THE EFFECT OF COGNITIVE LOAD ON THE INTERACTION BETWEEN THE DECLARATIVE AND PROCEDURAL MEMORY SYSTEMS

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I. Introduction

Human memory is characterized by multiple memory systems. Two of the most widely recognized of these are called the procedural (or implicit) and declarative (or explicit) memory systems. The interaction between these two systems in humans has received little attention in the literature historically. Recently, however, this trend has changed, with several new studies being published in the last several years.[1,2] The current project investigates whether the addition of a concurrent memory task facilitates an increased ability to switch from the declarative to the procedural system in order to achieve optimal accuracy while engaging in a categorization task that requires both declarative and procedural strategies. In order to test the effects of adding a memory task while engaged in a categorization task on the interaction between the declarative and procedural system, a behavioral experiment was used where subjects engaged in a memory and categorization task concurrently on a computer. Past research has shown that humans are particularly poor at switching between the procedural and declarative memory systems on a trial by trial basis, with a 12% success rate.[3] This poor performance led to the current hypothesis with the aim of improving this success rate.

1 M.A. Erickson. "Executive attention and task switching in category learning: evidence for stimulus-dependent representation." *Memory & Cognition* 36 (2008): 749–61.

2 F. Gregory Ashby and J. Matthew Crossley. "Interactions between declarative and procedural-learning categorization systems." *Neurobiology of Learning and Memory* 94 (2010): 1–12.

3 Ibid.

II. Background

Declarative memories are those accessible to conscious awareness. Typically this includes working memory, episodic memory, and often also semantic memory. Working memory is the ability to maintain and manipulate limited amounts of information during brief periods of cognitive activity. It is heavily used in reasoning and problem solving, and because of this, it is often associated with a wide variety of cognitive tasks.[4] The declarative system excels at generating and testing hypotheses, and if there is a relatively simple rule that governs a task, the declarative system will often identify it. As when learning a recipe, or following an instruction manual.

Procedural memories are the memories of skills that are learned through practice.[5] Traditionally these memories have been motor skills, for example while perfecting a golf swing, or in the playing of a musical instrument. There are several signatures of procedural learning that make it qualitatively different from learning that is mediated by declarative memory systems. First, there typically is little conscious recollection or even awareness of the details of procedural memories. Second, procedural learning is slow and incremental and it requires immediate and consistent feedback.[6] For example, learning to ride a bike can be a slow process that requires constant feedback, but once learned, the skill itself is often impossible to verbalize.[7]

The distinct neural substrates of these two systems are worth noting. The basal ganglia, a deep brain structure, are largely thought to mediate procedural learning, whereas the declarative system is largely thought to be mediated within the prefrontal cortex, with ties to the medial-temporal lobe as well.[8] The importance of these distinct neural systems becomes apparent when one considers the fact that these two systems interact in significant ways and can operate independently of one another as they occur in physically distinct areas of the brain.[9]

Consider a behavioral task that requires a certain behavioral output: for example, a key press on a keyboard. That behavior is generated by the motor cortex, but how does the motor cortex "decide" which button to press? One possibility is that the declarative system instructs the motor cortex on which action to take.[10] For example, when following a recipe, the correct response might be generated within the prefrontal cortex and sent to the motor cortex. On the other hand, when engaged in a procedural task, such as riding a bike, the procedural system might inform the motor cortex on what to do with your hands in order to turn. These sorts of actions are relatively simple for most people when one system or the other is engaged. However, when presented with a task that requires both systems to be active at the same time, something interesting happens. As it turns out, the declarative system actively interferes with the procedural system's ability to express itself, so that even if the procedural system were to "know" the correct answer, it would not be able to relay that information to the motor cortex.[11] The purpose of the current study is to investigate whether adding a distractor to the declarative system in the form

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4 F. Gregory Ashby and W. Todd Maddox. "Human Category Learning." Annual Review of Psychology (2005): 56, 1.

5 Ibid., 2.

6 Ibid.

7 Ibid.

8 C.A. Seger, C.S. Dennison, D. Lopez-Paniagua, E.J. Peterson, and A.A. Roark. "Dissociating hippocampal and basal ganglia contributions to category learning using stimulus novelty and subjective judgments." *Neuroimage* 55 (2011): 1739–1753.

