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The Effects of Sleep on Implicit and Explicit Motor Skill Sequence Learning and Task Integration: A Literature Review and Pilot Study

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B S J

ABSTRACT

Various studies have been conducted on implicit (unconscious) and explicit (conscious) motor skill sequence learning by means of serial reaction time tasks in order to understand the two learning systems in the human brain (Schimidtke & Heuer, 1996; Stickgold, 2003; Ivry, 2003). Although the effects of implicit learning, bimodal integration of tasks (task integration) and sleep on implicit motor skill learning have been explored in various combination, all three have yet to be studied in one research design. We conducted a pilot study in an attempt to investigate how these three mechanisms contribute to the implicit learning phenomenon. Results revealed that explicit sequence learners have overall quicker reaction times and more accurate responses. We also found a lower percentage of implicit learning during the less complex sequence tasks. Subsequent tests found that sleep had a significant effect on explicit sequence learning, but no significant effect on implicit sequence learning.

INTRODUCTION

Neuroscientists have developed literature concerning implicit (unconscious) and explicit (conscious) motor skill sequence learning in order to understand the two learning systems in the human brain (Schimidtke & Heuer, 1996; Stickgold, 2003; Ivry, 2003). Although the effects of sleep on the implicit bimodal integration of tasks (task integration) and implicit motor skill learning have been explored in various combinations, all three functions have yet to be studied in one research design. Our research team conducted a number of pilot studies in an attempt to investigate how these three mechanisms contribute to the implicit learning phenomenon.

Before we could begin pilot studies, our team performed a review of Neuroscience literature exploring the implicit and explicit learning systems. Subsequent to our neuroscience literature review, we examined existing research investigating the neural architecture that allows for these systems to function. Simultaneously, our team considered the literature on task integration and considered existing literature on the biological elements of human performance. Our research goal was to differentiate the biological constituents that directly influence the ability of the two learning

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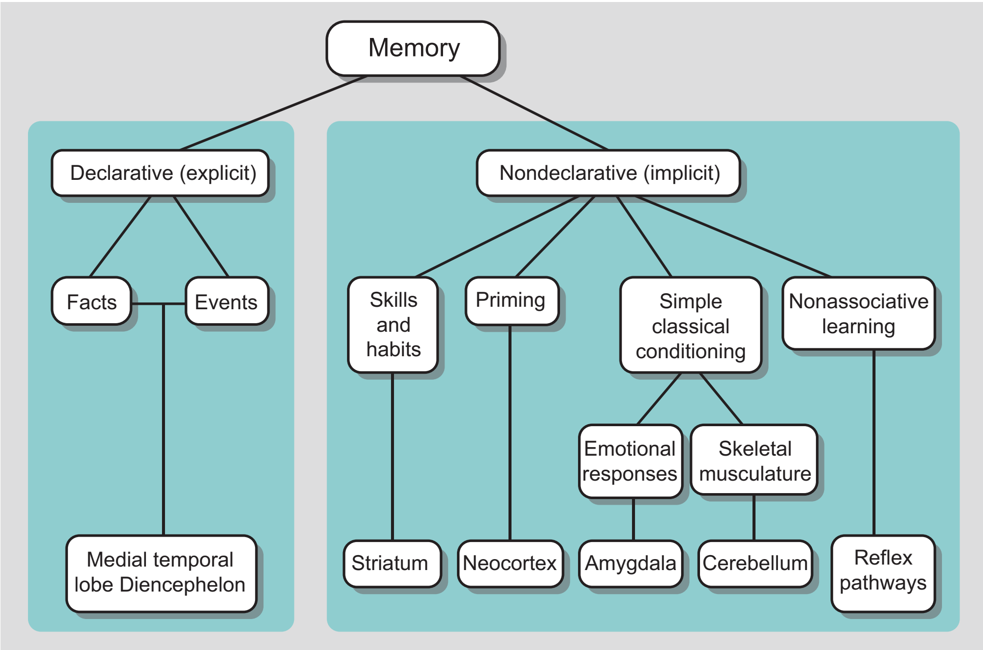

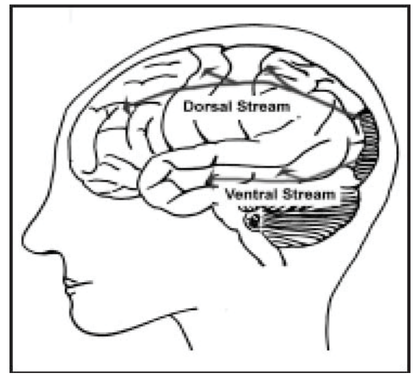

Figure 1: Memory Systems (left).
Figure 2: Dorsal and Ventral Pathways (top).

systems to function (e.g. sleep benefits on implicit and explicit learning). Ensuing, we developed a research question; how does sleep affect implicit motor skill learning and how are task integration techniques and different brain modalities utilized in the implicit learning process?

