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Confirming the Dynamic Model of Working Memory

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Abstract

The study of working memory capacity has resulted in a plethora of research that has obsequiously polarized professionals into two groups: one that favors a static model of working memory and the other, a dynamic model of working memory. This paper analyzes three areas related to working memory capacity to help confirm the dynamic model of working memory. A neuroanatomical analysis of an individual's brain undergoing a working memory task illustrates converging brain-centers that process information from multiple modalities, thereby, bolstering the dynamic model. Through a careful consideration of the role of inhibitory control on working memory capacity, an argument is made to dismiss the claim because there is no cross-over effect observed from explicit memory strategies, working memory capacity cannot increase. Additionally, this paper considers alternative methods which could lead to increases in working memory capacity, such as utilizing broad training programs to target all components of working memory.

Keywords: dynamic, memory, model, working memory

Introduction

In this highly technical era when people are incessantly bombarded with new information, the ability to retain and manipulate information in working memory is of utmost importance (Klingberg, 2009, p. 45). Working memory is a psychological construct used to describe a multi-component, limited-capacity cognitive system that processes transient information for the purpose of problem solving. Working memory comprises four fundamental components: phonological loop (sound processing), visuo-spatial sketchpad (visual processing), central executive (control of cognitive processes), and episodic buffer (linking of information to form an informational unit from incoming stimuli) (Conway, Jarrold, Kane, Miyake, & Towse, 2007, p. 110). In essence, working memory describes a relationship between short term memory and one's capacity to manipulate transient information. Working memory first gained noticeable attention in the 1970's through the work of Alan Baddeley, who redefined the construct and created a renewed interest in its research. Since that time, many research experiments were conducted on working memory while interest about its characteristics and features continues to grow.

Even among non-psychologists, the growing interest in working memory is evidenced by the development of an overwhelming number of memory exercises, some of which purporting to facilitate the improvement of working memory capacity. A myriad of such exercises appearing as games, have surfaced in the daily newspaper – Sudoku, crossword puzzles, word searches. Some individuals consider these exercises beneficial for the brain in strengthening memory, much like strengthening a muscle in the body; however, are the characteristics of working memory

analogous to that of any body muscle? While several studies conducted over the last decade suggest the possibility of improving working memory capacity through training, other similar studies have shown no significant correlation and dismiss the analogy between working memory training and muscular training (Nutley et al., 2011; Rouder et al., 2008, p. 5979). These studies affirm that working memory capacity is immutable and cannot be significantly improved through conscious efforts.

These two bodies of research support either a dynamic model of working memory, that working memory capacity can increase, or a static model, that working memory capacity is fixed. While each side of this argument has presented statistical evidence supporting their respective position, a careful analysis of available research illustrates how several oversights in the research of the static model, lends itself to support the alternative. These oversights are revealed through an investigation of the neurological components of working memory, the relationship between working memory capacity and attention, and the quality and content of various assessment and training programs. The examination of research in these areas will help highlight the oversights in the static model. This supports the dynamic model's assertion that working memory capacity can increase.

Neurological Components of Working Memory

Localizing Working Memory

Through the use of brain scans and other forms of research, the nascent field of neuroscience has made great advances in the scientific understanding of

many components of the brain: magnetic resonance imaging scans give detailed, three-dimensional maps of the structure of the brain; functional magnetic resonance imaging and positron emission tomography scans reveal the functional components of brain processing during a variety of tasks; and electroencephalography scans illustrate the minute changes in brain activity as subjects undergo various activities. Because of these technologies, the field of psychology has advanced in its understanding of the basic characteristics of the brain. However, even with our exponentially increasing knowledge of the brain, there is still much to be learned and discovered.

Often results in neurological research are inconclusive but gain meaning through replicated studies with large sample sizes under randomized and carefully controlled conditions. Through this rigorous process, mental processes are found to be associated with specific regions of the brain and a territorial map of the brain is slowly constructed (Klingberg, 2009). Within this map of the brain, there are several regions that have been charted and identified with a particular aspect of memory, such as long term memory, muscle memory, or working memory.

Researchers have found that aspects of working memory are primarily located in specific regions on the cerebral cortex and the basal ganglia. The regions of working memory in the cerebral cortex have been localized to the parietal lobe near the posterior primary associative cortex and the upper and anterior parts of the frontal lobe, as shown in figure 1 (Klingberg, 2009, p. 51). These regions of the cerebral cortex are associated with the retention and manipulation of specific information during a working memory task. The other area activated, the basal ganglia, has been associated with the control and filtering of information into working memory (McNab & Klingberg, 2007, p. 105).

