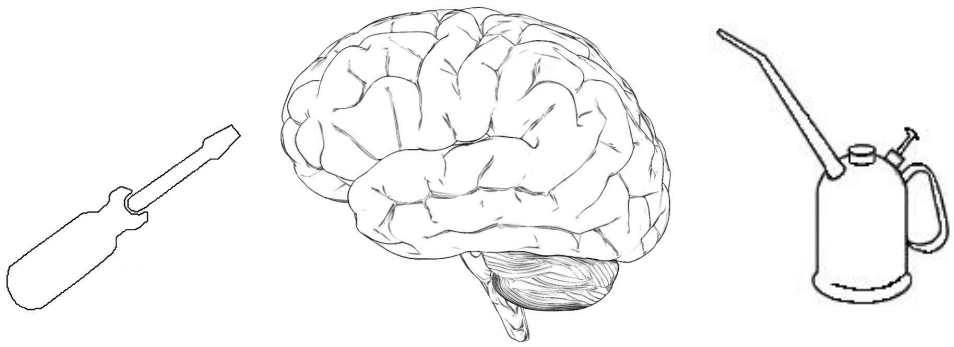
Understanding and using your brain



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Background

This document had its genesis in late 2007. The Young Professionals group in my employer's office was having a formal training session on innovative thinking, and I was asked to give the group a short presentation discussing a few examples. While thinking about what I might say I decided that I would talk instead about innovation's big brother — creativity (or inspiration, or

insight). And rather than deliver examples, which often have little relevance outside their highly specific context, I decided it would be better to discuss some of the conditions that might encourage creativity.

The presentation must have been reasonably well received, because I was asked to provide the attendees with copies. The resulting document was in essence just a rough transcript of my talk, and as such it retained much use of the perpendicular pronoun.

The document has been significantly modified and expanded since then, but because of its origins as a verbal presentation it still has a discursive style. The way its material is presented in sections might appear logical, but in reality the sections are not self-contained, and there is much overlap between them.

Introduction

My brother used to be a carpenter. He was a very good carpenter, principally because he understood his tools: how they worked, how to maintain them, how to use them, and when to use them. If I asked you to name the tools you use in your work, how would you answer?

The top tool you use, arguably the only tool, is your brain. It is the wellspring of your knowledge, the driver of your productivity. At school you might have been taught various techniques for getting facts into it. But I doubt you have delved much into techniques for processing those facts, or for getting non-factual results out from your brain. There can be no universal approach here, but modern objective research in psychology, physiology and neuroscience is revealing some of the ways our brains work. Interestingly, the research often confirms earlier subjective theories. Furthermore in some cases it is also suggesting ways in which we can assist our brains to work more effectively.

This document makes no claims to presenting anything original. It aims to be a work of synthesis, attempting to bring together and summarise in lay language some of the current knowledge of how our brains work. Hopefully such knowledge will help us to make better use of them.

Creativity

DOCUMENTED HISTORICAL EXAMPLES OF CREATIVITY

Let me start with two historical examples of geniuses describing their thinking. The first is from the mathematician Henri Poincaré, at a lecture he gave to the French Psychology Association in 1908. It is excellently described by a modern day mathematical genius, Roger Penrose [ref 1 p.418].

> Poincaré describes, first, how he had intensive periods of deliberate, conscious effort in his search for what he called Fuchsian functions, but he had reached an impasse. Then:
>
> > "I left Caen, where I was living, to go on a geologic excursion under the auspices of the School of Mines. The incidents of the travel made me forget my mathematical work. Having reached Coutances, we entered an omnibus to go to some place or other. At the moment when I put my foot on the step, the idea came to me, without anything in my former thoughts seeming to have paved the way for it, that the transformations I had used to define the Fuchsian functions were identical with those of non-Euclidean geometry. I did not verify the idea; I should not have had time, as upon taking my seat in the omnibus, I went on with a conversation already commenced, but I felt a perfect certainty. On my return to Caen, for convenience sake, I verified the result at my leisure."

> What is striking about this example [Penrose continues] is that this complicated and profound idea apparently came to Poincaré in a flash, while his conscious thoughts seemed to be quite elsewhere, and that they were accompanied by this feeling of certainty that they were correct — as, indeed, later calculation proved them to be. It should be made clear that the idea itself would not be something at all easy to explain in words. I imagine that it would have taken him something like an hour-long seminar, given to experts, to get the idea properly across. Clearly it could enter Poincaré's consciousness, fully formed, only because of the many long previous hours of deliberate conscious activity, familiarizing him with many different aspects of the problem at hand. Yet, in a sense, the idea that Poincaré had while boarding the bus was a "single" idea, able to be fully comprehended in one moment! Even more remarkable was Poincaré's conviction of the truth of the idea, so that his subsequent detailed verification of it seemed almost superfluous.

The second example, from a completely different field, is Mozart[2].

> When I feel well and in a good humour, or when I am taking a drive or walking after a good meal, or in the night when I cannot sleep, thoughts crowd into my mind as easily as you could wish. Whence and how do they come? I do not know and I have nothing to do with it. Those which please me, I keep in my head and hum them; at least others have told me that I do so. Once I have my theme, another melody comes, linking itself to the first one, in accordance with the needs of the composition as a whole: the counterpoint, the part of each instrument, and all these melodic fragments at last produce the entire work. Then my soul is on fire with inspiration, if nothing occurs to distract my attention. The work grows; I keep expanding it, conceiving it more and more clearly until I have the entire composition finished in my head though it may be long. Then my mind seizes it, as a glance of my eye a beautiful picture or a handsome youth. It does not come to me successively, with its various parts worked out in detail, as they will be later on, but it is in its entirety that my imagination lets me hear it.

Again, notice the totality. Mozart, in his own words, was able to "seize at a glance" an entire musical composition "though it may be long".

