A STUDENT'S GUIDE TO COGNITIVE NEUROPSYCHOLOGY

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WHY STUDY DAMAGED BRAINS?

Chapter Overview

Why do psychologists who are ultimately interested in understanding how the healthy brain functions study individuals who have brain damage? This chapter will provide a background to how this field developed. Given that there are a number of related but different fields, the connections and differences will also be addressed.

Chapter Outline

- Introduction
- Historical Background
- Modern Cognitive Neuropsychology
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INTRODUCTION

If, as stated above, one of the main goals of cognitive psychology is to understand normal (intact-brain) human behaviour, in particular mental abilities, it may initially seem strange that cognitive neuropsychologists accomplish this by studying damaged brains. To answer why they are effectively working 'backwards' from an incomplete system, a succinct quote from an important Scottish philosopher and psychologist, Kenneth Craik – who was the first director of one of the most important psychology research centres in the world, the Applied Psychology Unit – is very useful. Craik said, 'In any well-made machine one is ignorant of the working of most of the parts – the better they work, the less we are conscious of them… it is only a fault which draws attention to the existence of a mechanism at all' (1943, p. 84). The human cognitive system is a finely tuned 'machine', having evolved over millions of years, and while we may have access to *some* aspects of how and why we do things (for example, how we might plan a weekend away), for many abilities (for example, how you manage to convert the black ink on this page into an understanding of what I am trying to say) such an understanding is quite difficult. In fact, some skills that we think are effortless such as seeing or walking are the most complex, such that the best artificial intelligence systems cannot mimic them (Moravec, 1988). Although cognitive psychologists attempt to address this difficulty through research, in some aspects of behaviour, it is only when the intact system malfunctions, through for example brain damage, that it is possible to get a real sense of the complexity. It is in this sense of looking at a damaged system that cognitive neuropsychologists study the complex processes of memory, object recognition, face recognition, reading, problem solving, etc.

HISTORICAL BACKGROUND

The Ancients

Given that in the modern world the importance of the brain is taken for granted, it is interesting that much of the insights that have been gained into its functioning have happened since the middle of the nineteenth century; in fact, the vast bulk of knowledge gained has been only in the second half of the twentieth century. Compared to some other disciplines such as biology, physics and astronomy, psychology and particularly knowledge of the role of the brain in human behaviour is a very new discipline. A brief review of the history of the study of the brain will help in understanding why this has come about.

Figure 1.1 Portion of the Edwin Smith Surgical Papyrus with the ancient Egyptian hieroglyphics for the word 'brain' (Reprinted with permission from Wikipedia Commons)

It is known that at different times in ancient history and in civilisations that were quite far from one another, some knowledge of the brain existed. In an ancient Egyptian document known as the Edwin Smith Surgical Papyrus, the first written documentation of the word 'brain' appears; the papyrus gives physical descriptions of the brain, the consequences of damage to it and also proposed treatments (see Figure 1.1). While the physical document is from around 1700 BCE it is thought to be a copy of an earlier manuscript dating from between 3000 and 2500 BCE! In the Hindu culture in ancient India thousands of miles away, the *Atharava Veda* – one of the holy Hindu scriptures known as the *Vedas* (which were composed around 1000 BCE) – speaks of nine areas in the brain which map to different points along the spinal cord. These areas known as *chakras* are still much-used in contemporary alternative medicine. Within the same culture, the father of medicine was a physician called Jivaka who was known to have treated Lord Buddha (c. 563 BCE to 483 BCE). Ancient texts state that Jivaka learnt how to open the skull and is said to have removed two **tumours** from the brain of a merchant.

Moving to ancient Greece, there was great debate as to which organ controlled the body, the heart or the brain. While the prevailing view was that it was the heart, the father of Western medicine Hippocrates (c. 460 BCE to 375 BCE) wrote 'Men ought to know that from the human brain and from the brain only arise our pleasures, joys, laughter, and jests as well as our sorrows, pains, griefs and tears… It is the same thing which makes us mad or delirious, inspires us with dread and fear… brings us sleeplessness, inopportune mistakes, aimless anxieties, absent-mindedness and acts that are contrary to habit…' (pp. 174–175).

Phrenology and Diagram-Makers

Despite Hippocrates and later thinkers, the heart-centric view prevailed; this is seen all the way into the sixteenth century in the works of possibly the greatest playwright ever, William Shakespeare. For example, in *The Merchant of Venice* he wrote: 'Tell me where is the fancy bred, Or in the heart or in the head?' It wasn't until the seventeenth century, in the middle of the scientific revolution, that the Aristotelian, heart-centric view was rejected and the primacy of the brain recognised. However, although an understanding of the *physical* aspects of the brain was developed in the next two centuries, it wasn't until the end of the eighteenth century, largely thanks to pioneers like the Italian scientists Galvani and Volta, that thoughts that correlate in any way to modern knowledge of the brain were proposed.

