Spring 5-2005

Testing Working Memory: An Experimental and Analytical Approach

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2005 Senior Honors Project

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Abstract

The following paper is basically a brief review of my studies in the concentration of cognition under the guidance of Dr. Mahadevan. In addition to demonstrating laboratory procedures, Dr. Mahadevan recommended many of the subsequent references to literature pertaining to various memory constructs. Having acquired a broad taste (but admitted novice skill) for many interpretations, clarifications by and conversations with Dr. Mahadevan have enabled me to document some conclusions here. My hope is to convey some understanding of the history, methods, theories and models I have found to be instrumental to the present-day empirical study of memory.

Testing Working Memory: An Experimental and Analytical Approach

As the field of cognitive psychology developed extensively during the 1960s with the advent of computer programming and theories attributing computer-like models to the human mind, the concentration and empirical laboratory study of memory quickly came to the forefront of the discipline. Although founders of experimental psychology like Hermann Ebbinghaus were the first to apply scientific method to the study of human memory capacity (Baddeley, 1990, p. 1) as early as 1885 (R. S. Mahadevan, personal communication, August 19, 2004), modern laboratory procedures are far more sophisticated and stringently controlled than ever before. The importance of lengthy and often complex, logistically intricate endeavors in the study of memory include applications to deliberate methodological improvement of study strategies (R. S. Mahadevan, personal communication, November 11, 2004) as well as the study and diagnosis of various forms of brain damage and mental disorder (Baddeley, 2003). Memory is a fascinating component of cognition, which I have been fortunate to study alongside a lecturer able to make the often unwieldy subject accessible to his students.

Dr. Rajan Mahadevan, a cognitive psychologist and phenomenal memorist himself, hails from Madras, India where he received his undergraduate training in a slew of majors before earning an MA in clinical psychology, an MS in Cognitive Psychology and PhD in Cognitive & Behavioral Sciences from various U.S. universities. Rajan says he has, "always been fascinated by memory phenomena ever since age 5" when, at a party, he "memorized the license plate numbers of forty-some vehicles." By 1983, Rajan had made it into *The Guinness Book of World Records* for memorizing 31,811 digits of pi! Drawn to cognitive psychology because of his interest in individual differences in human memory processes (whether these differences are largely attributable to innate capabilities or to deliberate training and practice), Rajan considers himself fortunate to have worked for several years with Dr. Anders Ericsson, a world-leader in the area of expert performance, and Dr. Alan Baddeley, renowned cognitive psychologist (R. S. Mahadevan, personal communication, August 19, 2004).

Rajan's current research with University of Tennessee undergraduates involves laboratory testing of a memory model called Working Memory devised by Baddeley and Hitch (1974). Working memory is the more contemporary term for what Joseph Jacobs originally called Short Term Memory (STM). In 1887 Jacobs created the memory span task that he thought would accurately measure the STM capacities of his students, in turn reflecting their mental capacities. This procedure involves units of info (single digits or letters) presented verbally or visually to a subject at a rate of 1 unit per second. The subject is then instructed to serially recall (in the order presented) the list. When the subject accurately recalls a certain list length 100% of the time, the list length (# of units) is increased by 1 and retested using randomized units. The list length at which the subject accurately recalls the list only 50% of the time designates their memory span (Baddeley, 1990, p. 40). By 1956, empirical testing through repetition and variation of Jacob's memory span task implied that the average memory span capacity is 7 ± 2 units of information (Miller, 1994). In other words, the average STM capacity is 7 with a standard deviation of 2.

The ubiquitous rule of 7 ± 2 still stands today when using this old task to measure memory span. I underwent a computerized version of the memory span task, proctored by Rajan in the Fall term of 2004. The procedure was more or less the same as Jacob's, only in a modern context: a computer programmed to randomly present single digits (0-9) one at a time on a screen at a rate of one per second. Once presentation ceased, an auditory tone signaled me to begin verbal serial recall of the set. This tone, in addition to prompting the beginning of recall, also allows for very precise measurements of speech onset and reaction times of subjects through examination of sonic readouts for each trial's recording. Upon accurate recall, the set size is increased by one and so on. Musings and data since 1887 show however, that this memory span task is not an ideal measure of STM because memorization can and does occur even though items are presented as quickly as one per second.

