Neural correlates of performance after learning in dual or single task environments.

A long-standing hypothesis in memory research suggests that multiple separate learning and memory systems exist. These systems are anatomically distinct and support specific cognitive mechanisms. Two systems that are often defined in opposition to each other are a declarative memory system, thought to depend on the medial temporal lobes (MTL), and a procedural learning system, thought to depend on the striatum (or basal ganglia). Declarative memory encompasses memory for facts and events, whereas procedural learning encompasses a variety of motor, perceptual and cognitive skills. Extensive research in patients with neurological damage has elucidated how damage to one of these systems affects different types of learning and memory. In healthy humans both systems are available to support learning and memory in parallel, but other factors may instead influence functioning. Multi-tasking is one factor that may influence how the brain supports learning and memory, and differential engagement of neural systems may affect what information is learned and how this information can be applied to novel problems and learning situations.

In a set of behavioral and functional magnetic resonance imaging (fMRI) studies we examined how dual task conditions (learning with distraction) affected learning performance and the types of knowledge acquired (Foerde, Knowlton & Poldrack, 2006; Foerde, Poldrack & Knowlton, 2007). We used a probabilistic learning task called the weather prediction task, which has been used extensively to investigate incremental, feedback-based learning, a type of procedural learning. In this task, participants are required to learn to predict whether it will be rainy or sunny based on a set of four cues. Between one and three of the four cues appear on each trial and participants indicate whether they think it will be a sunny or rainy outcome. Feedback is provided on each trial allowing participants to improve performance. Cues are probabilistically associated with sun and rain outcomes, such that feedback on an individual trial is not completely informative. Instead, participants must learn which outcome the cues predict most of the time, making it necessary to integrate across multiple trials. Because there is no consistent mapping between cues and outcomes, it is thought that explicit encoding of the cue-outcome relationships is not helpful and not critical for performance. However, it has also been shown that healthy participants develop such knowledge about the task structure in addition to being able to make predictions about the weather. Following learning, participants are asked about task structure in a number of ways that require increasing flexibility of knowledge. They are asked to assess the overarching probability of outcomes associated with cues and also to indicate which cues would be most likely to have appeared on trials given a specific outcome. That is, participants are asked to use what they learned differently than in the learning context.

It has been suggested that incremental, procedural learning may be relatively automatic and therefore robust in the face of interference. We tested this by asking participants to learn either with or without concurrent distraction. Distraction was introduced by playing high and low pitched tones and requiring participants to keep a running count of high tones while performing the weather prediction task (dual task condition) or while ignoring the tones and performing the weather prediction task (single task condition).

Interestingly, learning under single and dual task conditions allowed participants to perform the weather prediction task equally well, consistent with the view that task performance can be supported by a procedural learning system. However, learning under single task conditions led to significantly greater flexibility of knowledge about task structure than did learning under dual task conditions. Thus, learning conditions affected the quality of what was learned.

Using fMRI, we assessed brain activity during performance of the tasks learned under single and dual task conditions. After learning under dual task conditions, performance was associated with activity in the striatum, whereas performance was associated with activity in the MTL after learning under single task conditions, indicating that learning under different conditions led to different neural systems supporting performance. Additionally, the amount of flexible knowledge an individual had about the task was related to MTL activity only after learning under single task conditions.

In summary, learning under dual task conditions did not interfere with the ability to perform the primary weather prediction task, but did interfere with development of more flexible knowledge about the task. Although performance of the weather task was similar after learning under single and dual task conditions, performance was associated with different neural systems depending on learning conditions.

These results have a number of critical implications for education and development. As one would expect, learning conditions are critical for the quality of knowledge that is acquired. But perhaps less obvious, it is critical to assess learning in several ways. Looking only at performance on the primary task would not reveal the differential quality of learning, nor that distinct neural system supported performance. Consistent with this idea, another study demonstrated that neural activity in the MTL during a learning phase predicted later ability to flexibly apply learning (Shohamy & Wagner, 2008). As with the weather prediction study described above, monitoring one's performance on the main learning task online does not reveal how this knowledge can be applied in a novel choice situation.

<u>Further questions about multitasking effects on learning and memory</u>

A number of questions remain unanswered. There may be benefits to learning under dual task conditions. For example, performance may remain less vulnerable to interference or be more durable over the long term as a consequence of being less flexible and relying on the striatum rather than the MTL.

Some preliminary studies addressing the question of durability over time have not yielded strong support for the idea that learning is more durable after dual task learning (Foerde, Knowlton, & Poldrack, in preparation). One possibility is that single task learning allows additional flexible knowledge to be acquired while procedural learning is also being acquired. Although we could not directly assess this in our study, we did not see differences in activity in the striatum during learning under single and dual task conditions, allowing the possibility that procedural learning representations were developed, but not applied, in the single task.

We have not assessed whether later performance is differentially sensitive to dual task interference. However, if a habitual representation develops in parallel under single task conditions, dual task conditions may not better prepare for future multitasking conditions. Further research on the costs and benefits of multitasking will address these questions.

A broader question is whether becoming better at multitasking in general will allow additional flexible knowledge to develop when learning under dual task conditions. If general multitasking and task switching abilities improve with consistent exposure to such learning environments, learning under dual task conditions may not be different than single task learning and may not have the consequences for quality of learning we observed in healthy young adults. In order to assess this, it is critical to test the ability to flexibly apply knowledge beyond a learning situation to novel contexts. This has direct implications for how learning is assessed in educational settings and across development. In order to fully appreciate consequences of multitasking, it is important to probe the quality of learning outside the learning context.

A number of studies have assessed training of executive functions in childhood and it may be the case that some abilities are more easily trained than others (e.g. Thorell, Lindqvist, Bergman, Bohlin, & Klingberg, 2008). It is possible that some cognitive functions are more malleable across development, but that no amount of practice can overcome the detrimental effects of multitasking on some types of learning. Extending existing training interventions to assess the effect on different memory functions beyond executive functions would therefore be of interest in order to assess the consequences of multi tasking.

Broader future directions

Currently, it is not well understood how different memory systems interact to support learning and behavior. Memory systems may function independently in parallel, but it has also been suggested that there is competition between systems (Poldrack et al., 2001) and that such competition may be mediated through the prefrontal cortex (Poldrack & Rodriguez, 2004). If the same processes engaged during multitasking are also involved in mediating the engagement of memory systems during learning and performance, a multi tasking environment could have profound effects on the quality of learning.

Moreover, there is accumulating evidence of extensive changes in gray and white matter in frontal and striatal regions throughout adolescence (e.g Sowell et al., 1999; Ofen et al., 2007; Casey, Galvan, & Hare 2005). Tracking the contribution of different learning systems to performance across development along with assessments of structural changes, would be valuable in order to understand whether development in a multitasking environment alters the fundamental balance between learning systems. This could address the possibility that multitasking has lasting consequences for how different learning mechanisms are deployed.

An important contribution from cognitive neuroscience could be application of tasks targeted at assessing specific learning and memory mechanisms and the neural mechanisms underlying their functioning. Paired with recent advances in brain imaging methodologies such approaches could provide a valuable addition to understanding the development of learning and memory systems and how this interacts with learning environments.

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