The very earliest roots of neuropsychology lie in the field of **phrenology** developed primarily by a German doctor, Franz Joseph Gall, in 1796. The phrenologists believed that certain mental 'faculties' (or abilities) were located in different parts of the head and that the strength of this faculty determined the size of bumps on the skull. The American Lorenzo Niles Fowler believed, for instance, that the 'literary, observing and knowing faculties' were situated above the right eye, that selfish properties resided under the skull above the right ear whilst 'marriage, conjugality, constancy' was found near the base of the skull at the back of the head slightly to the left of centre. Given this correspondence between a mental ability and contours on the skull, this approach suggested that measuring the size of the bumps would reveal how much of a particular faculty an individual had (see Figure 1.2). Given its novelty, phrenology seemed exciting at the time and was even used as the basis for therapy in psychiatry for a while, but in the end it did not gain any support within the scientific community and therefore, as a basis for a theory, was discredited and forgotten. However, its importance was that it started to build momentum behind the concept of **functional specialisation** – the idea that our mental abilities were separable into **modules** (such as memory and language) and that these modules may be localised in specific parts of the human brain.

The true roots of contemporary neuropsychology can be found in the work of the French neurologist Paul Broca. In 1861, he reported the case of a man who had suffered a **stroke**, which is the bursting of a blood vessel in the brain (see Chapter 2 for more on causes of brain damage). Broca reported that his patient had great difficulty making intelligible utterances. At most, only a few syllables were ever produced at any one time, i.e. nothing that sounded like real connected language, and due to the sound of one of the syllables that the patient could make, he became known as 'Tan'. Despite this profound inability to produce intelligible language (which later became known as **aphasia**), the interesting thing was that Tan was able to fully understand what was said to him. He could follow verbal commands, could show that he could remember something said to him earlier that day, point to objects if asked to do so, etc. as long as no verbal response was required. As a result of his work with Tan, Broca proposed that the part of the brain

Figure 1.2 Diagram of a phrenology head map or of a classic phrenology bust (Reprinted with permission from Upsplash.com)

that was damaged was responsible for co-ordinating the patterns of muscle movements required for saying individual words. He suggested that damage to this area would mean that, although the vocal apparatus in the throat and mouth probably worked, they were not sent the appropriate signals by the brain to make the correct movements for speech, resulting in the pattern of behaviour found in Tan. After Tan's death, analysis of his brain revealed what Broca had suspected – that a particular area of his brain had been damaged with the rest of the brain being relatively intact; Figure 1.3 shows Tan's brain which has been preserved at a museum in Paris, with the blackened area towards the front of the brain being that which once occupied brain tissue but was destroyed following Tan's stroke. This area of the brain is now known as Broca's area, in recognition of his pioneering work in the field of language production.

Figure 1.3 Tan's Brain (Copyright © 1997, rights managed by Georg Thieme Verlag KG, Stuttgart & New York)

Just a decade after Broca's seminal work, in 1874, Karl Wernicke, another neurologist was working with a number of patients who demonstrated a pattern of problems that seemed to be the reverse of those shown by Tan. These patients appeared to be able to speak fluently (in that whole words were produced in continuous speech that, superficially at least, *sounded* like full sentences), but they had difficulties in understanding what was said to them. However, although the speech sounded fluent, it had many errors (known as 'neologisms') and was almost incomprehensible. In an attempt to explain this pattern of impaired speech, Wernicke proposed that the area affected in his patients was responsible for storing the sound patterns of words and that damage to this area resulted in difficulties in comprehending speech. Although Wernicke's suggestion explained poor comprehension, it didn't account for the patients' problem in *producing* fluent speech; this issue is still not fully understood. Following the death of one of the patients, a post-mortem revealed a clear specific area of damage. The damage was slightly further back in the brain than Broca's area, this time in an area known as the left **temporal lobe**; this area is now known as Wernicke's area (see Figure 1.4).

Although both Broca and Wernicke were neurologists (medical doctors who treated patients with brain damage), they can be regarded as the forefathers of modern neuropsychology; the reasons are twofold. The first was a demonstration of the separation of mental abilities, since the patients documented by these neurologists had deficits that were largely restricted to their language, leaving other abilities (e.g. memory) intact. This **dissociation** of abilities has been instrumental in the development of modern neuropsychology (see Chapter 3). The second important contribution was that by examining the patients' brains at post-mortem and showing that their damage was restricted to very specific areas, there was some vindication of the idea of functional specialisation within the brain that the phrenologists had promoted. Whilst the actual faculties proposed by