FIGURE 1. Regions of the Brain Activated during Working Memory Tasks (Source: Adapted from McNab, Leroux, Strand, Thorell, Bergman, & Klingberg (2008).)

Neuroanatomical Features Associated with Working Memory

Flow of Information. When a working memory task is performed, the associated regions of the cerebral cortex and basal ganglia become more activated as an increased volume of blood is transported into those regions to facilitate the increased rate of synaptic firing. Each of these areas, as they are activated, receive information for processing from other brain structures. Once the information has been processed, it is passed on to another region of working memory for further manipulation or temporary storage. These structures depend on one another for the processing of information and are vital for such cognitive abilities as problem solving and reasoning (Olesen, Westerberg, & Klingberg, 2003, p. 75). The information transferred through this system can be classified into two groups: visual information and auditory information (Blakemore & Frith, 2005).

Visual and auditory information are first processed at nuclei that only encode for one modality, but as the information is further processed, the two modalities eventually converge at points called multi-modal areas (Klingberg, 2009, p.52). These areas have a significant functional importance for working memory because they give insight into the neural implications of encoding and manipulating information.

Interpretations of Informational Flow Design. Several researchers have concluded that this converging design places severe limits on the capacity of working memory as multi-modal areas become bottle-necked by an overabundance of stimuli. Structural and cognitive limitations such as these support the static model of working memory, that working memory capacity is a permanent trait of an individual and a reliable measure of fluid cognitive ability (Myake & Shah, 1999). However, although a bottle-neck effect is witnessed, it does not necessarily indicate a hindrance on the developmental potential for working memory as much as it explains why working memory capacity is so low for most individuals. Recent findings continue to suggest that the brain is malleable and that it changes its structural makeup in response to stimuli; therefore, the dynamic model in its understanding of these multi-modal areas is more consistent with current brain structure research than the static model, which imposes limitations on future alterations in neural restructuring (Rakic, 2002, p. 65). Implications from studying the multi-modal areas suggest which areas of working memory might be intentionally trained to measure whether working memory can increase in capacity and efficiency. By knowing which areas of working memory need to be

targeted, researchers are able to determine which training exercises are useful. They do this by observing the density changes of the dopamine neuroreceptors in these cortical regions (McNab et al., 2009, p. 800).

Working Memory's Interaction with other Psychological Constructs

Relationship between Working Memory and Attention

Attention is the ability to concentrate and is closely associated with the development of the prefrontal cortex (Olesen, Macoveanu, Tegner, & Klingberg, 2007, p. 1048). Individual's prefrontal cortex is not fully mature until around age 20; as the prefrontal cortex develops, working memory capacity increases proportionally (Klingberg, 2009). This illustrates the importance of attention on working memory capacity because, according to Olesen et al. (2007), "in order to retain information in working memory during a delay, it is necessary to ignore interfering stimuli from the surroundings" (p. 1047). The component of attention that helps one to ignore interference is known as inhibitory control.

The Role of Inhibitory Control

Consistency of Working Memory Capacity. Since George Miller's (1956) findings fifty years ago, the capacity of working memory was believed to be limited to plus or minus seven pieces of information (p. 81). In 2001, new research suggested that working memory capacity can only process four pieces of information (Cowan, 2001, p. 80). However, even as the psychological understanding improves of the number of pieces in working memory capacity, there has not been evidenced an increase in working memory capacity in the general population. Many researchers consider this evidence, suggesting that the capacity of working memory is fixed. In addition, the proponents of the static model argue that although a person can learn strategies to increase the amount of information retained within each of the pieces or chunks of information, memory strategies do not increase the number of total chunks that can be processed by working memory at any one time (Blakemore & Frith, 2005). For example, through extensive training with strategies to chunk strings of numbers together, a person can process dozens of numbers; however, when that person is required to use working memory on a verbal task, the number of words remembered is much less. That person's number strategy does not actually enhance his or her working memory capacity. The strategy merely allows him or her to chunk one type of

information more efficiently with no cross-over effect (Gobet, 2000, p. 571).

Inhibitory Control on the Cross-over Effect.

Although many strategies and interventions have not shown a cross-over effect from working memory training, an important component often overlooked within these experiments is the role of inhibitory control on working memory capacity. "Studies that have combined inhibition and working memory demands within the same task have reported overlapping activation in a variety of frontal and parietal regions" (McNab et al., 2008, p. 2679). Inhibitory control and working memory are intimately related neurologically and need to be jointly considered when evaluating whether the capacity of working memory can increase through training exercises (McNab & Klingberg, 2007, p.103). Since inhibitory control overlaps in several neurological regions with working memory centers, it may be possible that through exercises designed to train inhibitory control rather than teach a singular memory strategy, there may be an observed cross-over effect.