Memorization under these extreme laboratory bombardments of information often takes the form of processes known as grouping and chunking (Baddeley, 1990, pp. 40-42). Grouping involves regrouping a long continuous stream of units (e.g. 263455680) into smaller more manageable sets (e.g. 263, 455 and 680). Cowan (2000, p. 89) describes a chunk as "a collection of concepts that have strong associations to one another and much weaker associations to other chunks concurrently in use." The idea here is that a set of random digits (e.g. 365180322) could be rearranged to form more sensical groups (e.g. 365 (days/year), 1803 (year of Louisiana Purchase) and 22 (my age)) all of which become easier to recall because they now make some sense. Through chunking, these random numbers have been attributed semantic significance. Having already learned about the phenomenon of chunking when I underwent the memory span task, I was aware of the process when three consequent digits (6,1,5) formed "615," my home area code! The problems that memorization techniques play at the testing stage arise because STM is an entirely active process. Like a holding pen for incoming information before it's even processed enough to enter more durable Long Term Memory (LTM), memory span should not include chunking, or each chunk should be considered one unit successfully recalled. Ideally, memorization should play no role in facilitating recall.

Because Baddeley and Salamé's (1986) working memory is "an active system for temporarily storing and manipulating information needed in the execution of complex cognitive tasks (e.g., learning, reasoning, and comprehension)" (French, 1995), one would expect the average memory span to be less than 7 once rehearsal and chunking are eliminated. This indeed seems to be the case in forthcoming procedures designed to do just this. Cowan (2000) describes the history of the quest for a whittled down pure capacity limit and ultimate claim that the real "magic number" is actually nearer to 4 ± 2. Even though pure capacities are more a guide than a rule for understanding storage, decay and memory limits only observable in the context of models and scientifically controlled conditions, the "4 ± 2" findings correspond to Broadbent's (1975) own which claim this capacity reflects the number of chunks accurately recalled (Cowan, 2000). In fact there are four specific circumstances under which the capacity limit of 4 can be observed. First, information overload must serve to overwhelm a subject's ability to memorize; limiting chunks to individual units. Second, steps must be taken to interfere with the subject's ability to rehearse and code information into LTM. Third, reaction time data and proportion correct serve as telling evidence correlated to the set size (number of items to be held in STM). Finally, various indirect effects of presentation like semantic priming must be accounted for (Cowan, 2000).

Working memory is comprised of what is often called the focus of attention, which serves as a capacity-limited "global workspace" for dealing with memories activated in the brain for the purpose of recall (Cowan, 2000, p. 91). Cowan (1995, pp. 28, 33) considers information in a heightened activated state (but not yet in the focus of attention) to be time-limited, or susceptible to decay. In addition, the transferal of this information into the focus of attention is said to be rate-limited, or susceptible to a bottleneck effect. To avoid decay, thinking of an item to be remembered over and over (maintenance rehearsal), helps to keep that item inside the focus of attention. Other mnemonic recoding and elaborative rehearsal methods convert information into meaningful, more memorable sets and help account for compound STM capacities (7 ± 2) rather than pure capacity-based limits (4 ± 2) (Cowan, 2000).

Baddeley's conception of working memory as a phenomenon separate from memorization necessitates new tasks by which memorization of incoming units of information is impossible. Pollack, Johnson and Knaff (1959) provide a supplement to Jacob's old memory span task with that of the running memory task. The procedure here is that units of info (single digits, 0-9) are presented verbally to a subject at varying rates (4, 2, 1, or 0.5 digits/second). The crucial difference between previous studies is that the subject has no idea of the list length they are being presented (it could be 25 items; it could be 35, etc.). At the end of the presentation, the subject is asked to recall as many units as possible from the end of presentation. Since the subject has no idea when the presentation of the list might end, memorization is theoretically prevented (or its effects are minimized). This is thought to be a more accurate measure of memory span than earlier tests. The average here, which supports other methods of testing the number of units held in the focus of attention, is 4.2 units.