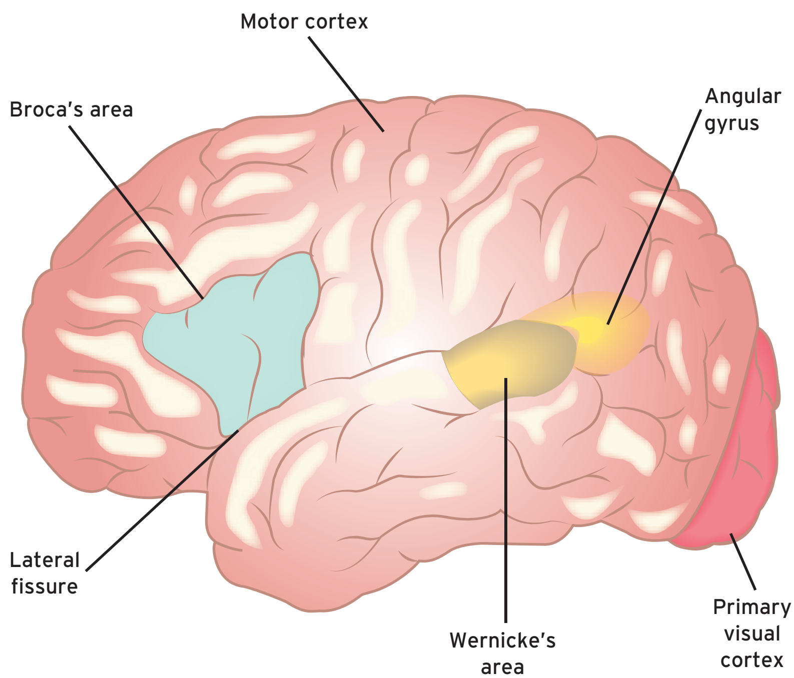

Figure 1.4 Broca's and Wernicke's areas on one brain image (Garrett & Hough, 2017)

the phrenologists were largely wrong, at a basic level, their idea of discrete functions in specific areas of the brain was supported.

As a result of their approach, Broca and Wernicke became known as 'localisationalists' because they believed that certain functions were firmly localised in particular areas of the brain, i.e. speech production in Broca's area and comprehension in Wernicke's area. The result of this trend towards localising functions anatomically was that, eventually, other neurologists like Lichtheim (1885) started attempting to create models of the production of spoken language. Due to the box-and-arrow visual models that were created, they became known as the 'diagram-makers' (see Figure 1.5).

Initially, this approach received considerable support. In fact, Wernicke even made predictions based on such models about the possible existence of another form of language problem which *as yet* had not been documented by any clinician. Lichtheim (1885) went on to discover a patient with such a problem, thus demonstrating the scientific validity of the methodology; from clinical observations, claims were made about certain aspects of language and their physical location in the brain, a model was proposed to incorporate these suggestions, a new prediction came out of the model and this prediction was upheld with a new discovery. Such was the impact of the early diagram-makers and localisationalists that Shallice refers to the period between 1860 and 1905 as the 'golden age of the flowering of neuropsychology' (p. 3, 1988).

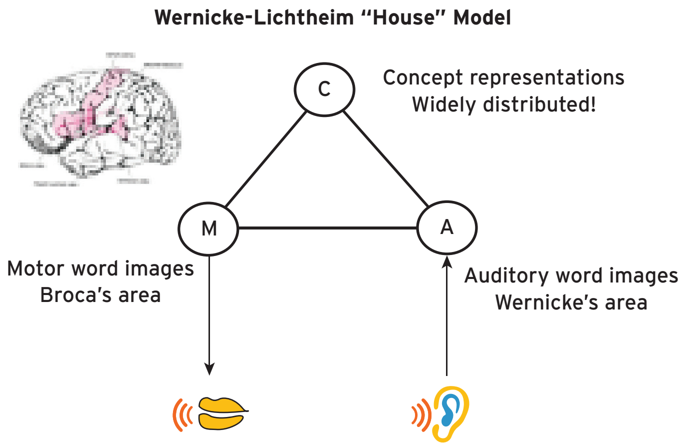

Figure 1.5 Lichtheim's model of language (Speak by Gregor Cresnar from NounProject.com, Listen by Rémy Médard from NounProject.com)

Disfavour with 'Black Boxology'

Although the diagram-makers had created a very energetic momentum, unfortunately, during the early part of the twentieth century, their approach weakened. This happened for a number of reasons, both from within the field of neurology and from outside the field. Many neurologists criticised the earlier work saying that while the localisation of suggested functions was very precise, the descriptions of both the patients' problems and the concepts that were used to explain the problems were rather vague. For example, Broca interpreted Tan's problems as being caused by a loss of 'motor images' required for making intelligible sound. However, patients who suffer the same fate as Tan (known as Broca's aphasia: see Chapter 10) tend to be able to make individual sounds and therefore seem to have the 'motor images' to make these utterances, but they cannot create connected meaningful sentences to communicate effectively. Therefore, there was a lack of clarity concerning how each of the centres in the elaborate models functioned. A particularly damning definition of this 'black boxology' (since the centres were likened to boxes that couldn't be looked into) comes from Sutherland who defined it as 'the construction and ostentatious display of meaningless flow charts by psychologists as a substitute for thought' (1989, p. 58).

In addition to the criticism of the level of clarity, another challenge came in the form of Lashley's (1929) theory of 'mass action'. This was the suggestion that many parts of the brain can serve the same functions as one another and so loss of a particular part of the brain does not result in any specific loss of behaviour but a general decrease in efficiency proportional to the amount the brain that was damaged. If it didn't matter which part of the brain was damaged, just the extent of the damage, that challenged one of the bedrocks of the nineteenth-century diagram-makers, i.e. functional specialisation. Although Lashley's views have largely been disproved, at the time that he proposed his theory, it added a further nail in the (temporary) coffin of the diagram-makers.