HADAMARD'S FRAMEWORK

This second example is taken from a remarkable book, "The Psychology of Invention in the Mathematical Field", written by the French mathematician Jacques Hadamard[3] of Princeton University in the mid 1940s. It concentrates upon creativity at the highest possible level, and examines the roles of the conscious and the subconscious in solving a problem.

Among many other things, Hadamard lists the phases through which mathematical creativity often passes.

- Preparation. This is when the subconscious is "primed" for the problem. It is usually intense, and often protracted. Some other researchers use the term "immersion" to describe this phase.
- Incubation. This is when the subconscious actually does its thing: cross-linking ideas, synthesising, sifting, sieving, etc. It is generally assisted by a state of relaxation, which can be mental, physical, or both.
- Intimation. This phase, which seems to be much rarer than the others, consists of some sort of warning that the subconscious is about to say something.
- Illumination. This is when the subconscious "delivers the goods". It happens suddenly, and the answer tends to be complete rather than partial.
- Verification. This self-explanatory phase is necessary because the process is not infallible.

Hadamard does not claim that these are ever sufficient, and he does not claim that they are always necessary. But he does claim that at the very least they appear to be conducive to creativity.

Let us explore several of these phases individually, with some random added comments.

PREPARATION

Here Hadamard means hard, focused thought — by the bucket-load. The alternative and more modern title "immersion" is a better description in many ways. Knowledge specific to the problem at hand is required. This knowledge is then concentrated upon.

Timothy Gowers, professor of mathematics at the University of Cambridge, in a 2005 interview[4], emphasises the importance of immersion. He also believes that mistakes are an important part of the immersion process, and adds that "it's a good strategy to be a bit cavalier about the details and go back and check them afterwards, it speeds up the process of having ideas."

In addition to specific knowledge you cannot have too much general knowledge, a point that Hadamard (surprisingly) does not explore. Cross-pollination of ideas from other, sometimes distant, areas is a frequent ingredient of inspiration. According to creativity specialist Mark Runco[5] of California State University, the "creative personality" tends to place a high value on aesthetic qualities and to have broad interests, providing a variety of resources to draw upon, and knowledge to recombine into novel solutions.

Thomas Jefferson (or maybe it was Samuel Goldwyn of Hollywood fame)[6] is supposed to have said, "It's a funny thing, but the harder I work, the luckier I get". Modern science would say that Jefferson/Goldwyn was only partly right. Up to a point, the stress associated with hard work helps you to become more focused, alert and efficient. But beyond that point it compromises your performance, and eventually your health. This highly nonlinear relationship between stress and performance is known, somewhat grandiloquently, as the Yerkes Dodson Law.

You need to discover your own optimum point on the Yerkes Dodson curve. Obviously it can vary according to circumstances. For example, music can help you achieve and maintain a conducive mental state in which you are relaxed and alert, but it cannot be ANY type of music: functional magnetic resonance imaging has shown that classical baroque music is particularly effective at increasing the proportion of theta waves in the brain, and theta waves are believed to play a significant role in the encoding of new information[7, 8]. This is hardly surprising, since the objective of much baroque music was to liberate the mind from earthly concerns, and to create a contemplative state of mind.

Thinking is hard work. Even when you are firing synapses rather than chopping wood you are still burning energy: Over twenty percent of the body's glucose metabolism occurs in the brain[9], as does around twenty percent of its oxygen consumption. And the chemical reactions that drive your mental processes produce toxic by-products. Unless they are flushed away, these by-products will build up in your brain, leading to headaches and even (in extreme cases) cell death. The vascular system does this flushing, but when you are physically inactive it may not be up to the job if you are thinking hard. Thus the old saying about getting some exercise "to clear your head" is literally true[10].

INCUBATION

Another old saying is that you will "sleep on" a problem. Findings from some 2003 research in Germany support the literal truth of this one as well. The leader of the research team says[11]: "we think the strongest explanation is that sleep acts on the patterns created during training, restructuring them to give insights".

Nobel laureate James Watson (co-discoverer of DNA) once said[12] that "It is necessary to be slightly underemployed if you are to do something significant." Australia's Elizabeth Blackburn, winner of the Nobel Prize for Medicine in 2009, has a different way of saying something similar: "I think you need time to daydream, to let your imagination take you where it can. […] I've noticed that among the creative, successful scientists who've really advanced things, that was a part of their life."[13]

Dr Herbert Benson, founder of the Mind/Body Medical Institute in Massachusetts and an associate professor of medicine at Harvard, was interviewed in 2005 by *Harvard Business Review*[14]. He has developed a concept he calls the "relaxation response", which is very much a parallel of Hadamard's incubation phase, and is suitable for group and corporate environments. He describes it as "a complex physiologic dance between stress and relaxation". Paraphrasing roughly from a part of the interview:

> We found that by taking the stress level up to the top of the Yerkes Dodson curve and then turning to a calming activity, subjects could counteract the negative effects of the stress hormones, and trigger the release of such neurotransmitters as endorphins and dopamine, which enhance general feelings of well-being. As the brain quietens down, a phenomenon we call "calm commotion" occurs. There is a focused increase in activity in the areas of the brain associated with attention, space time concepts, and decision making: individuals can experience a sudden creative insight in which the solution to the problem becomes apparent. Thereafter the individual enters a state of sustained improved performance.

INTIMATION AND ILLUMINATION

I am combining these two phases together because the distinction between them is far from clear to me. How do you define the difference between fringe-consciousness and full-consciousness anyway?

The earlier quotations from Poincaré and Mozart describe this phase brilliantly, albeit through extreme examples. Normally (if any instance of inspiration can be called normal), it is the sudden emergence of a relatively simple but somewhat revolutionary idea, an idea that just "pops into your head". Popular history abounds with examples, albeit possibly apocryphal ones: Newton and his famous apple; Archimedes running naked down the street shouting "eureka", thereby giving the ladies of Syracuse a thrill at the same time as he gave mankind a name for the phenomenon, the *eureka moment*.