Implicit and Explicit Learning

Cognitive Neuroscientists theorize that the human brain consists of two independent learning systems: the implicit learning system and the explicit learning system. To commence our study, our research team utilized the *Cognitive Neuroscience: The Biology of the Mind* text in order to gain an overview of the fundamentals of learning and memory. We explored the operational properties of learning and memory to offer ourselves a basis for comprehending the two learning systems in the brain.

To distinguish learning from memory, Gazzaniga, Ivry, & Mangun (2002) define learning as the process of acquiring knowledge and memory as the result or the retrieval of the learning process. Gazzaniga *et al*. introduce us to two categories of long-term memory: declarative memory (explicit memory) and non-declarative memory (implicit memory). Declarative memory is the portion of memory that stores facts. In contrast, our research was concerned with a type of non-declarative memory known as procedural memory, which is the segment of memory responsible for the unconscious maintenance of learned procedures. The difference between implicit and explicit memory is that implicit memory is the unconscious process by which we retain information, whereas with explicit memory we are aware that we are retaining the information. Explicit memory is the consolidation of facts or events and implicit memory is a procedural, perceptual representation, classical conditioning, or non-associative way of learning. (see Figure 1).

Our team's next goal was to investigate existing studies on sequence learning in order to investigate the second piece of our research question. During our review of relevant studies, we came across an article entitled *The Cognitive and Neural Architecture of Sequence Representation*. This article introduced us to the topic of sequence learning, it suggests that our brain contains two sequence learning systems: the dorsal learning system and the ventral learning system (Keele, Ivry, Mayr, Hazeltine, & Heuer, 2003). To visualize, the dorsal pathway of the brain travels superiorly from the posterior to the anterior regions of the brain. It extends from the occipital lobe, through the parietal lobe, and finally to the frontal lobe. Alternately, the ventral pathway streams inferiorly, from the posterior to the anterior regions of the brain, running from the occipital to the temporal lobes (See Figure 2).

Keele *et al*. (2003) propose that the dorsal learning system controls implicit learning and "uni-dimensional" (uni-modal) information. The article uses the example of driving a car while listening to a radio (visual-spatial and auditory information processing) to

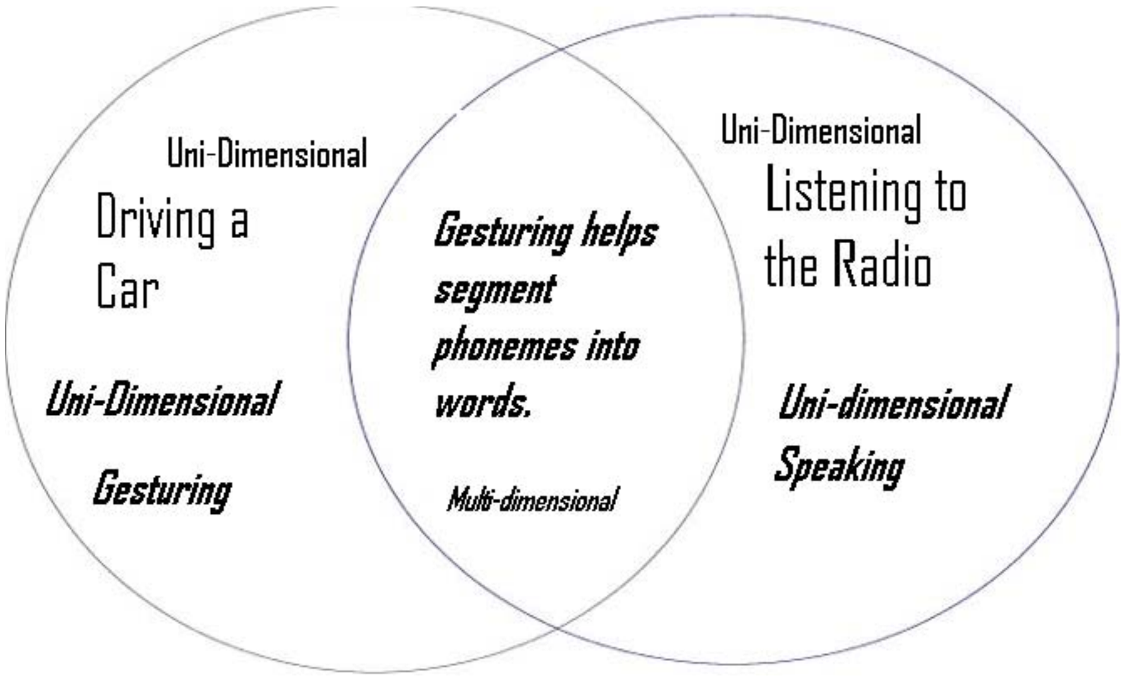

Figure3: Uni-Dimensional vs. Multi-dimensional

offer an example of a uni-dimensional type of learning activity. Because listening to the radio while driving a car is considered two separate tasks, they are seen as two separate dimensional activities, which therefore exist on two separate dimensions of your brain. Alternately, the ventral learning system can control implicit or explicit learning and is categorized as a "mulit-dimensional" or (multi-modal)[1] system.