A final major reason for the demise of the diagram-makers' approach was a shift in the focus of the general field of psychology. While the neurologists had been studying patients with brain damage to understand some aspects of behaviour, parallel to that, in Germany Wilhelm Wundt founded what many people see as the first systematic methodology in psychology known as **introspection**. This approach flourished between 1860 and its eventual demise in 1927 and, in brief, involved the observation of one's own thoughts, feelings and mental states to try to derive theories of general human behaviour. They trained participants on how to report their experiences and, after this training, they might have asked the person how they solved a mathematical problem and the way that they described it would be seen as indicative of mental processes common to everyone when carrying out the same task. Whilst this approach flourished for over half a century in Europe, its demise came when there was a huge shift in psychology. There was criticism of the unreliable and subjective nature of much of the findings that came from individuals' observations of their own thought processes.

Instead, in 1913, John Watson in America suggested that the proper scientific study of human behaviour should be based on what was observable, measurable and replicable. A classic example from the school of behaviourism was the work of the Russian physiologist Ivan Pavlov who was studying the digestive system in dogs. He noticed that dogs would start salivating when they heard the footsteps of the researchers bringing them food. This anticipatory behaviour at the sound of the footsteps then became formalised in experiments where he began to play sounds from different objects (buzzer, harmonium, etc.) just before the dogs were meant to be fed; what he found was that eventually the dogs had become 'conditioned' to the sounds and would salivate simply when they heard them being played. This work, which won Pavlov a Nobel Prize for Medicine/Physiology in 1904, was seen as a perfect example of solid observable, measurable and replicable work that could be applied to the understanding of both animal and human behaviour. Given the criticisms that were coming from within neurology concerning the unscientific observations and explanations offered by the diagram-makers, it was no surprise that, for psychologists investigating normal human behaviour, the subjective research on rare individuals with brain damage didn't take off.

Consequently, for a number of different reasons, the approach of the nineteenth century neurologists faded into the background for those attempting to study the human mind. During the middle of the twentieth century, therefore, while some neurologists continued studying individuals with brain damage, their approach was a different one, that involving studying large groups of patients who all had similar areas of brain damage.

The Emergence of Cognitive Psychology

The next milestone in research on mental functions happened with what has become known as the 'cognitive revolution'. There are a number of different factors that resulted in what was to be a huge shift in focus. In 1959, two quite pivotal events occurred.

Noam Chomsky presented a paper at the Massachusetts Institute of Technology which criticised the dominance of the behaviourist approach, particularly with respect to a theory by one of its prominent leaders, B. F. Skinner who had claimed that human language could be explained using principles derived from an offshoot of Pavlov's conditioning work. Chomsky outlined a number of areas where this was not possible and argued strongly that there was at least some biologically inherited aspect to the learning of language. This weakening of the behaviourist stranglehold on psychology was mirrored by the events in Cambridge in the UK where Donald Broadbent in 1958 proposed that human mental abilities could be seen as a sequence of processing stages. This view has become known as the **information processing approach** and was partly driven by the very early stages of the development of computers. At the time, these devices were only known within the scientific research arena and were being used for processing of information through a series of defined stages.

This comparison between a computer and the human brain can be seen at a number of levels (see Figure 1.6). Both systems have got input devices, physical hardware that does the processing of information and some form of output. In the case of a simple computer its input device is the keyboard, the physical hardware is the range of internal circuit boards and the output device is the screen or a printer. To allow someone to use the computer, it needs software such as a word-processing programme; the result is that a series of ordered key presses on the input device (keyboard) is transformed by the circuit boards (hardware) using the word-processing programme (software) into a written piece on the computer screen or printed onto paper (output). In an analogous

Input system	*Hardware/software*	*Output*
computer		
typing on keyboard	PC or Mac/Word	essay
human cognition		
asked D.O.B.	brain/memory	"14/2/1967"
see 'CAT'	brain/reading system	"cat"
see 	brain/visual recognition	"Garfield"

Figure 1.6 The analogy between a computer and human cognition

way, human **cognition** has five input devices which are the five senses which transform different external stimuli (light, sound, tastes, odours and skin pressure) into nerve signals that are sent to the brain. These signals are processed here and depending on the particular cognitive function and the action you are aiming to perform, there is usually some sort of behaviour towards this input. Sometimes it may simply be to pay attention to it to decide what you are going to do later, or it may be to visually recognise what you are seeing, or it may involve acting towards the input; this action can either be a physical movement such as reaching out to pick up an object or it may be a verbal response. The functioning of the input and output devices (the five senses and motor control) is studied by physiologists and is relatively well understood. Therefore, for example, a substantial amount is known regarding the effect of light on the various components of the eye, on the physical rods and cones found on the retina and then the conduction of nerve signals from there via a major bundle of fibres known as the optic nerve. Similarly, the physical structure of the brain is fairly well understood and had been mapped out to some degree of accuracy by the end of the nineteenth century. What is not well understood about the human system, however, is the equivalent of the word-processing programme, i.e. the 'software' that processes information in the brain. The software that is involved in mental abilities is known as cognition. For example, looking at a cartoon of a cat activates the 'visual recognition' software (see Figure 1.6). This software processes the series of shapes, colours and possibly even context to finally derive the 'output' which is the name of this object, i.e. Garfield the cat. Similarly, if I was asked my date of birth, this would activate my memory software which would access that bit of information about myself to give you the answer. Finally, seeing a series of letters on a page will activate the reading system to name the word as */cat/*. In each of these examples a different aspect of cognition is accessed to enable the brain to process the external information to produce the desired behaviour. The work of the cognitive psychologist is to unravel the extremely complex programmes that have effectively been written through the very long process of human evolution.