MODERN SCIENTIFIC EVIDENCE FOR HADAMARD'S FRAMEWORK

Advances in medical technology have enabled researchers to observe the brain while it is working. These technologies include functional magnetic resonance imaging (mentioned above), positron emission tomography, electroencephalography, and multiple electrode recording. Used in conjunction with cleverly designed experiments, and drawing also on studies of people with damage to specific areas of their brains, these tools have begun to reveal the actual physiology of brain function. In the case of insightful thought the results appear to confirm Hadamard's categorical framework.

An excellent article on the physiology of the "insight process" (*inter alia*) was published by Jonah Lehrer in 2008[15]. Except where otherwise noted, this section is based on Lehrer's article, which itself quotes numerous researchers. Some of the material is highly technical, and might be helped by reference to the brain diagrams presented in Appendix 1 below.

It will also help to bear in mind the differing roles of the brain's two hemispheres. As a gross generalisation, the left hemisphere tends to undertake tasks of denotation, the right hemisphere tasks of connation. Put another way, the left tries to see the trees while the right tries to see the forest. Studies have shown that cells in the right hemisphere are more "broadly tuned" than cells in the left hemisphere, collecting information from a larger area of cortical space. Given the more subtle nature of its role, the right hemisphere was thought for a long time to be the less important, minor hemisphere.

When a person is tackling a mental problem some or all of the following stages will usually occur, in this order.

- The first brain areas activated are those involved with "executive control", areas such as the prefrontal cortex and the anterior cingulate cortex. At the same time, the various sensory

areas (such as the visual cortex) go silent. The brain is devoting its considerable "computational power" to the problem, and is suppressing distractions.

- Then the brain starts looking for answers in all the relevant places. The brain areas activated depend upon the nature of the problem. With a word puzzle, for example, brain activity is fired up in areas related to speech and language. The search can quickly get frustrating, and within a few seconds (if an immediate solution has not been found) the executive control areas need to become involved again, either to prod the search along, or to change strategies and start searching in other areas.
- Sometimes, just before the brain is about to give up, an insight appears. This happens suddenly, with a burst of brain activity.
  - Up to eight seconds before the insight hits the conscious brain, a steady rhythm of alpha waves begins emanating from the right hemisphere (the right frontal cortex[16]). Alpha waves typically correlate with a state of relaxation.
  - About a second before the insight hits, a small fold of tissue on the surface of the right hemisphere, the anterior superior temporal gyrus (aSTG), experiences a sudden and intense surge of electricity, leading to a rush of blood. The function of the aSTG remains mostly a mystery, but studies have linked it to aspects of language comprehension such as the detection of literary themes and the interpretation of metaphors: activities requiring the brain to make a set of distant and unprecedented connections.
  - About 300 milliseconds before the insight hits there is a spike of gamma waves. Gamma waves, or gamma rhythms, are the highest electrical frequency generated by the brain. They are thought to come from the "binding" of neurons, as cells distributed across the cortex draw themselves together into a new network that is then able to enter consciousness.
- The insight immediately grabs our attention, and as soon as this happens we recognise that it is correct (even if we subsequently discover that it is not correct). The brain area responsible for this act of recognition is the prefrontal cortex, which "lights up". It also lights up when people who have been working hard on a problem are **shown** the answer, even though they have not come up with the answer themselves.

  Multiple electrode recording enables scientist to see how cells in different brain areas interact. It has revealed that the prefrontal cortex acts like the conductor of an orchestra, directly modulating the activity of other areas. Not only is it responsible for focusing on the problem at hand, it also figures out what other areas need to be engaged to solve the problem. If it decides to turn on parts of the right hemisphere, then we **might** end up with an insight solution. If it decides to restrict its search to the left hemisphere, we'll probably arrive at an incremental solution (or none at all).

  This "integrative" theory of the prefrontal cortex suggests why we can instantly recognise the insight. The brain has been concertedly pursuing the answer, but we were unaware of this. Because our consciousness is very limited in capacity, our prefrontal cortex makes all these plans without telling us. When the aSTG (that obscure circuit in the right hemisphere) generates the right connection, the prefrontal cortex is able to identify it instantly, and the insight erupts into awareness.

The parallels between Hadamard's phases and these stages, with each change of stage involving a change of brain area, are glaringly obvious.

FURTHER IMPLICATIONS OF MODERN RESEARCH

Back in the early 1990s, psychologist Jonathan Schooler demonstrated that it was possible to interfere with insight by making people explain their thought processes while they were trying to

solve a problem. As a result of the above description of the insight process we can now see why this happens: the very act of verbal explanation shifts mental activity to the left hemisphere, cutting off any subtler associations that might come from the right side of the brain. The relevance of this is that if your mind wants to wander (in the pursuit of a problem), let it wander. Concentration has its place, and in fact it is essential, but you have to know when to step back and encourage mental rambles.

Relaxation is another vital part of the process. You have to put in the hard yards of concentration, reach some sort of impasse, then relax. This combination encourages the prefrontal cortex to involve the right side of the brain. It all dovetails neatly with Dr Benson's "relaxation response" described above.

Attention versus distraction

IS MODERN LIFE UNDERMINING OUR ABILITY TO CONCENTRATE?

William James, a renowned psychologist and philosopher from over a century ago, defined attention as follows [ref 17 p.13]. "It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneous possible objects or trains of thought: withdrawal from some things in order to deal effectively with others." The importance of attention (or concentration, or focus) should already be clear to you, both from your personal experiences and from the above descriptions of its role in creative thought. Yet many of the features of modern life are limiting our opportunities to concentrate, perhaps even undermining our concentration abilities.