9 F. Gregory Ashby. "Human Category Learning, Neural Basis." *In H. Pashler (Ed.), The Encyclopedia of the Mind.* Thousand Oaks, CA: Sage Publishing (in press).

10 Ibid.

11 Ashby and Crossley, "Interactions between declarative and procedural-learning."

of a concurrent memory task will allow for greater expression of the procedural memory system when engaging both declarative and procedural systems.

III. Methods

In order to address the hypothesis that the addition of a memory task would facilitate an improved ability to switch memory systems, the current study used an experiment that engaged participants in a category learning paradigm in which both procedurally and declaratively learned stimuli were presented randomly on a trial by trial basis. A memory task that preceded each category stimulus was added as a manipulation in order to further engage the declarative system, with the intention of diminishing its ability to interfere with procedural memory expression due to limited cognitive resources.

In a typical categorization paradigm, participants are shown a fixation cross followed by a stimulus which varies on at least one dimension (i.e. orientation), and are required to indicate a category affiliation by pressing a corresponding button on a keyboard.[12] Feedback is then given indicating whether they were correct or incorrect. This procedure is repeated, typically hundreds of times in order to allow for learning. In the current experiment, stimuli were circular sine wave gratings that varied on two dimensions, spatial frequency (i.e. bar thickness) and orientation (i.e. bar angle). These stimuli were divided into either a declarative or a procedural group. Stimuli in the declarative group were distinguished as either category A or category B by a simple one-dimensional rule of spatial frequency. That is, thick bars were category A, and thin bars were category B (examples of these stimuli can be seen in the appendix).

Stimuli in the procedural group were distinguished as either category A or category B by a two-dimensional rule that required participants to take into account both spatial frequency and orientation. An equation governed this rule, such that if the spatial frequency value was greater than orientation value, then it was category A. Otherwise, it was category B. For example, a given stimulus might have a spatial frequency value of 45 and an orientation angle of 30 degrees. In this case, since the spatial frequency is larger than the orientation angle, this stimulus would be labeled as an "A."

A manipulation, intended as a distractor for the declarative system, in the form of a simple memory task was added. Subjects were presented with a word corresponding to the numbers 1 through 10. On the subsequent trial, they were presented with another word and were required to indicate whether the currently displayed word is the "Same" or "Different" from the word they saw on the previous trial. For example, in the first trial, the word "six" is presented. On the next trial, the word "ten" is presented. In this case, since "six" and "ten" are not the same, the correct response would be to indicate that the words are "Different." This task was chosen based on previous work that has shown that such a task selectively impairs declarative learning but not procedural learning.[13] As such, we hypothesized that this task would lessen the declarative system's ability to interfere with procedural expression.

In order to help subjects switch between systems, a colored cue was provided on each trial. A blue outline indicated a declarative stimulus, in which only spatial frequency was relevant, and a green outline indicated a procedural stimulus in which both spatial frequency

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12 Ibid., 4

13 E.M. Waldron, and F.G. Ashby. "The effects of concurrent task interference on category learning: evidence for multiple category learning systems." *Psychonomic Bulletin & Review* 8 (2001): 168–76.

and orientation were relevant. After training subjects on stimuli, we introduced a button switch to the categorization task in which the response location for each category was switched so that instead of responding with "d" for category A and "k" for category B, they now responded with "d" for category B and "k" for category A. Previous literature on category learning has shown that button switch interference selectively impairs procedural but not declarative expression, such that accuracy on declarative stimuli is unaffected, but accuracy on procedural stimuli suffers as a result.[14]

IV. Results

Our results showed approximately 80% accuracy on the "Same" / "Different" memory task, which is important to note because it indicates subjects were actively engaged in the manipulation. Accuracy for declarative stimuli achieved asymptote at roughly 70%, which is generally lower than performance on a declarative categorization task without a concurrent cognitive task, but was in line with previous work and expectations.[15] Interestingly, accuracy for procedural stimuli was essentially at chance. This result contradicts our predictions and indicates no evidence of procedural expression, and it is discussed below.

V. Discussion

The current findings show no evidence for procedural expression with accuracy rates around 50%. A possible account for these results is that the increased activity in the prefrontal cortex due to the concurrent memory task led to an increase in the interference between the declarative and procedural systems, as opposed to the decrease in interference that was predicted. If this were the case, it would explain our results by accounting for the chance accuracy on procedural stimuli.