This analogy between a computer and the way that the brain processes information has proven very fruitful. In the same way that the computer has a series of subroutines (that are usually chugging away in the background without you realising it), so does human cognition. For example, a very important part of visual recognition involves edge-detection and working out which lines belong to which object. It is only once this subroutine has been completed that the next stage of visual recognition can proceed. Similarly, the computer performs many tasks in **parallel**, i.e. a number of processes can occur at the same time. For example, my laptop is playing me soothing music at the same time as converting my finger-strokes into words on the screen. In the same way, my hearing apparatus can listen to and enjoy the music whilst simultaneously letting my language system produce the text you see before you. Similarly, the computer can take information stored in one format, for example on a numerical spreadsheet, and use it in a word-processing format. This interaction between different aspects of the computer can be seen in the interaction between the modules of human cognition. For example, when watching a film, while it is the visual recognition system that is making sense of what you are seeing, the memory system will be activated if trying to remember where you have seen a particular actor before.

The importance of the cognitive revolution is that a number of the criticisms made against the diagram-makers at the end of the nineteenth and beginning of the twentieth centuries were no longer valid. Cognitive psychology resulted in more box and arrow diagrams but armed with the ideas about information processing, computation and representation, researchers are now able to put something inside the black boxes that had been the downfall of the early diagram-makers. For example, whereas Lichteim may have said that there was a centre for word recognition which, if damaged, would result in difficulties in understanding language, cognitive psychologists could now attempt to describe what might happen in such centres. So for example, there now exist very complex models of reading (e.g. Patterson et al., 2017: see Chapter 10).

MODERN COGNITIVE NEUROPSYCHOLOGY

With the advent of cognitive psychology, it was possible for clinical neuropsychologists to work with those who were building cognitive models to try to better understand the disorders suffered by neurological patients. Two vital papers that seemed to really signal the birth of modern cognitive neuropsychology were those by British researchers Marshall & Newcombe (1966) on a patient with a very specific reading disorder (see Chapter 10), and Warrington & Shallice (1969) on a patient with a very selective short-term memory deficit (see Chapter 8). Within a decade of this, in 1980, Max Coltheart wrote the first ever book to discuss the use of neuropsychology as a cognitive approach, *Deep Dyslexia*. The arrival of this approach as a field was signalled by the founding of the journal *Cognitive Neuropsychology* in 1984.

A final important factor in the history of cognitive neuropsychology was the development of more and more sophisticated techniques for looking at the brain (e.g. PET, MRI and fMRI: see Chapter 2). Whereas Broca and others had to wait until their patients' deaths to be able to look at their brains, now it is possible to look at the patients' brain while they are alive. This has a huge impact for a number of reasons. Firstly, before the development of these techniques, researchers had to rely on simple paper and pencil tests which were developed with the rationale that bad performance on them indicated damage to specific parts of the brain (e.g. bad performance on certain subtests in an aphasia battery would imply damage in Broca's area). Now, however, it is possible to 'see' the damage in the living brain. This has a significant impact on being able to treat patients – if surgery is involved, surgeons have a much more accurate picture of what they need to work on. Secondly, the information on which parts of a brain are damaged in particular patients allows psychologists to develop more accurate models of the behaviour that they are trying to explain. Techniques such as fMRI make it possible to look at what parts of the brain are particularly active when normal healthy participants carry out tasks (e.g. reading). This allows cognitive neuropsychologists to bring together data from both the healthy and the damaged brain.

Overall, the aims of cognitive neuropsychology are:

1 The attempt to understand healthy function by studying dysfunction.
2 The use of the new understanding of healthy functions to help diagnose and understand difficulties of new patients.
3 The application of knowledge about both impaired and intact functions to develop methods of rehabilitation for patients.
4 The localisation of cognitive functions to specific parts of the brain.

Very few neuropsychologists work at all the levels above. For example, some might exclusively work with patients as a mirror onto healthy functions while others might do this but also use their understanding to develop new assessments of the dysfunctions they have studied. In general, those working in clinical settings are the only ones likely to attempt to develop rehabilitation techniques. Finally, only some neuropsychologists will be interested in trying to localise functions; they may be particularly interested in trying to develop functional architectures of brain systems to show how different parts work together in networks to perform the intricate cognitive functions that most humans can perform effortlessly. As an example, however, Figure 1.7 is a 'map' with landmarks of the specialisations of different parts of my brain (the image has been created using the Brainvox system described in Chapter 2). However, many neuropsychologists will seldom do this since they feel that working on the 'programme' of how we perform a cognitive function is much more important than where the hardware for that programme is situated.