Psychologist Edward Hallowell, an expert in cognitive health, published a summary of his researches into human concentration in a 2005 edition of *Harvard Business Review*[18]. He has coined the term "attention deficit trait" (ADT) to describe the distractibility, inner frenzy and impatience now epidemic in organisations. ADT is brought on by the demands on our time and attention, demands that have exploded over the last two decades. People with ADT have difficulty staying organised, setting priorities, and managing time. (Note that ADT should not be confused with "attention deficit / hyperactivity disorder", frequently acronymed as ADD or ADHT. The latter is a neurological disorder that has a genetic component, whereas Hallowell's ADT springs entirely from the environment.)

Studies show that as the human brain is asked to process dizzying amounts of data, its ability to solve problems flexibly and creatively declines, and the number of mistakes it makes increases. The executive control areas of the brain (the prefrontal cortex and the anterior cingulate cortex) have become overloaded. This induces subconscious fear or panic-type reactions elsewhere in the brain, which in turn shift us towards survival mode.

Survival mode prevents fluid learning and nuanced understanding. Even if you do learn during periods of overload, the learning mechanism is adversely affected. An area of the brain called the striatum is involved, at the expense of the hippocampus which is involved in normal (unstressed) learning. As a result of this change, you will not be able to retrieve the "learned" information as easily.

The effects of this overloading go beyond the mental, too. In response to what is going on in the brain, the rest of the body also shifts into crisis mode. Among many other physiological responses, stress-related hormones such as cortisol and adrenaline are released. These can cause long-term health problems and short-term memory loss. As Walter Kern[19] puts it: "in the short term, the confusion, fatigue, and chaos merely hamper our ability to focus and analyse, but in the long term they may cause it to atrophy."

Hallowell offers some suggestions on how to "control your ADT". These include all the usual candidates, but he includes a few comments that might be new to some readers.

- On diet, he warns that you should avoid simple sugary carbohydrates and instead eat complex carbohydrates (vegetables, whole grains, fruit). The former cause blood glucose levels to yo-yo. Then the brain, which relies on glucose for energy, is left either glutted or gasping, "neither of which makes for optimal cognitive functioning".
- Exercise. Yair, yair, yair. You've heard that many times before. And it was explained above how exercise helps flush out brain toxins. But exercise also induces the body to produce an array of chemicals that the brain loves and thrives upon[20, 21, 22].

SOME MODERN TOOLS THAT MIGHT ERODE CONCENTRATION

In a slightly different, more specific, vein, several "tools of modern life" have been singled out in some literature as being prone to being used ways that can be detrimental to our ability to concentrate and/or think.

[Most of the material presented in the other sections of this document is relatively uncontentious. However you should bear in mind that some of the comments in this section are still "the subject of robust discussion" among psychologists and neuroscientists. No prizes for guessing which.]

Google

Google gets a bit of a pasting from Nicholas Carr in *The Atlantic*[23]: "For me, as for others, the Net is becoming a universal medium, the conduit for most of the information that flows through my eyes and ears and into my mind. The advantages of having immediate access to such an incredibly rich store of information are many. …. But that boon comes at a price. As the media theorist Marshall McLuhan pointed out in the 1960s, and summarised in his famous quotation "the medium ***is*** the message", media are not just passive channels of communication. They supply the stuff of thought, but they also shape the process of thought. And what the Net seems to be doing is chipping away my capacity for concentration and contemplation. My mind now expects to take in information the way the Net distributes it: in a swiftly moving stream of particles. Once I was a scuba diver in a sea of words. Now I zip along the surface like a guy on a jet-ski."

PowerPoint

Edward Tufte, a renowned expert on the presentation of information in visual formats, has written a powerful and informative, yet highly amusing, booklet on the failings of PowerPoint[24]. Among many criticisms, Tufte discusses how bullet outlines do not bring intellectual discipline — instead they accommodate the generic, the superficial, the simplistic. He further abhors what he calls "creeping PowerPoint", where the information-poor format of PP is increasingly used outside a face-to-face context (in which, in theory at least, it can serve as merely an outline to be talked around), for reports, internet pages, etc. Tufte concludes that: "PP routinely disrupts, dominates, and trivialises content. It allows speakers to pretend that they are giving a real talk, and audiences to pretend that they are listening."

Facebook

Facebook and similar *social networking* sites have drawn the ire of Baroness Susan Greenfield, a neuroscience professor at Oxford University and a director of the UK's Royal Institution. She believes that excessive use of these is causing alarming changes in the brains of young users[25, 26]. Social networking sites can provide a "constant reassurance — that you are listened to, recognised, and important". This is coupled with a distancing from the effort involved with face-to-face, real-life conversation, leading to self-centredness and an inability to empathise. Furthermore, children's experiences on social networking sites are devoid of cohesive narrative

and long-term significance. "It is hard to see how living this way on a daily basis will not result in brains, or rather minds, different from those of previous generations."

Computer games

Greenfield also takes aim at computer games. "If the young brain is exposed from the outset to a world of fast action and reaction, of instant new screen images flashing up with the press of a key, such rapid interchange might accustom the brain to operate over such timescales. Perhaps when in the real world such responses are not immediately forthcoming, we will see such behaviours and call them attention-deficit disorder". Greenfield is not alone in her views on computer games. Educational psychologist Jane Healy believes children should be kept away from computer games until they are at least seven years old: "most games only trigger the 'flight or fight' region of the brain, rather than the vital areas responsible for reasoning."[27]

MULTITASKING

One particular modern behavioural trait responsible for mental overload is *multitasking*, whose deleterious effects on individuals, corporations and society as a whole are described by Christine Rosen in an article that appeared in *The New Atlantis*[28]. Except where noted otherwise, what follows in this section is drawn mainly from that article.

