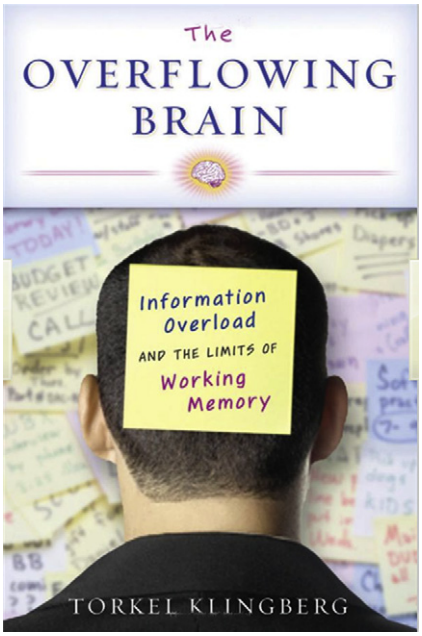
Working Memory from the Trailing Edge of Consciousness to Neurons

The Overflowing Brain: Information Overload and the Limits of Working Memory

Torkel Klingberg
Oxford University Press (2008)
224 pp., $21.95, hardcover.



This book on working memory limits by Klingberg (2009) is one to which I certainly can relate. When I was in high school in the late 1960s, I decided that the only career that made sense for me, to make the best use of a finite life span, was investigating the scientific basis of human conscious experience. In graduate school, I came to feel that two specialties could best satisfy that aim: perception and working memory, the small amount that can be kept in mind at once. There have been many exciting advances in these two topics over the years, by both neuroscientists and cognitive psychologists. So as to avoid solipsism, I also wanted my research to be of practical use to medical science and society. I could have gone various ways but ended up doing behavioral studies of working memory and its development.

Klingberg's title strikes a chord with me. In 2005, I published a book on working memory capacity limits and their neural underpinnings (Cowan, 2005). Originally, I planned to use the title "The full brain," in allusion to a *Far Side* cartoon by Gary Larsen in which a student asked to be excused from class because his brain was full. The publisher felt that the title was not appropriate for the series of scholarly essays of which mine was part. I had to agree, given the emphasis on subtle theoretical distinctions and the heavily referenced style; the "full brain" expression was used instead within the first subtitle in my first chapter. Still, after all of the work, I wistfully understood that I had not written a book for everyone. It was for academics in my field, students in the behavioral sciences, and potentially researchers from other areas, but not so much for the public.

Now Torkel Klingberg (2008) has written an elegant scientific book of the most accessible type with a like-minded title, *The Overflowing Brain*. Among other things, he highlights his research, which itself is of popular interest, demonstrating the effect of training working memory on mental performance in various people, including children with attention deficit disorder and hyperactivity (ADHD) and aging adults. This type of research finding offers an important challenge to the predominant, drug-oriented maxims of modern medicine. The book is supported by a lot of research literature, but the citations are neatly tucked into a footnote section. That section is carefully coregistered with the book pages, allowing the most relevant background information to be found easily. Yet, the main text is fully comprehensible even without reading the footnotes.

The prospect of measuring the contents of the conscious mind was important to even the first scientific investigators of psychology. One of these was Wilhelm Wundt, who is often credited with establishing the first laboratory of experimental psychology in 1879. Strangely, his voluminous writings on behavior and physiology have still only partly been translated into English; Hungarian and Russian were more important at the time. William James (1890), working at Harvard, helped make the works of Wundt and others popular in the United States, and he coined a term for the storage of information in the human mind. He called it *primary memory*, conceived as the trailing edge of the conscious present. As he further discussed, a complex human capability known as attention, which is partly under the person's voluntary control, helps to determine which information is perceived and which of the perceived events are considered further and retained for a while in primary memory. Klingberg's approach to working memory makes him (like me) a benefactor of this early approach by Wundt, James, and others. His present attention-based approach was nevertheless difficult to come by, in light of key events taking place in the century following these early researchers. It has been not so much an uninterrupted dynasty from the early days as a renaissance. Here is what happened.

As the book indicates, modern research on working memory is generally considered to have begun with George Miller and his observation in 1956 that experimental participants can repeat back a list of no more than about seven separate items. The book mentions the use of the term working memory by animal researchers in the 1960s, but the term may have been used first by Miller et al. (1960) to describe the memory by which humans carry out plans, retaining the main goal in memory while various subgoals are tackled.

