must be related to earlier events stored in working memory. This is consistent with the proposed role of the mid-dorsolateral prefrontal cortex in the monitoring of events in working memory. By contrast, a cortical basal ganglia loop involving the mid-ventrolateral prefrontal cortex (area 47/12), caudate nucleus, and mediodorsal thalamus increased activity specifically during the reception of negative feedback, which signals the need for a mental shift to a new response set. The posterior prefrontal cortex response was less specific; increases in activity occurred during both the reception of feedback and the response period, indicating a role in the association of specific actions to stimuli. The putamen exhibited increased activity while matching after negative feedback but not while matching after positive feedback, implying greater involvement during novel than routine actions.

Key words: basal ganglia; caudate nucleus; fMRI; prefrontal cortex; set-shifting; Wisconsin card sorting

The Wisconsin Card Sorting Task (WCST) has been used to investigate deficits in executive function in humans (Milner, 1963; Nelson, 1976; Stuss et al., 2000). The subject is asked to match test cards to reference cards according to the color, shape, or number of stimuli on the cards. Feedback is provided after each match, enabling the subject to acquire the correct rule of classification. After a fixed number of correct matches, the rule is changed without notice, and the subject must shift to a new mode of classification. Thus, the WCST measures cognitive flexibility, that is the ability to alter a behavioral response mode in the face of changing contingencies (set-shifting).

Patients with lesions of the prefrontal cortex (PFC) are impaired at card sorting (Milner, 1963; Nelson 1976; Stuss et al., 2000). The basal ganglia also play a role in WCST performance as shown by impairments observed in patients with Parkinson's disease (Bowen et al., 1975; Lees and Smith, 1983; Gotham et al., 1988), consistent with the strong anatomical connections between the PFC and basal ganglia (Alexander et al., 1986; Middleton and Strick, 1994). Alexander et al. (1986) proposed the existence of parallel cortical basal ganglia loops, each comprising a specific location in the cortex, basal ganglia, and thalamus. There is evidence that the nature of the deficit is different in Parkinson's disease than after PFC lesions (Rogers et al., 1998), although the specific roles of PFC and basal ganglia remain unclear.

Functional neuroimaging studies have confirmed the involvement of the PFC in set-shifting (Berman et al., 1995; Nagahama et al., 1996; Goldberg et al., 1998; Konishi et al., 1998, 1999a; Rogers et al., 2000; Nagahama et al., 2001). Basal ganglia involvement has been less evident. Rogers et al. (2000), using positron emission tomography (PET), reported increased activity in the caudate nucleus during an attentional set-shifting task only during reversals in the rule of classification, but not during the types of extra-dimensional set-shifts that occur in the WCST. Moreover, the events during set-shifting can be separated into those occurring at the point of receiving negative feedback, indicating that the current set must be changed, and those occurring while the action is performed under the new attentional set. Thus far, brain imaging studies of the WCST have not attempted to differentiate brain activity between these two aspects of set-shifting. In addition, these studies did not separate activity occurring during the moment of receiving positive feedback, indicating that the current set must be maintained, and activity occurring when matching according to the current set. A computational model predicted the involvement of distinct corticostriatal loops during these four stages of the WCST (Monchi et al., 2000). Here, we used mixed-trials event-related functional magnetic resonance imaging (fMRI) to determine the specific location and pattern of activation in the PFC and basal ganglia during these four stages of the WCST.