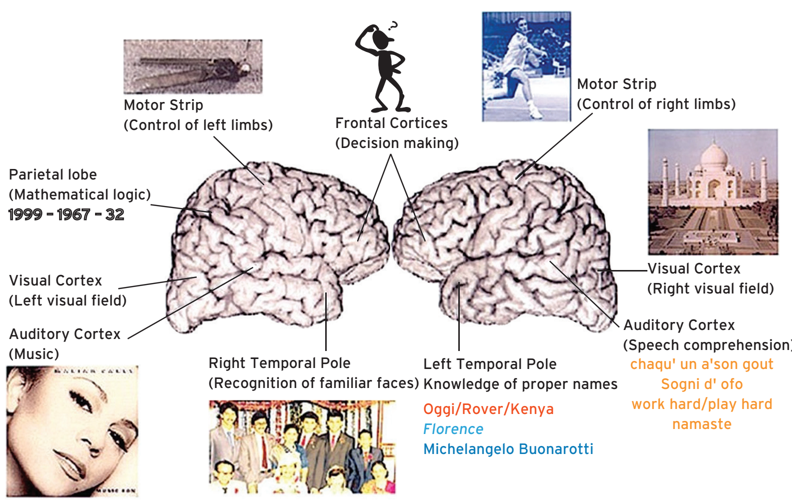

Figure 1.7 Three-dimensional images of AJ's brain showing the localisation of some of the main cognitive functions

It is important to note that the brain works in networks so although the areas that are marked specialise in the named specific functions, they will be receiving input from and sending output to other brain areas as well.

CONNECTIONIST MODELLING

In the 1980s a new piece of the arsenal for some neuropsychologists was the birth of connectionist modelling, which came from the broader field of cognitive science. The principle behind this approach is that it is possible to describe mental processes (such as how you translate the visual input CAT into the sound /*cat*/ by very simple units in an interconnected network. The network would have a layer of input units, a layer of output units and either one or more 'hidden' layers (see Figure 1.8). The individual units between two adjacent units would be connected to one another and have the possibility of activating or inhibiting each other; the strengths of these connections varied and could *change* depending on how the model was programmed; this change was to mimic learning that can occur after we experience something a number of times. It should be noted that these networks were *not* developed to be a *direct* representation for the three layers in Figure 1.6 (on p. 10); however, at some levels, the attempt is to *eventually* try to scale up to that level of explanation. So although units are not supposed to represent individual neurons and their connections, the synapses between neurons (see Chapter 2), the analogy would be appropriate.

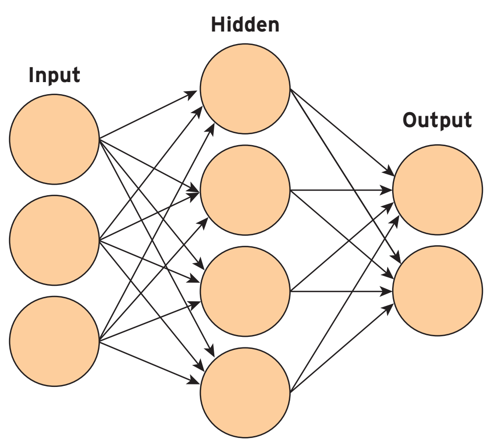

Figure 1.8 An example of a simple connectionist network model (CC BY-SA 3.0)

The process would involve programming the model to define what the input layers could process, what the form of the output would be and importantly how the individual units connect to one another. Do some units in the input layer have very strong connections with some of the hidden units but virtually no connection with the remainder? Do units in the hidden layer only activate the ones in the output layer if they receive a *minimum* level of input from the input layer? The actual process of how the model is programmed and how it 'learns' is beyond the scope of this chapter but the overall aim is that if the programme and its 'output' mirrored that of healthy or brain-damaged individuals then the programme could represent those cognitive processes in the brain.

In this approach, mental representations (such as reading) were programmed as information units and the models were then given inputs (such as the letter string CAT and the output was evaluated to see if it was the *same* as human performance. Importantly, in connectionist models, it was important that the output was the *same* as the output of human cognition *including* the errors that are made. If there was a difference between the two, then this meant that the processes programmed into the model did not *yet* represent human cognition. By a process of trial and error, the *strengths* of the connections or the representations themselves were adjusted and then the model was tested again with inputs and the output evaluated. This process of testing with inputs, evaluating the output, adjusting the strengths, and then repeating the process was run many times until the model produced an output that resembled human performance. Within cognitive neuropsychology, connectionist modelling was used to try to explain the difficulties shown by patients. To do this, a model was 'lesioned' by either 'damaging' the representations or the connections between them; the damaged model was then tested again to see whether it produced the same errors as the patients. If the model mimicked either intact or brain-damaged performance, it was plausible to suggest that the representations and the processes within the model were simulating human cognitive processes.