Baddeley and Hitch (1974) then started a tidal wave of research on working memory by arguing for a new theoretical

model of that concept. Whereas previous models considered working memory to be a single thing, Baddeley and Hitch persuasively argued that the evidence points to multiple, separate working memory stores. In addition to an all-purpose working memory store for abstract information, there was said to be a separate store for phonological information (whether from speech or print) and another for visual, spatial, nonverbal information. Then, in the spirit of parsimony, Baddeley (1986) omitted the general, abstract store for many years, though it was still advocated by some (e.g., Cowan, 1988). Baddeley (2000) was convinced that the evidence finally supported that type of store. Most importantly, though, the phonological and visuospatial stores of Baddeley and Hitch were thought of as automatically operating mechanisms that did not require attention once the information was loaded in. So Klingberg's return to an emphasis on the importance of attention in working memory is important.

There is also a long history regarding what aspects of working memory can be trained (not much described in the book) and conventional wisdom from this area, too, had to be overcome. The consensus from the skill-training literature is that effects of training, though sometimes remarkable, are specific to the skill being trained. The most dramatic example may be the case studies of improved memory span beginning with Ericsson et al. (1980). Over the course of a year, they trained an individual to increase his digit span from seven items to about 80. It was done through the application of specific practice. In a digit span task, a random series of digits is presented, and the task is to repeat the series in order. Span is defined as the longest list that can be repeated with a particular rate of success (such as error-free repetition of at least half the presented lists of that length). The participant in Ericsson et al. already knew a large number of athletic records, which served as prememorized, multidigit chunks. For example, suppose that a list began, *8, 3, 4, 1, 9, 5, 8*…. If he knew that 83.4 s is the world record time in one particular running event and 195.8 is a national record number of feet in some throwing event, then the series so far can be recoded as the two chunks [83.4] [295.8], reducing the memory load from seven items to two. The participant in this way increased his ability from about seven items to about 20, reached a plateau, and then increased further to 80 by learning to make higher-level chunks out of the first-order chunks. Still, after all of this training, the ability to perform a closely related but unpracticed task, letter span, remained at about seven items.

The type of specific-skill training described by Ericsson et al. (1980) and others seems to rely on the existence of a more abstract form of working memory storage that can hold meaningful units, including clusters of digits forming meaningful chunks. This was consistent with George Miller's concept of chunking and with the abstract store already to be found in the seminal sources in the field (e.g., Baddeley and Hitch, 1974). The method of training, moreover, was thought to be one in which specific knowledge about the material to be remembered was put to use in forming the chunks. The new findings on training highlighted by Klingberg (2008) would be seen as surprising indeed, from that point of view. He maintains that challenging working memory training exercises can raise performance on a variety of attention-demanding tasks, including intelligence tests. Training effects are generalized, rather than just task specific.

Klingberg (2008) also documents new research using brain imaging techniques, which show that improvements in attention-related training are accompanied by enhanced activity in a circuit of the brain that includes parts of the frontal and parietal lobes. Actually, there is further evidence of specialization of function within this circuit, with the frontal areas having more to do with the control of working memory and the parietal areas more with the storage of information in working memory. Postle et al. (2006) showed this using not only neuroimaging techniques but also transcranial magnetic stimulation (TMS), which momentarily impairs the stimulated part of the cortex. They found that working memory tasks activate both the frontal and parietal areas no matter whether these tasks require manipulation of the remembered materials (rearrangement of them or calculation based on them) or memory with no manipulation. TMS applied to the parietal lobes impaired both sorts of task, but TMS applied to the frontal lobes impaired only the tasks that included manipulation of the materials.

Consistent with most of the recent literature, Klingberg (2008) places considerable emphasis on the importance of filtering out irrelevant information. This is important for the efficient functioning of working memory, and Klingberg and his colleagues even have identified brain areas in the prefrontal cortex and basal ganglia that help do the job. Individuals with better working memory appear to do a better job of filtering out irrelevant information.