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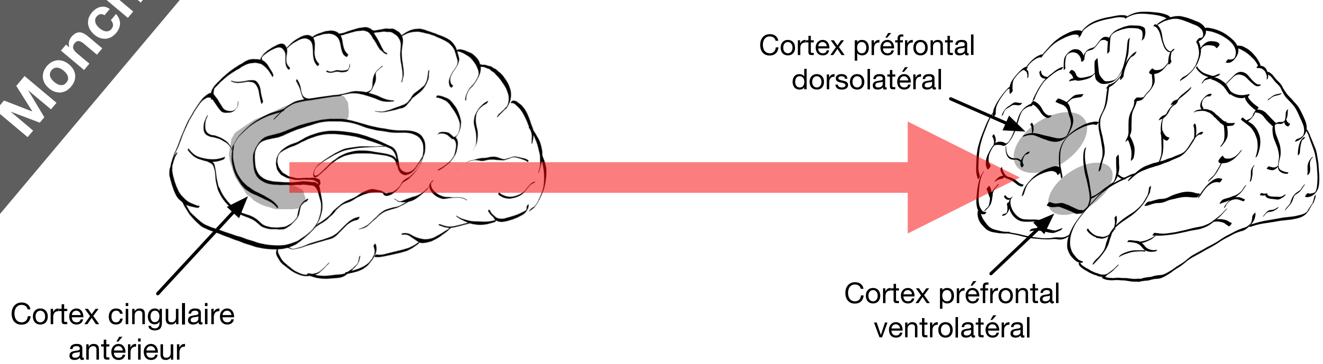
Correspondence should be addressed to Dr. Alain Dagher, McConnell Brain Imaging Centre, Montreal Neurological Institute, 3801 University Street, Montréal, Québec, H3A 2B4, Canada. E-mail: alain@bic.mni.mcgill.ca or oury@bic.mni.mcgill.ca.

Effets de la **rétroaction négative** sur le cerveau

Étude de Monchi et al.



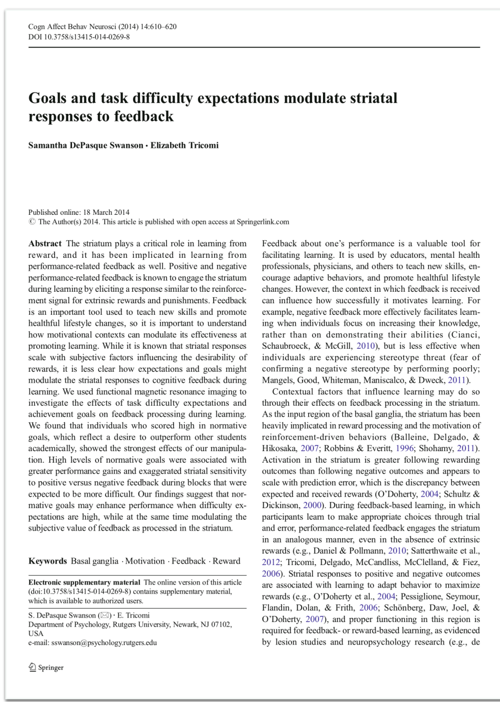
Étape 1
Détection de **conflit** d'information

Étape 2
Analyse de la situation

Activation du système de **correction d'erreur**

Rétroaction positive =
retour d'**information** confirmant la **réussite**
ou les bienfaits d'une action

Étude de **DePasque et al.**



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Goals and task difficulty expectations modulate striatal responses to feedback

Samantha DePasque Swanson · Elizabeth Tricomi

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Abstract The striatum plays a critical role in learning from reward, and it has been implicated in learning from performance-related feedback as well. Positive and negative performance-related feedback is known to engage the striatum during learning by eliciting a response similar to the reinforcement signal for extrinsic rewards and punishments. Feedback is an important tool used to teach new skills and promote healthful lifestyle changes, so it is important to understand how motivational contexts can modulate its effectiveness at promoting learning. While it is known that striatal responses scale with subjective factors influencing the desirability of rewards, it is less clear how expectations and goals might modulate the striatal responses to cognitive feedback during learning. We used functional magnetic resonance imaging to investigate the effects of task difficulty expectations and achievement goals on feedback processing during learning. We found that individuals who scored high in normative goals, which reflect a desire to outperform other students academically, showed the strongest effects of our manipulation. High levels of normative goals were associated with greater performance gains and exaggerated striatal sensitivity to positive versus negative feedback during blocks that were expected to be more difficult. Our findings suggest that normative goals may enhance performance when difficulty expectations are high, while at the same time modulating the subjective value of feedback as processed in the striatum.