Bringing our team to the third component of our research question, we find that multi-dimensional activities would include task integration. Task integration is the process by which we carry out two different tasks that exist on two different dimensions of the brain, but are associated with one another; or rather the tasks are able to cross dimensions in our brain. To explain, the article uses the example of how manual gestures may help unite phonemes to create words. A person is able to associate two different actions (e.g. hand gestures and speech) in order to create one function (Keele *et al*.) (see figure 3). Even though gesturing and speaking are two separate activities, gesturing can advance speech. Hence, the speaker's message is optimally conveyed through the integration of the auditory and visual procedures.

[1]Modality-The term dimension is used interchangeably with the term modality, thus a multi-dimensional task can mean the same thing as a bi-modal or multi-modal task.

Studies Involving Implicit and Explicit Sequence Learning

The aforementioned article was a powerful resourceful because it introduced us to the fundamental tool to test for implicit motor skill learning and task integration: serial reaction time tasks (SRT task). SRTs have been utilized in numerous studies to measure implicit and explicit sequence learning (Heuer *et al*. 1996; Stickgold *et al*. 2003; Ivry *et al*. 2003). To implement these tasks in our pilot studies, we asked our participants to respond as quickly and as accurately as possible to the stimuli presented in the experiment. After a participant responds to each block or interval within the study, reaction times (RTs) are recorded. When the experiment finished, we analyzed the aggregate reaction times, such that we are able to infer whether the subject's task taking speed increased over time. Acquiring a greater amount of speed within the RT tasks signified learning. Because many of the RT tasks incorporate a sequence within the visual or auditory stimuli presented, increasing speed can be a sign of learning the sequence. The way we can tell whether or not a subject is actually learning the sequence rather than just learning the task is by implementing random blocks into the experiment, so that if participants improve their RTs during the random blocks in the experiment, that would suggest that they are merely learning the task and not the sequence. On the contrary, if the participants' speed decreased during the random blocks, it suggested that they were learning the sequence.

Task Integration

As previously mentioned, one multi-dimension learning activity that has been explored is know as task integration (Schmidtke & Heuer, 1996). Schmidtke *et al*. (2006) suggest that during a dual-task experiment, in this instance, a visual-spatial and an auditory dual-task, the two tasks are considered as a single unit. To clarify, the primary task of responding to sequential visual stimuli, for example, and the secondary task of counting sequential tones "are not kept separate functionally but are treated as a single sequence." This particular article found that the participants not only got slower while performing on the random blocks within either the visual or auditory domain, but they also got slower on the secondary task while responding to the random stimuli for the primary task. This finding supports the theory that tasks can be performed across modalities in that they are able associate themselves to one another.

Schmidtke *et al*. did an effective job in focusing on one particular aspect of implicit and explicit learning. This article was beneficial in incorporating task integration into my understanding of cross-dimensional learning and acquisition. Because this article was pertinent to my understanding of my research question, I thought that it could have been more connected to real world concepts. The authors merely addressed task integration without really explaining what it has to do with other models of knowledge. Although I found the previous research article on neural architecture complex, I felt that it provided more of a connection to various concepts and perceptions within the field.

MATERIALS AND METHODS

The study conducted by Sumn was a motivation for my study, and in turn, my study had a similar design. We recruited participants with fliers and offering a small compensation for the participants' time. To visualize the set up we used to administer the study, we had a computer screen that sat on a table in front of the participants, a keypad that rested on the table on the left of the participant, and two key pedals that sat on the floor in front of the participants' feet.

Specifically, the participants were told that we were conducting a dual-task experiment because we wanted to see how people can do two things at one time. We explained that it was an experiment that would take a lot of concentration on their parts. To explain the mechanics of the experiment, I had the subjects visualize four boxes aligned horizontally on the computer screen in front of them. I told them that X's would pop up into each of the boxes, one right after another. Their job was to respond to the X's using the fingers on their left hand. They used all of their fingers except their thumb to respond to the visual stimuli while concurrently responding to three different pitch tones with their feet. The subjects were told to respond to all of the visual stimuli on the screen and to respond to the high pitch tones with their right foot, the low pitch tones with their left foot, and to ignore the medium pitch tones. Finally, we told the participants to respond as quickly and as accurately as possible to the stimuli presented. We offered the participants a demonstration of the experiment, so that they could concentrate on the complexity of the tasks. The experiment lasted in length about thirty to forty-five minutes, depending on how quick the participants responded to the stimuli and how many blocks were in the experiment.