As an example, in the field of object recognition, Farah and McClelland (1991) attempted to create a model to explain an intriguing finding whereby some patients had difficulties recognising only certain categories of visually presented objects (see Chapter 6: Visual Agnosia & Object Recognition). They took the prevailing understanding within the field and created a model which involved the input units representing either visual or functional information about objects; so for example with a bicycle, visual information is useful but the functional information is much more important, whereas deciding whether a banana is ready to eat relies very heavily on the visual information. Their model was able to mimic a number of findings in general 'healthy' object recognition, but importantly they were able to 'lesion' their model by damaging some of the units in the hidden layer. Depending on whether they damaged visually-based information or function-based information, the Farah and McClelland (1991) model had difficulties 'recognising' visually presented living things or non-living things respectively. This perfectly mirrored the pattern of object recognition difficulties of the patients being documented in the 1980s; this finding therefore helped to inform the cognitive theories that were being developed at the time to explain the patterns of problems that patients were exhibiting (see Chapter 6 for more on this specific disorder).

Renewed Connectionism in the Age of Deep Learning

In the early 90s the parallel distributed processing (PDP) or connectionist movement went out of fashion, in what was then recognised as 'the second artificial intelligence (AI) winter'. More than two decades later, there has been a true renaissance of PDP under the name of 'deep learning' thanks in part to technological advances in both hardware (increasing computing power) and software (open-source software, and better machine learning algorithms). The new generation of models, called deep neural networks (DNNs), are 'deep' in the sense that they have many layers of units or 'neurons' (sometimes hundreds). Such DNNs are starting to pervade almost every aspect of our society, and can rival human object recognition ability, master natural language, beat humans at games such as chess, predict the weather and, most recently, assist mathematicians in proving new theorems.

DNNs have also proven to be the best (i.e. most predictive) computational models of brain function, leading to a renewed convergence between AI and neuroscience. As an example, Higgins et al. (2021) recently found that a DNN trained to process certain aspects of face recognition best accounted for how the inferotemporal cortex of macaque monkeys responded to faces. This is a quickly advancing area of research and is likely to mushroom further in the next decade.

Given the success in mimicking some aspects of human cognition, the next big step is that the lesion method used in neuroscience and cognitive neuropsychology is now being applied to gain insights into how DNNs work. The basic idea in these so-called 'ablation' experiments is similar to the experimental surgeries conducted on animals whereby part of a DNN is 'damaged' and the impact on the behavioural output of the network is observed. For example, Zhou et al. (2018) ablated individual units within a DNN that had already been trained to classify objects finding that specific units were selective to specific object categories. This is clearly analogous to cognitive neuropsychologists assigning a function (or functions) to a brain area based on the deficits following lesion to that area. Therefore, more than 160 years after the seminal work by Paul Broca, this emerging work on brain-damaged DNNs or ***in silico* neuropsychology** (Innocenti, 2022, personal communication) may well be the next stage in our understanding of cognitive functions.

This research also reveals that the lesion method, though closest to cognitive neuropsychology, does not belong to any particular field. It can instead be viewed as a general principle to gain insights about the workings of a system, although it might need further development to provide more informative insights into complex systems such as the brain.

Cognitive neuropsychology has therefore had a rocky ride since its 'golden flowering' in the nineteenth century and has entered the twenty-first century with a growing momentum, which makes it an extremely fascinating field. However, there are various challenges that the field needs to address. The first is societal pressures on the ethics of working with individuals with brain damage. The need for appropriate ethics is obvious since the individuals being studied have sometimes suffered extremely distressing illnesses or accidents and so great care needs to be taken when working with them. However, unless there is a deeper understanding of the vital clues that can emerge from this type of work, the field could be under serious threat. A second related challenge is the rise of other methods of research that entered the arena towards the end of the twentieth century. The emergence of **cognitive neuroscience** has led some to see cognitive neuropsychology as redundant. Chapter 2 will address the importance of this issue but the main point is that it is important for the field to be seen as a vital contribution to the understanding of the incredible complexity of the human mind.