In the late 1990s and early 2000s there was an exuberance about the possibilities of multitasking, and the term began to appear in the "skills" sections of CVs. But since then challenges to the ethos of multitasking have begun to emerge. Research conducted by the Institute of Psychiatry at the University of London (research funded by Hewlett-Packard) found that "workers distracted by e-mail and phone calls suffer a fall in IQ more than twice that found in marijuana smokers".

The same study also found that multitasking is a serious threat to workplace productivity. Separate work at the University of California at Irvine monitored interruptions among office workers, and found that workers took an average of 25 minutes to fully recover from interruptions such as phone calls or replying to e-mail. (This 25 minute duration, large as it seems, is quoted by author Richard Florida [ref 29 p.125] as well. Some other sources put it at around 15 minutes.) Discussing multitasking with the *New York Times* in 2007, Jonathan Spira, an analyst at business research firm Basex, estimated that extreme multitasking — information overload — costs the US economy $US650 billion a year in lost productivity[30].

Can people be trained to multitask better? At this stage, science cannot give a definitive answer to this question. However the weight of opinion seems to favour the view that we can learn to multitask for certain simple tasks, but not complex ones. In the view of David Meyer, psychology professor at the University of Michigan: "Training can help overcome some of the inefficiencies by giving you more optimal strategies for multitasking, but except in rare circumstances you can train until you're blue in the face and you'd never be as good as if you just focused on one thing at a time. Period." [ref 17 p.79]

This emphatic statement is taken even further by later research conducted at Stanford University[31]. This research began with the aim of finding the secret to good media multitasking, but ended up concluding that heavy multitasking was correlated with broad-based incompetence. It seems to reduce practitioners' abilities to focus attention, to ignore irrelevant information, to organise memories and information, and to switch between tasks. It even reduces the ability to multitask. Furthermore, "the more you do it, the worse you get". The authors hope to extend their research into whether people who multitask excessively are drawn toward doing so because their brains are wired differently, or they begin to think differently after they have been multitasking chronically. Either way, the results will have tremendous implications.

The link between close (note *close*) attention and learning has been observed in experiments on monkeys. Using a set of techniques collectively known as *brain mapping*, Professor Michael Merzenich has found that long-term physiological change in the brain ("plastic change") occurs

only when his monkeys pay close attention. When the animals perform tasks automatically, without paying attention, they change their brain maps, but the changes do not last [ref 32 p.68]. So, while you can learn when you divide your attention, divided attention does not lead to abiding change in your brain map.

ATTENTION IN CHILDREN

If, as stated above, multitasking changes the way people learn, what might this mean for today's children and teenagers, raised with an excess of new entertainment and educational technology, and avidly "multitasking" from a young age? The picture that emerges from several modern studies is of a generation of great technical facility and intelligence, but of extreme impatience, unsatisfied with slowness and uncomfortable with silence. There is a worry that they might become adults who engage in "very quick but very shallow thinking", and that "constant intentional self-distraction could well be of profound detriment to individual and cultural well-being".

And the very young? Daniel Anderson, a psychology professor at the University of Massachusetts, as reported by Maggie Jackson [ref 17 p.72], has researched the effects of television on very young children. Television, with its quick cuts and rapid imagery, is designed to tug at our natural inclination to be attracted by the bright, the shiny, the mobile — whatever is eye-catching in our environment. This works all too well with children, to the point where they are influenced even when they don't seem to be watching. When a television set is on, children aged between one and three play with toys for half the amount of time and show 25% less focus in their play. In other words they exhibit key characteristics of attention-deficient children. They move from toy to toy, forgetting what they were doing when they were interrupted by an interesting TV snippet. And remember that in most homes these days the television is on most of the time, even if just as "background".

Walter Kern[19] again puts it pithily. "Young people's still-maturing brains are being shaped to process information rather than to understand or even remember it."

Memory

What are we, if not our memories? Our memories define us. Yet memory is not an archive, nor does it record "in real time". The intensity of an experience may sharpen the memory of it, while making that memory less accurate. During periods of acute stress, for example, the body is flooded with damaging amounts of the hormone cortisol, breaking down communication relayed by neurotransmitters in the brain[33]. So our memory is not even reliable.

There is a dichotomous distinction between short-term and long-term memory. The brain can retain memories on a short-term basis for some minutes, or even hours, by some process of "keeping them in mind". But in order to be able to recall these after they have left one's attention, it is necessary that they be retained in a permanent way, and for this the hippocampus is essential. The hippocampus plays a vital role in the laying down of long-term memories, the actual memories being stored somewhere in the cerebral cortex — probably in many places at once [ref 1 p.380].

Note that there is a different form of "memory" that is stored in the cerebellum, the part of the brain which is responsible for precise physical coordination and control of the body: its timing, balance, and delicacy of movement. It seems that, when one is learning a new physical skill initially one must think through each action in detail, with the cerebrum in control. When the skill has been mastered — has become "second nature" — the cerebellum has taken over. Most of us have experienced situations where if we think about our actions in a skill that we have

mastered, then we temporarily lose our easy control. What is happening here is that we are reintroducing cerebral control.

AIDS TO MEMORY

A 2008 article in *New Scientist* listed four suggestions to assist memory[34]. The fifth suggestion below comes from elsewhere.