Pollack, Johnson and Knaff's (1959) methods are similar to another experiment I underwent in Rajan's lab. Instead of auditory presentation, the digits were presented visually on a computer screen at a constant rate of 1 digit/second. Also, instead of recall measured by writing as many digits as memory would allow, I was instructed to verbally report these items in reverse sequential order beginning with the final digit presented. Understandably, I found this task exceptionally more difficult than the memory span tasks for "known-length" (Pollack et al. 1959, p. 138) sets. My own comparatively poor performance reflects an inability to use memorization during the running memory task. Although an average of 4 units seems to better reflect focus of attention capacity than known-length tasks, even performance on unknown-length tasks can be improved through practice (Pollack et al. 1959).

An interesting compliment to evidence that the capacity of an active system of temporary storage, encoding and retrieval of information is actually smaller than once thought is the work of Dr. Hugh Garavan (1998). He measured reaction times of participants instructed to mentally tally the number of each of two geometric shapes (squares and triangles) following their presentation. His results indicate a 300-500 ms longer reaction time for recall when a square followed a triangle (or vice versa) than when a square followed another square or a triangle followed another triangle. These data imply that only a single categorical counter (for one shape or the other) can be held within the focus of attention at a time. A switch in the category being presented involves a shift in the focus of attention to incorporate different information held in working memory. These categorical shifts account for the increased reaction times. Garavan's (1998) conception of a narrow focus of attention, specifically able to contain only one unit at a time, contrasts Cowan's (1995, p. 33), but reaction time data provides interesting insight into the human mind's ability to simultaneously attend to multiple varied stimuli.

A somewhat compromising representation of focus of attention capacity comes from Oberauer (2002), whose concentric model exhibits memories connected by neural pathways. A region of direct access can only encompass a few of the activated memories at a time, while the focus of attention, within this region, can only include a single item or chunk selected as necessary for the immediately impending cognitive process. To recall an item, an individual must deliberately bring it into the region of direct access from which it will automatically replace the previous item in the narrow focus of attention. These active and passive distinctions of memory retrieval characterize Oberauer's (2002) research and seem to provide evidence for the concentric model.

Perhaps the most comprehensive and imperative component of the working memory model, however, is Baddeley and Hitch's 1974 proposal that the construct is comprised of at least three subsystems (Baddeley, 2003). Baddeley claims working memory is comprised of (1) the phonological loop concerned with verbal and acoustic information, (2) the visuospatial sketchpad for visual equivalents, both of which are regulated by (3) the central executive, an "attentionally-limited control system" (Baddeley, 2003, p. 189). The most recent addition to the model, the episodic buffer, serves as the part of the central executive involved in memory storage. This working memory model came about in response to less comprehensive two-component models that could not explain why aphasic patients' complex cognitive tasks often go unhindered regardless of deficits in STM capacity. Instructing subjects of normal memory spans to hold sequences of digits in memory while performing concurrent activities hypothesized to interfere with working memory, Baddeley and Hitch (1974) witnessed massive impairments in ability and consequently divided the concept of STM into the three components of working memory (Baddeley, 2003).

The phonological loop consists of a short-term storage system that is reinforced by a subvocal rehearsal system that serves to perpetuate information within the storage system and catalog nameable visual information. This system is evidenced by the phonological similarity effect by which subjects encounter difficulty recalling similar sounding items (e.g. CBZTPDGV) as compared to dissimilar sounding items (e.g. QRBIOSLJ). Although the list length is the same, recall performance for the first set suffers drastically due to sonic ambiguity and inability at distinct subvocalization (R. S. Mahadevan, personal communication, September 16, 2004).

The word length effect also hinders recall when five-syllable words are used as opposed to one-syllable words. Word length effect can be eliminated by subjects repeating a word like "the" over and over during presentation of items. This verbal repetition interferes with the subject's ability to subvocally rehearse, providing evidence for the phonological loop (Baddeley & Salamé, 1986).

The visuospatial sketchpad serves to amalgamate visual, spatial and possibly kinetic information into brief storage. Evidenced by the separation of verbal and spatial abilities through dramatic interference in verbal recall and tracking tasks (Baddeley, Grant, Wight, & Thomson, 1973), the visuospatial sketchpad may play a large role in language comprehension as well (Baddeley, 2003).