This emphasis on filtering has, however, underestimated the role of individual differences in information storage. Illustrating such differences, Gold et al. (2006) investigated memory for spatial arrays of objects in normal and schizophrenic individuals and found that the ability to filter less-relevant objects could not account for differences between the groups. On a trial in one experiment, for example, participants were usually tested on memory for the orientation of one sort of object in a recently seen array (such as one red bar out of several), though they were occasionally tested on memory for the orientation of another sort of object also in the array (such as one blue bar out of several). Schizophrenic patients performed better on the frequently tested objects, to the same extent that normal control participants did. Still, the patients remembered far fewer of the objects overall. As Klingberg (2008) noted, working memory for spatial arrays of objects has been strongly linked to parietal lobe areas limited to representing a few objects at a time, and I would add that we should look for group differences in these brain areas.

The book is well-organized and broad-ranging. After an engaging introduction, the discussion turns to the mind as an information portal, as in attention research (chapter 2), and the mind as a mental workbench, as in working memory research (chapter 3). Theoretical models of working memory are discussed (chapter 4), followed by a consideration of how the brain may underlie capacity limits of working memory (chapter 5). In this chapter, by the way, a fascinating point was that Albert Einstein's brain was enlarged in areas thought to underlie working memory. The emphasis of the book then returned to models in more depth, with a description of simultaneous capacity in

dual tasks and the concept of the brain as a receiver of information with its own mental bandwidth (chapter 6).

In all of this, Klingberg establishes a position that differs from the norm in the field. The norm (e.g., Baddeley, 1986) is to favor the idea that there is a central executive faculty in the brain responsible for coordinating different storage areas in working memory. Conflicts between different tasks, like remembering visual objects and sounds at the same time, would come from the limit in how much the central executive can do. No conflict is expected between a nonverbal visual task and a verbal task, for example, except in the process of putting information into each type of memory store. Instead, Klingberg favors the view that there might be no such central executive processing limit. The conflict between different working memory tasks could be caused entirely by overlap in the neural circuits that would be needed for the two tasks if they were performed one at a time. To take this idea further, there appears to be a constant capacity of about three to four items that applies even when the items include disparate objects such as some colored squares and some spoken digits, provided that information specific to a sensory modality is wiped out by additional stimulation (Saults and Cowan, 2007). Therefore, there may be a general capacity-limited storage mechanism, such as the focus of attention (Cowan, 1988, 2005).

Chapter 7 steps back to examine the evolutionary value of working memory and its limits. This is an exciting topic; there are many ideas as to why working memory limits exist, all still unproven. One can focus on why a limit exists, as Cowan (2005) does, or on why a larger limit is advantageous for survival and reproduction, as Klingberg (2008) does. Working memory apparently has increased over evolutionary time as societies and technologies have become more complex. Given the need for an economy of energy, not every stimulus can be processed to the same level of detail, and it makes sense to have a subsystem that provides expertise in determining which material to give preferred treatment.

Many researchers have said that there is nothing as practical as a good theory. The next few chapters set up the reader theoretically for the training studies to follow. Chapter 8 discusses brain plasticity, the ability of the brain to grow, change, and get rewired even in adulthood, which is much greater than researchers used to think. It allows training of basic abilities. Chapter 9 discusses attention deficit disorders as possibly not medical diseases in need of drug treatments (with their inevitable side effects), but rather as the extremes of a normal continuum of attention styles. Attention function can be altered through intensive training, which, it is hoped, can even alter the neurochemical balance on which working memory depends.

In chapter 10, we are introduced to a laboratory-based program to improve our working memory and attention capabilities through training, and chapter 11 explores how to accomplish the same thing with everyday tasks. Chapter 12 discusses computer games, indicating that the pitfalls that parents usually fear (violence, loss of mental discipline) are balanced by possible benefits of some of the games as attention-training regimens.

The added technological complexity of modern life may explain why measures of intelligence are increasing all over the world compared to previous generations (chapter 13, The Flynn Effect). The benefit is explained in neurochemical terms (chapter 14, Neurocognitive Impairment). Also, futuristic aids to enhancing performance are discussed, such as computer memory that would plug into the human brain. A broad and enlightened perspective is taken. For example, people may fret over the ethics of allowing college students to take memory-enhancing drugs before a test but that mental angst tends to disappear after the enhancing drug has been around for a while, which is precisely the case with caffeine. Still, training of working memory is cast as a better option than drugs.

In the final chapter on The Information Flood and Flow (chapter 15), the target for superior cognitive performance is identified as the point at which one's attention is absorbed by the task but one remains in control. Challenges that are taken on push to the limit one's ability to cope, but do not hopelessly exceed that limit. At this point, one gets the experience of "flow" in which it feels good to work hard mentally, with full and efficient use of one's inspiration and creativity.