- **Pay attention**. (Discussed above.)
- **Be organised**. Memories are like pieces of mail. It takes very little effort to open your mail and throw the contents all over your desk, but you'll have trouble when you need to retrieve a particular piece. If you file related pieces together it is a lot easier. For memories, some sort of framework helps. Then you can "file" a memory item by linking it to an existing strong memory.
- **Get emotional**. Emotional arousal enhances memories, even when the memories themselves aren't emotional. (Lay-level technical explanation: the part of the brain known as the amygdala is involved in both emotions and memory, so firing it up on one front has benefits for the other front.)
- **Review**. (Your old friend from school days, come back to haunt you.) The act of retrieving items from memory makes them more likely to be remembered in future, and keeps them from being bumped out of the way by new memories. Do this very soon after your first encounter with something you want to remember, preferably within about 30 seconds. Then do it once or twice more, with increasing time between retrievals.
- **Get enough sleep**. Sleep is extremely important to the processes of consolidation of learning and memory. During parts of the night your brain can be more active than it is during the day. Sleep does more than just stabilise recently formed memories. It helps in the brain's processing of memory, integrating new memories into networks of older memories, identifying commonalities and differences among them, and providing insights based on this process. Rapid eye movement (REM) sleep is when this happens. Most sleeping pills reduce REM sleep, and therefore might reduce the amount of valuable work the brain can do [ref 32 pp.240–241, ref 35].

LOSS OF MEMORY

Before discussing *memory loss*, it should be noted that *forgetting* is important for mental health. "A system that records every detail willy-nilly and makes that information accessible on an ongoing basis is one that will result in mass confusion. We forget because the brain has developed strategies to weed out irrelevant or out-of-date information. Efficient forgetting is a crucial part of having a fully functioning memory. When we forget something useful it just shows that this pruning system is working a little too well." [34]

According to a survey conducted by the MetLife Foundation in 2006, Americans over the age of 55 fear getting Alzheimer's disease (AD) more than any other disease, while among respondents of all ages AD was second only to cancer. In spite of its unreliability, our memory is the fullest record we have of ourselves. We live through it as we live through breathing. (And not only in the figurative sense: in the most advanced stage of AD — a disease that first strikes the hippocampus, where short term memory is created, before spreading throughout the rest of the brain — one forgets, on a muscular level, how to exhale.)

There are two "common" diseases of memory loss. These are mild cognitive impairment (MCI), and Alzheimer's. The incidence of both these increases with age. It is not correct, as is frequently assumed, that MCI is a precursor to AD: only a small proportion of MCI sufferers go on to develop AD[36], and it is usually people who have memory problems combined with

problems in some other cognitive domain. Furthermore, some people diagnosed with MCI actually go back to being normal.

Specifically, AD begins with a thinning of the hippocampus's entorhinal cortex, an important memory centre in the brain, as a result of the death of neurons there. (Non-AD memory loss affects the dentate gyrus, a different part of the hippocampus.) When neurons in the entorhinal cortex fail to project into the next region of the brain, the neurons in that region die as well, starved of the connections needed to keep them alive.

One focus of present research is to understand the process by which neurons are created, neurogenesis. This remains elusive from a pharmacological point of view, but one incontrovertible means of neurogenesis has come to light. It is our mate *exercise* again. Aerobic (note *aerobic*) exercise promotes new cell growth in old brains by increasing their blood volume, and cell growth improves memory. In addition exercise increases the amount of brain-derived neurotropic factor (BDNF) circulating in the brain, and it is BDNF that stimulates the growth of new brain cells. BDNF also enhances neural plasticity, which is to say that it enables the brain to prosper. In diseases like MCI, AD, depression, Parkinson's disease, and dementia more generally, BDNF levels are low. In people who exercise adequately, BDNF levels rise. In summary, exercise both jump-starts neurogenesis and encourages the new neurons to join the existing neural network[20, 21, 22].

There is heartening news, too, for people worried about normal forgetfulness. Older people who do poorly on timed memory tests actually do as well or better than younger people when permitted to work at their own pace. This is because as we age we recruit the left side of the prefrontal cortex into action, whereas when we are younger we rely mainly on the right side. The neuropsychologist Elkhonon Goldberg believes, somewhat philosophically, that this "bilateralism" is a "physical manifestation of wisdom". (This increasing reliance on "wisdom" is sometimes talked about as a decline in "fluid intelligence" and an increase in "crystallised intelligence" [37].)

Expertise

According to a comprehensive article on the subject in *Scientific American*[38], expertise can be defined as "rapid, knowledge-based perception", sometimes called apperception.

Much of the research into expertise is based upon chess players. The reasons for this include the following: it has a reputation as a "touchstone of the intellect"; it can be measured (because of its rigorous, long-standing ranking system); it can be broken into components; it is readily observed and can be subjected to laboratory experiments; and there is a vast reservoir of historical information that can easily be tapped into. However this apparent narrowness turns out to be less of a limitation than you might fear, because (contrary to popular belief) chess masters do not utilise a "photographic" image of the board. Their visualisation is much more abstract, and is based on "implicit structured knowledge". These characteristics have been shown to be used by experts in other areas: what distinguishes experts is mostly more and better-organised knowledge [ref 39 p.397].

How do experts "structure" their vast amounts of information, their knowledge? There is no consensus of opinion among those with expertise on *expertise*. Several theories take as a starting point the established fact that our "working memory" — the scratch pad of the mind — has only a limited capacity. In 1956 the Princeton University psychologist George Miller estimated the limits of working memory by showing that people can contemplate only five to nine items at a time, famously calling his paper *The magical number seven, plus or minus two*.[40] The question then becomes how experts seem to be able to get around this limitation.

One theory posits that experts pack hierarchies of information into "chunks". Then each of Miller's seven (± 2) "items" can be an information-rich chunk. The more expert a person is, the richer the person's chunks have become. Allied with this, it seems that as people become expert some mechanism enables them to employ long-term memory as if it, too, were a scratch pad [ref 39 p.397]. Brain-imaging studies provide support for this.

One thing all expertise theorists agree on, however, is that it takes enormous effort to build these structures. Expressions such as the *ten year rule* and the *ten thousand hour rule* are used, and are supported by research into a wide range of fields[39, 41]. Even child prodigies must have made an equivalent effort, perhaps by starting earlier and working harder.