The central executive controls attention in working memory and acts as the master of the slave system comprised by the two previous components (Galotti, 2004). Processes by the central executive are considered to be mainly responsible for individual differences in working memory capacities. In studying retention capacity for which age, knowledge and memory span are variables, all prove to be influential, but level of expertise is clearly the largest contributing factor (Hambrick & Engle, 2002).

Scores of other memory procedures have found practical applications in diagnosing and coping with various brain damages, studying learning disorders and predicting and assessing individual learning abilities (Baddeley, 2003). An understanding of memory capacity and processes can shed light upon both normal and disordered language processing with the phonological loop component contributing greatly to native and second language acquisition. Many brain and motor disorders often resulting from stroke are implicated in the ever-evolving knowledge of working memory. People suffering from dysarthria, for example, who have impaired ability to form words or spoken language due to motor inability (C. Hodgson, personal communication, April 3, 2004), show apparent evidence for subvocal rehearsal. Conversely, verbal disorders stemming from the inability to bring together speech and motor control programs, as with dyspraxia, show no sign of such rehearsal (Baddeley & Wilson, 1985). Identifying defining features of neuropsychological speech disorders may certainly be helpful in diagnosis. Working memory has a lot to offer to identifying and treating less severe learning disabilities in otherwise healthy individuals as well. Such is the case with students struggling immensely with language acquisition due in part to deficits in working memory capacity. Subvocal rehearsal is thought to have behavioral implications as the mediating force controlling actions in young children and brain damaged adults. Baddeley (2003) even infers that subvocal rehearsal may aid in strategic control, like repeating driving directions again and again in an unfamiliar and distracting setting for example. Finally, Daneman and Merikle's (1996) study reviews working memory span's correlation with, and predictability of, performance on reasoning tests. These diverse examples reflect a truly rich potential influence that research into better memory models and understandings of memory processes has sown and will continue to promote. Through brief laboratory experience and literature review, it is clear to me that the psychological study of memory has potentially limitless contribution to so many facets of life; many yet to be determined.

References

Baddeley, A. D. (1990). *Human memory: Theory and practice*. Boston: Allyn & Bacon.

Baddeley, A. D. (2003). Working memory and language: An overview. *Journal of Communication Disorders, 36, 189-208.*

Baddeley, A. D., Grant, S., Wight, E., & Thomson, N. (1973). Imagery and visual working memory. In P. M. A. Rabbitt & S. Dornic (Eds.), *Attention and performance* (205-217). London: Academic Press.

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. *Recent Advances in Learning and Motivation, 8, 47-90.*

Baddeley, A. D., & Salamé, P. (1986). The unattended speech effect: Perception or memory? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 12, 525-529.*

Baddeley, A. D., & Wilson, B. A. (1985). Phonological coding and short-term memory in patients without speech. *Journal of Memory and Language, 24, 490-502.*

Broadbent, D. E. (1975). The magic number seven after fifteen years. In A. Kennedy & A. Wilkes (Eds.), *Studies in long-term memory* (pp. 3-18). New York: Wiley.

Cowan, N. (1995). *Attention and memory: An integrated framework*. New York: Oxford University Press.

Cowan, N. (2000). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences, 24, 87-185.*

Daneman, M., & Merikle, P. M. (1996). Working memory and language comprehension: A meta-analysis. *Psychonomic Bulletin and Review, 3, 422-433.*

French, B. M. (1995). *Working memory*. Retrieved November 27, 2004, from http://penta.ufrgs.br/edu/telelab/3/working_.htm.

Galotti, K. M. (2004). *Cognitive psychology in and out of the laboratory*. Belmont, CA: Wadsworth/Thomson.

Garavan, H. (1998). Serial attention within working memory. *Memory & Cognition, 26, 263-276.*

Hambrick, D. Z., & Engle, R. W. (2002). Effects of domain knowledge, working memory capacity, and age on cognitive performance: An investigation of the knowledge-is-power hypothesis. *Cognitive Psychology, 44, 339-387.*

Miller, G. A. (1994). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 101, 343-352.*

Oberauer, K. (2002). Access to information in working memory: Exploring the focus of attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28, 411-421.*

Pollack, I., Johnson, L. B., & Knaff, P. R. (1959). Running memory span. *Journal of Experimental Psychology, 57, 137-146.*