Not all of the conclusions in the book are for sure. For example, the increase in IQ over time, the Flynn Effect, may not occur because of the training effect. It could occur instead because the tests no longer serve their original purpose. Tests of what is called fluid intelligence, such as Ravens Progressive Matrices, were designed to measure an individual's ability to figure out how to perform a novel task. Given that the characteristics of such tasks are not very different from some computer games, perhaps these tasks no longer seem novel to today's young test-takers. It may take some creativity to keep the intelligence tests one step ahead of the populace.

There are parts of mental performance that have not been handled very well by the field at large and, understandably enough, are still not settled in the book. Consider the example of remembering where one parked one's car this morning. Laymen often refer to that as short-term memory, whereas cognitive psychologists reserve that term for information that was held in mind only within the last minute or so. But then, cognitive psychologists have no clear concept that can explain why we can remember where we parked the car this morning. The predominant concept in the literature is that there are cues that help us to recall the most recent event in a series (in this case, the series of parking spaces used on successive days). An alternative formulation is that there is some intermediate-term memory faculty, a notion that is common among neurophysiological researchers but rare among human behavioral researchers.

Another issue that has not been addressed in enough detail by the field, let alone in the book, is the massive influence of emotion on cognition. What is seen as the human ability to be rational is often actually no more than a human ability to rationalize and do or think what we want to.

The book has some general lessons. It shows how, through persistence, a few people can successfully overturn established scientific maxims, such as the one that says that the effects of practice are only narrow and specific. It also shows the practical value of theoretical thinking. A final lesson is the value of combining literatures from fields that have remained separate; probably for the sake of expedience, the neurologically and behaviorally oriented researchers of attention and working

memory have tended to ignore each others' literatures and have not talked to each other as much as they should. The book helps to bring them together.

Finally, one can see in the book that there are important benefits of not being too reductionistic in one's scientific view. As an analogy, to understand computers one must grasp not only the functioning of magnetic memory locations, but also other, higher-level concepts: information encoding, simple operations and, at a macroscopic level, logical flow charts. Similarly but further afield, to understand the United States government one needs abstract concepts. One cannot point to a single part of Washington, D.C., and say that it fully encapsulates the legislative, executive, or judicial branch; the physical plants are fairly well commingled. Likewise, the intellect depends on faculties such as working memory, attention, and planning that are enacted in the brain by interwoven ensembles of neurons. Discussions incorporating all levels of analysis are necessary, and they occur in Klingberg's book.

REFERENCES

Baddeley, A.D., and Hitch, G. (1974). The Psychology of Learning and Motivation, *Volume 8* (New York: Academic Press), 47–89.

Baddeley, A.D. (1986). Working Memory (Oxford: Clarendon Press).

Baddeley, A.D. (2000). Trends Cogn. Sci. *4*, 417–423.

Cowan, N. (1988). Psychol. Bull. *104*, 163–191.

Cowan, N. (2005). Working Memory Capacity (Hove: Psychology Press).

Ericsson, K.A., Chase, W.G., and Faloon, S. (1980). Science *208*, 1181–1182.

Gold, J.M., Fuller, R.L., Robinson, B.M., McMahon, R.P., Braun, E.L., and Luck, S.J. (2006). J. Abnorm. Psychol. *115*, 658–673.

James, W. (1890). The Principles of Psychology (New York: Henry Holt).

Klingberg, T. (2008). The Overflowing Brain: Information Overload and the Limits of Working Memory (New York: Oxford University Press). Translated by N. Betteridge.

Miller, G.A., Galanter, E., and Pribram, K.H. (1960). Plans and the Structure of Behavior (New York: Holt, Rinehart and Winston, Inc).

Postle, B.R., Ferrarelli, F., Hamidi, M., Feredoes, E., Massimini, M., Peterson, M., Alexander, A., and Tononi, G. (2006). J. Cogn. Neurosci. *18*, 1712–1722.

Saults, J.S., and Cowan, N. (2007). J. Exp. Psychol. Gen. *136*, 663–684.

Nelson Cowan[1,*]
[1]Department of Psychological Sciences, Brain Imaging Center, University of Missouri, 18 McAlester Hall, Columbia, MO 65211, USA
*Correspondence: cowann@missouri.edu
DOI 10.1016/j.neuron.2009.03.018