Another concept that appears when you read about expertise is "deliberate practice" or "effortful study". This entails continually tackling challenges that lie just beyond one's competence. It is why "enthusiasts" can spend their tens of thousands of hours on something without ever advancing beyond the amateur level, and why a properly trained student can overtake them in a relatively short time. The amateurs relax, and their performance becomes automatic and therefore impervious to further improvement. In contrast, experts-in-training keep their minds open all the time, so that they can inspect, criticise, and augment their skills. A neat definition of "deliberate practice" is given by Geoff Colvin[42].

> Deliberate practice is characterized by several elements, each worth examining. It is actively designed specifically to improve performance, often with a teacher's help; it can be repeated a lot; feedback on results is continuously available; it is highly demanding mentally, whether the activity is purely intellectual, such as chess or business-related activities, or heavily physical, such as sports; and it isn't much fun.

It is worth noting that there is usually a clear distinction between work and deliberate practice [ref 39 p.368]. People are expected to give their best at work, and hence will tend to rely on well-entrenched methods rather than explore alternative approaches with unknown reliability. The costs of mistakes or failures to meet deadlines are generally great, which frequently discourages learning and acquisition of new and possibly better methods during work time.

In the development of expertise, motivation appears to be a more important factor than innate ability. Furthermore, success builds on success because each accomplishment can strengthen motivation. Experts are made, not born.

Final remarks

To wrap up, let's summarise some of the sorts of things you can do to increase your mental abilities.

Firstly, maintain and train your brain.

- Exercise it, because the "use it or lose it" rule applies to mental acuity. In fact, modern theories of brain plasticity suggest that the human brain is particularly vulnerable to this effect.
- Feed it facts and information. Then feed it more facts, and more information.
- Help it flush itself by getting regular physical exercise. For flushing, this exercise does not need to be all that vigorous. However vigorous exercise brings further mental benefits, as well as numerous benefits for your overall health.
- Eat well:
  - Include long-chain omega-3 fatty acids in your diet. These are most easily found in fish, particularly oily fish such as salmon.

- Eat more antioxidants. These are good in general. However they are particularly good for brain health. The brain consumes a lot of energy, and the reactions that release this energy also generate oxidising chemicals. Moreover, brain tissue contains a great deal of oxidisable material, particularly in the fatty membranes surrounding nerve cells[43].
- Do not overeat. This puts oxidative stress on the brain.

Secondly, learn how to use your brain properly.

- Discover your optimum stress level.
- Discover the relaxation methods that work best for you.
- If your preferred relaxation method involves staring out the window with a glazed look on your face, do so whenever you feel it might help, and do so without any feeling of guilt.
- Learn to enjoy baroque music.
- When you need to concentrate hard on something, do whatever it takes to avoid interruptions.
- Dust off and re-learn the memory-aiding techniques you used as a student. You are still a student, and will remain so all your working life (and beyond).
- The best way to assist your recall of material in an area is to develop a genuine interest in that area. Then what might have been a chore becomes a pleasant relaxation. How hard will Geelong supporters have to work to be able to recall, a decade after the event, that they won the 2007 Grand Final by 123½ points?
- Read voraciously, both to deepen and to broaden your interests.
- Encourage your boss to understand these requirements.

Finally. Do not expect that you will be able to summon inspiration frequently or on demand through these techniques, or through any other techniques for that matter. Instead be cheered by the words of Warren Buffet, the world's most successful investor, who said at his shareholders' meeting in 2006, "You don't need to have a ton of good ideas, just one idea worth a ton."

References

I have my own copies (or partial copies) of nearly all these references, and more. They can be borrowed for short periods on request, but some conditions might be imposed.

1 Penrose, Roger. 1989. *The Emperor's New Mind*. Oxford University Press. [It was this book, a brilliant but quixotic attempt to argue against the then-current view that "artificial intelligence" would eventually mimic then exceed human intelligence, that first kindled my interest in how our brains work.]

2 Quoted by Hadamard. See below.

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5 Quoted by Helen Phillips in *New Scientist* of 29 October 2005, p.40. Article titled *Looking for inspiration*.

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31 This research was widely reported at the time it was published. See, for example, *The Age*, 27 August 2009, page 12. Also the Wall Street Journal's URL http://blogs.wsj.com/digits/2009/080/26/why-multitaskers-stink-at-multitasking/ [accessed 28 August 2009]. I have not been able to read the research article itself, but its details are: Ophir, E., C. Nass, and A.D. Wagner. *Cognitive control in media multitaskers*. Proceedings of the National Academy of Sciences, Vol.106, No.33, 25th August 2009.

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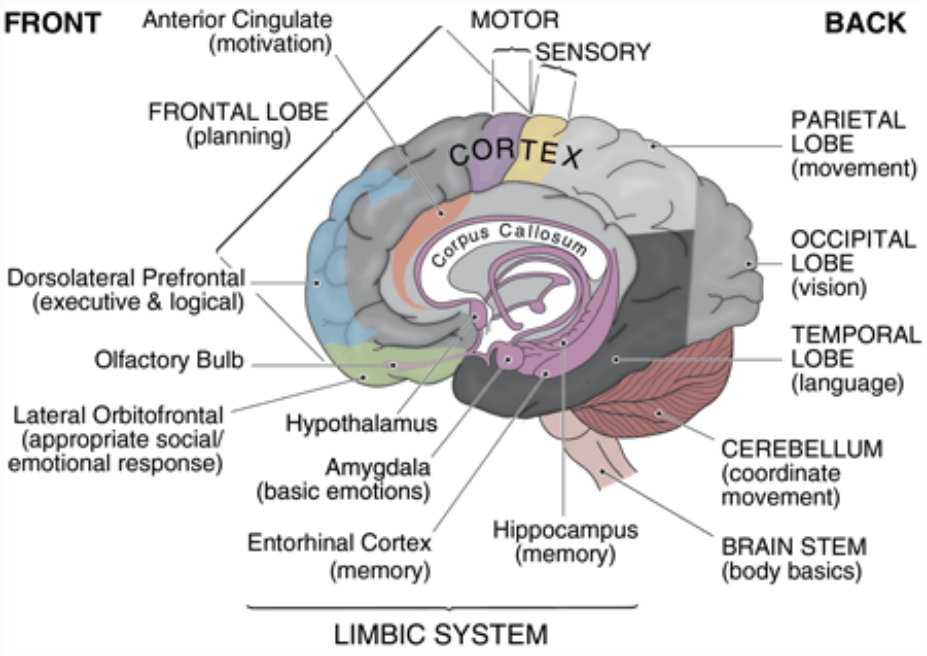
Revision History