We recorded the participants' reaction times for each block as well as the number of errors in their responses made with their hands and feet in response to the visual and auditory stimuli. The visual and auditory stimuli were presented to the participants in a sequence at which their fingers and feet were responding. We created a complex dual task in order to divert the participants' concentration to the task at hand and away from the sequence within the visual and auditory stimuli. The purpose of creating a sequence was to measure the amount of learning that occurs over the course of several blocks within the experiment. In order to control for implicit learning, we had to make sure that the participants were not aware that the sequence existed, hence the unconscious learning of the sequence. From the data we collected, we viewed whether the participants were learning the sequence by looking at whether they obtained a lower reaction time and a lower number of errors throughout the blocks within the experiment. Also, we asked them questions at the end of the experiment, where

Pilot Study #	Visual and Auditory Sequence	# of Stimuli in Sequence	# of Blocks	Participant Initials	Amount of Awareness
1	3,1,2,1,4,2 l,l,h,h,l,h	6	10	rbi, jls, pda, awa, ela, ecs, emc	high
2	3,2,4,3,2,4,1,2,4,1 h.l.h,h,l,h,l,l,l,h	10	10	ega	high
3	3,4,2,3,4,3,1,2,4,1 h,l,l,h,l,h,l,l,h,h	10	11	jla,	high
4	4,1,3,4,2,1,3,4,2,1,4,3,1,2 h,h,l,l,h,l,h,l,h,h,l,l,h,l	14	11	kaa, jps, rtt, jeh, pga, hpa, pad, rjp, jan	mid-high
5	4,1,3,4,2,1,3,4,2,1,4,3,1,2 h,h,l,l,h,l,h,l,h,h,l,l,h,l	14	15	lmt, nss, tja, der, joa, pap, nmx	mid-high

Table 4: Pilot Study Modifications

one asked whether they were aware that a sequence existed in the experiment. If they responded with "no," and they improved over time, then we knew that they were implicitly (unconsciously) learning, whereas if they reported that they were aware of a sequence, we knew they were explicitly learning. In order to find out whether they were using task integration techniques, we asked them whether they had a specific strategy of completing the experiment. If the participant said that they responded to both the visual and auditory stimuli simultaneously, then we could infer that they were treating the dual task as a single integrated task. We were not able to test the sleep benefits of implicit learning because most of the participants were aware of the sequence, therefore we were not able to test for implicit learning.

Modifications

During the beginning of the experiment we noticed that a large proportion of participants' were aware of the visual sequence in the experiment. For this reason, my research changed from conducting studies to find an answer to my research question (a qualitative research experiment) to finding out the effectiveness of a new research design (a quantitative research experiment). I conducted a total of five different variations to our specific experiment. These variations consisted of adding in a greater number of random blocks within the experiment in order to distract the subject from discovering the sequence in the stimuli presented. Also, we altered the visual and auditory sequences throughout the pilot studies to in order to make sure that the sequence was inhibiting consecutive finger tapping rhythms in order to make the sequence more difficult. Additionally, we increased the number of stimuli in the sequence so as to make the sequence more challenging to determine (see table 4).

RESULTS/ANALYSIS

Through a mean value comparison, we observed that explicit sequence learners have overall quicker reaction times and higher accuracy in responses. Thus, participants performed faster and more accurately when they were conscious of the sequence. Additionally, a lower percentage of implicit learning occurred during the less complex sequence tasks. Moreover, subsequent tests found that sleep had a significant effect on *explicit* sequence learning, but no significant effect on *implicit* sequence learning.

DISCUSSION

My initial expectation for this research project was to work with a group of researchers and administer an experiment to several participants in order to find the data necessary to answer my research question. As the study began to unfold, I learned that my work began the process of discovering the effects of sleep on the implicit motor skill learning. Moreover, further studies explored how task integration techniques are utilized in this learning process. The results revealed that participants performed at a faster speed with more accuracy when utilizing their declarative or conscious memory. Likewise, when using their procedural or unconscious memory system, the participants did not perform as well. Observing a lower amount of implicit learning during less complex tasks suggests that the procedural or unconscious memory system is utilized for more complex procedural tasks. The findings from this study suggest that the implicit and explicit learning of patterns can be examined to understand how the human mind consciously and unconsciously retrieves information.

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