Training Programs and Memory Strategies

Oversights of Assessments

To properly assess working memory capacity of an individual, researchers inform the development of a myriad of tests. Many of these tests focus on very specific working memory tasks, such as recalling a string of digits in order, as in the WISC-IV (Wechsler, 2003). These tests that are task-specific are frequently used to generalize the capabilities of working memory capacity. This can be problematic because working memory encompasses a broad set of tasks and focusing on a singular set of exercises can result in equivocal data. These data may suggest either higher working memory capacity through strategy-specific training, or lower working memory capacity resulting from an individual's isolated deficit. In order to properly evaluate working memory capacity, a set of exercises broad enough to evaluate all components of working memory needs to be developed.

Failing to assess all components of working memory, Rouder and associates devised an experiment to test whether working memory has a fixed-capacity. They developed a test that focused solely on the visuo-spatial component of working memory. Subjects were presented with squares of differing colors and asked to remember them and compare the colored squares against a test square. The distribution of the subjects' memory capacities measured in this test aligned in straight-line plots, which suggests that working memory does not vary; thereby, helping support the

static model of working memory through its supportive findings on the fixed-capacity of visual working memory (Rouder et al., 2008, p. 5979).

Although these findings are suggestive of a static model of working memory, they are far from conclusive. The experiment was too narrow to account for the several sub-components of the visuo-spatial component of working memory. Confirmed studies cite at least ten visuo-spatial sub-components which include: visual organization, planned visual scanning, spatial orientation, visual reconstructive ability, imagery generation ability, imagery manipulation ability, spatial sequential short-term memory, visuo-spatial simultaneous short-term memory, visual memory, and long-term spatial memory (Vandierendonck & Szmalec, 2009, p. 122). Owing to the complex nature of both the visuo-spatial component and of working memory itself, it is difficult to extrapolate the properties of the visuo-spatial component by attempting to target and evaluate each individual sub-component.

In order to account for the complexities of working memory and its components, the only other alternative is to develop a broad range of exercises that aim to test all known components of working memory collectively. This battery of exercises might then be used on individuals over a given period of time to determine whether there is a statistically significant increase in working memory capacity as a result of the training exercises.

Memory Strategies and Improvements

As previously mentioned, a number of task-specific strategies have been developed and aimed at improving recall and retention of particular information. While these strategies can be effective for task-specific information, they fail to have any cross-over effect into other areas of working memory (Westerberg & Klingberg, 2007, p. 187). For example, digit-span strategies can increase digit retention but not verbal retention, and verbal-span strategies can increase verbal retention but not processing speed. However, the assertion that the static model of working memory is affirmed because task-specific strategies seemingly fail to have a cross-over effect is a myopic stance. This position fails to consider the cumulative effect that multiple task-specific strategies could have on working memory if employed simultaneously. If an individual were to learn and employ multiple strategies targeting individual components of working memory, then the cumulative effect of those strategies may evidence a

cross-over effect of working memory and substantiate the dynamic model of working memory.

Conclusion

Even though the study of working memory is still in its beginning stages, a substantial amount of evidence appears to support both the dynamic and static models of working memory. However, considering the oversights that have been left unaccounted for in several studies arguing the static model of working memory, a strong case can be made in confirming the dynamic model of working memory, that working memory capacity can increase.

Upon examining the neurological components of working memory, one finds that certain centers in the brain are activated during working memory tasks and that these centers converge at multi-modal areas, regions that process information from more than one sensory modality. While this may indicate a physiological limitation imposed on working memory, it better serves as an indication of current capacities and not of developmental potential. Considering that the concept of brain plasticity continues to gain support in research focused on specific areas of the brain, it is likely that multi-modal areas are also plastic and capable of being restructured to more efficiently handle information.

Although memory strategies have not typically shown a cross-over effect in working memory, the role of inhibitory control in working memory has not been properly considered when evaluating the effectiveness of these strategies on working memory capacity. Since working memory centers share regions with attention and inhibitory control centers, it may be possible that by focusing on improving inhibitory control, there may be a notable increase in working memory capacity. Another reason why some of these strategies may not prove effective in increasing overall working memory is because the evaluations assessing the strategies are not broad enough in scope, nor are the strategies effective if employed singularly rather than collectively. Through developing strategies that focus on individual components of working memory and using these strategies simultaneously to target individual working memory components, there may be a significant cross-over effect observed. Although some research may seem to support the static model of working memory, it's the several oversights in the static model argument that gives confirmatory evidence for the dynamic model.

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