Revision	Released	Comment	Released by
1.0	Oct 2007	Published	R.M.Niall
1.1	Nov 2007	Licked into a shape slightly more appropriate for a written document, then provided to the original attendees.	R.M.Niall
0	Mar 2009	Restructured. Sections on concentration, memory and expertise commenced. Converted a new format.	R.M.Niall
1	—	Minor refinements.	Never released
2	Aug 2009	Commenced June 2009. Added more on "deliberate practice", and multitasking.	R.M.Niall
3	Nov 2012	Commenced September 2009. Minor rewordings. Additional references.	R.M.Niall
4	Nov 2013	Commenced December 2012. Minor rewordings. Additional references.	R.M.Niall

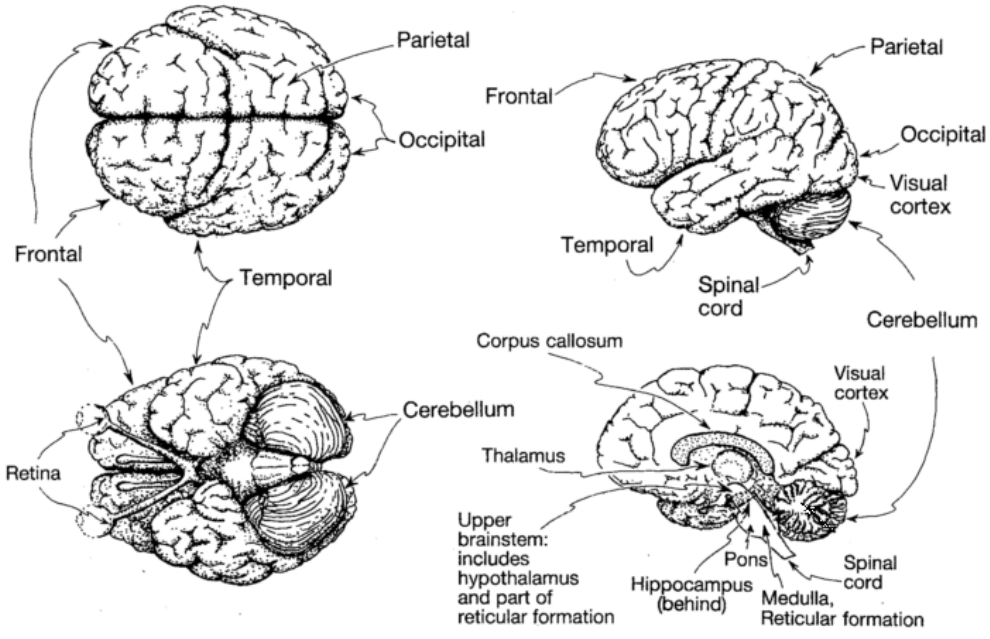
Appendices

A1. THE VARIOUS REGIONS OF THE HUMAN BRAIN

This first diagram comes from the web site www.brainwaves.com (as at January 2009).



This second diagram comes from Roger Penrose's book[1].



The human brain: above, side, beneath, split.

Penrose's book, in its chapter 9, provides an excellent non-specialist description of brain structure at the cellular level, covering (among a lot of other interesting material) neurons, axons, synaptic knobs, and the electrochemical processes involved in brain signalling.

A2. A PERSONAL EXAMPLE OF UNCONTROLLED CREATIVE THOUGHT

I have had just one personal experience of a more elaborate birth process for an idea. It was downright spooky, and potentially dangerous in the circumstances. Along with a couple of other engineers, I was trying to assess the likely ground shock waves that would be set up when a tall, brick chimney was deliberately toppled. Large lumps of brickwork would be hitting the ground at random intervals, each impact initiating its own shock wave. These waves would be superimposed on each other, some positively and some negatively. How big was the resulting combined wave likely to be?

Vibrations and vibration waves can be described geometrically by mathematical entities called phasors, which are really nothing more than rotating vectors, and which are usually drawn as rotating arrows. A phasor's length represents the unchanging magnitude of the vibration's amplitude, its orientation represents the changing phase of the vibration, and its rotation speed represents the frequency of the vibration. I had been wrestling with this superposition problem intermittently for several days. Come 6pm on Friday evening I left work, with no intention of doing anything on the problem until Monday morning. I was driving home, through a particularly busy area. There were pedestrians darting all over the place, cars everywhere, trams, bicycles. It was full peak-hour chaos, requiring my total concentration: the very antithesis of a calm and relaxed atmosphere (sorry, Professor Hadamard).

Suddenly, in front of me, so real that I felt I could reach out and touch them, there appeared a host of phasors, all in the same vertical plane and all quietly rotating in random relation to each other. Then, as I watched them, mesmerised by them, they slowed down and stopped rotating. Finally, holding their frozen, random orientations, they rearranged themselves one by one, joining up head to tail, and forming a perfect circle. I immediately realised that the diameter of that circle was the answer we had been seeking. The entire process probably took about five seconds, but I really have no idea: it wasn't so much that "time stood still", more that time ceased to exist.