Keywords Basal ganglia · Motivation · Feedback · Reward

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S. DePasque Swanson (✉) · E. Tricomi
Department of Psychology, Rutgers University, Newark, NJ 07102, USA
e-mail: sswanson@psychology.rutgers.edu

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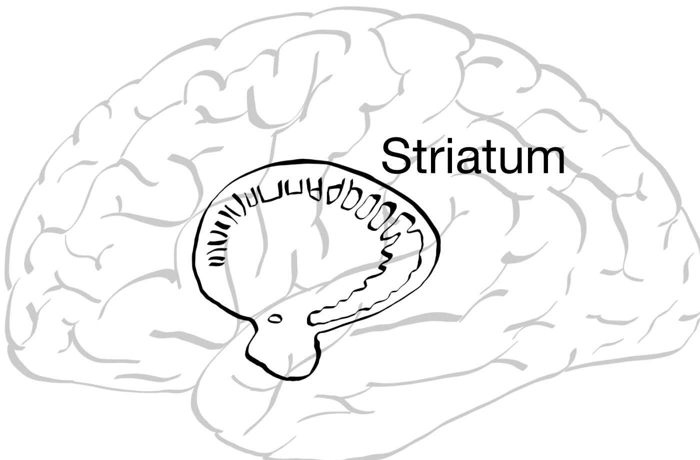
Feedback about one's performance is a valuable tool for facilitating learning. It is used by educators, mental health professionals, physicians, and others to teach new skills, encourage adaptive behaviors, and promote healthful lifestyle changes. However, the context in which feedback is received can influence how successfully it motivates learning. For example, negative feedback more effectively facilitates learning when individuals focus on increasing their knowledge, rather than on demonstrating their abilities (Cianci, Schaubroeck, & McGill, 2010), but is less effective when individuals are experiencing stereotype threat (fear of confirming a negative stereotype by performing poorly; Mangels, Good, Whiteman, Maniscalco, & Dweck, 2011).

Contextual factors that influence learning may do so through their effects on feedback processing in the striatum. As the input region of the basal ganglia, the striatum has been heavily implicated in reward processing and the motivation of reinforcement-driven behaviors (Balleine, Delgado, & Hikosaka, 2007; Robbins & Everitt, 1996; Shohamy, 2011). Activation in the striatum is greater following rewarding outcomes than following negative outcomes and appears to scale with prediction error, which is the discrepancy between expected and received rewards (O'Doherty, 2004; Schultz & Dickinson, 2000). During feedback-based learning, in which participants learn to make appropriate choices through trial and error, performance-related feedback engages the striatum in an analogous manner, even in the absence of extrinsic rewards (e.g., Daniel & Pollmann, 2010; Satterthwaite et al., 2012; Tricomi, Delgado, McCandliss, McClelland, & Fiez, 2006). Striatal responses to positive and negative outcomes are associated with learning to adapt behavior to maximize rewards (e.g., O'Doherty et al., 2004; Pessiglione, Seymour, Flandin, Dolan, & Frith, 2006; Schönberg, Daw, Joel, & O'Doherty, 2007), and proper functioning in this region is required for feedback- or reward-based learning, as evidenced by lesion studies and neuropsychology research (e.g., de

Effet de la **rétroaction positive** sur le cerveau

Étude de DePasque et al.



Activation du système de **récompense** et augmentation de la **dopamine**

Réussite ⇒ rétroaction positive ↑ ⇒ striatum ↑ ⇒ dopamine ↑ ⇒ sentiment de plaisir/satisfaction ↑ ⇒ **motivation**

Réussite ⇒ **motivation**

Principe 3
Maximiser la rétroaction

Comment ?

Stratégie 1
Offrir un maximum de rétroaction

Stratégie 2
Viser un équilibre entre rétroactions positive et nég.

Effets de la rétroaction

Rétroaction **positive** ↑ ⇒ satisfaction ↑ + correction d'erreur ↓

Rétroaction **négative** ↑ ⇒ correction d'erreur ↑ + satisfaction ↓

Donc équilibre

Principe 3
Maximiser la rétroaction

Comment ?

Stratégie 1
Offrir un maximum de rétroaction

Stratégie 2
Viser un équilibre entre rétroactions positive et nég.

Stratégie 3
Privilégier la rétroaction immédiate

Stratégie 4
Privilégier la rétroaction élaborée et axée sur la tâche

Synthèse

Principe 1
Activer à plusieurs reprises

Principe 2
Espacer les activations

Principe 3
Maximiser la rétroaction