These results, while unexpected, may offer further support for the competitive nature of the declarative and procedural systems with regards to procedural knowledge expression. In order to better understand the nature of this competition, it is important to distinguish between expression of knowledge and acquisition of knowledge. Previous research on category learning has shown that both systems learn concurrently in a categorization task.[16] While past evidence suggests that, in the current study, procedural knowledge was gained during the categorization task, the inability to express that knowledge, likely due to interference from the declarative system, points to an interesting distinction between knowledge acquisition and expression. Thus, one possible interpretation of these results is that the declarative system plays a critical role in mediating procedural expression as opposed to skill acquisition such that while activity in the prefrontal cortex is high, the likelihood of being able to express relevant knowledge that has been learned procedurally drops.

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14 W.T. Maddox, B.D. Glass, J.B. O'Brien, J.V. Filoteo, and F.G. Ashby. "Category label and response location shifts in category learning." *Psychological Research* 74 (2010): 219–36.

15 Ibid.

16 J. Matthew Crossley and F. Gregory Ashby (under review). Procedural Learning During Declarative Control.

Further work is required in order to investigate the precise nature of these interactions as well as methods that can be used to overcome this limitation. Another interesting line of research might explore ways to distinguish between knowledge acquisition and expression.

Appendix

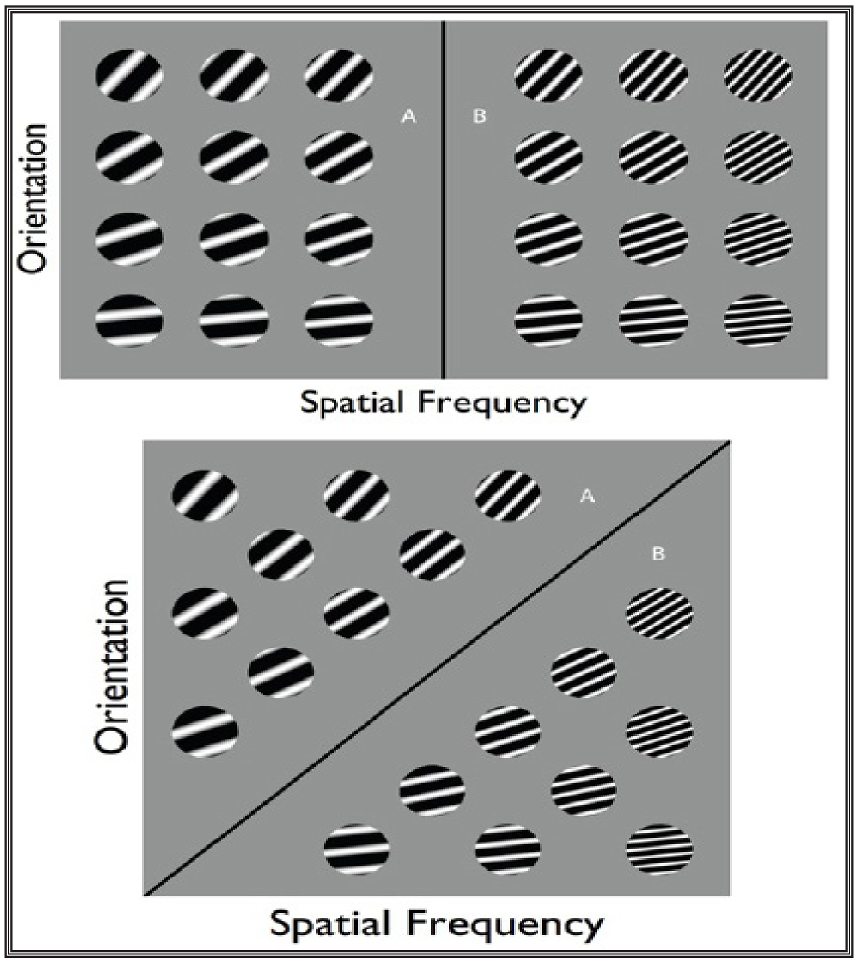

Figure 1. Circular sine wave gratings composed of two dimensions, spatial frequency (line thickness) and orientation. The top segment is divided based on spatial frequency. The bottom segment is divided by integrating information from both dimensions (spatial frequency and orientation). This division is governed by an equation where the category boundry is x=y (if spatial frequency is greater than the orientation, then it is one category, whereas if orientation is greater than spatial frequency, it is another category).

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