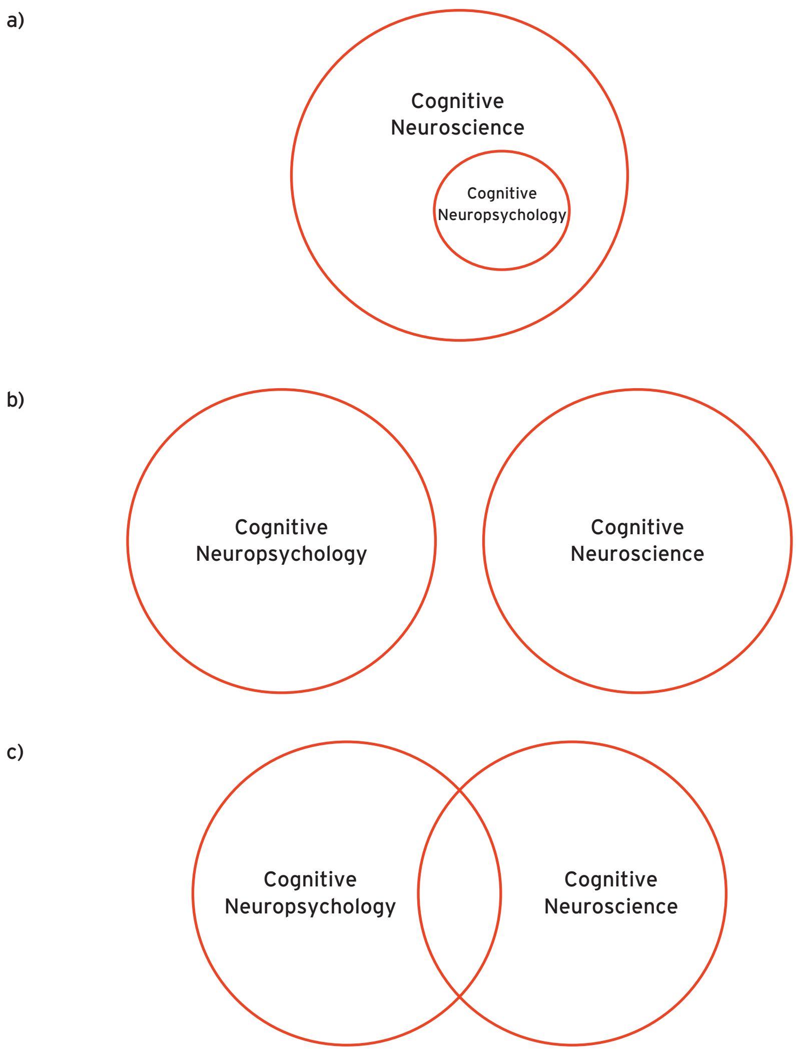

Figure 1.9 The relationship between neuroscience and neuropsychology: a) Neuropsychology is simply a part of neuroscience; b) The two fields are not related at all; c) The two fields have commonality and can borrow from one another but are also independent of one another

THE MANY FACES OF 'NEURO'

Given that there are a number of different aspects of studying with or working with the brain, along with the fact that compared to some of the other sciences, it is a relatively new area, there can be some confusion, *even among scientists*, as to what the many faces of 'neuro' are. For students, therefore, it is unsurprising that cognitive neuropsychology, clinical neuropsychology, cognitive neuroscience, clinical neuroscience, clinical neuropsychiatry, etc. all sound more or less the same. Sometimes even people within the field can get confused, or rather misunderstand the relationship of their field to the other related fields. For example, just taking two of the big ones, cognitive neuropsychology and cognitive neuroscience, some people (mainly within the neurosciences) feel that the situation is what is seen in Figure 1.9a, with neuropsychology being entirely within neuroscience. It is unsurprising that many think like this because of the rapid rise of the field which has effectively swamped the other areas. Figure 1.10 shows the number of scientific publications which had the words/phrases 'neuroscience', 'neuropsychiatry', 'cognitive neuropsychology' and 'clinical neuropsychology' in them for each year from 1960 to 2020; there will have been some overlap between the publications but the picture is pretty clear; since the early 1990s, there has been an enormous increase in the neuroscience field which has often led some to feel that it's the only 'neuro' left on the block… This issue is picked up again in Chapter 2.

Returning to the relationship between neuropsychology and neuroscience, some could be extreme and say that there is no relationship whatsoever; perhaps to be controversial, Max Coltheart might say that it is more like Figure 1.9b, with neuroscience not informing

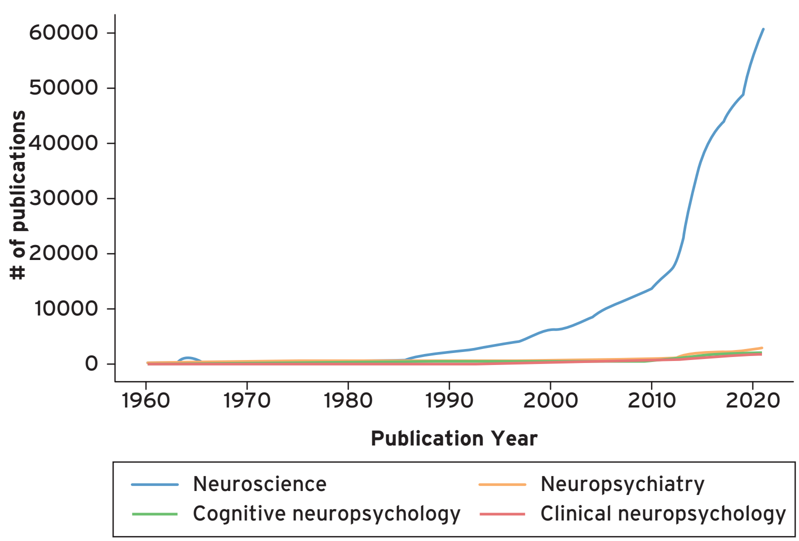

Figure 1.10 The number of papers published each year that included the terms neuroscience, neuropsychiatry, cognitive neuropsychology and clinical neuropsychology from 1960 to 2020

neuropsychology at all. This extreme position effectively would be suggesting that nothing that we learn from the neurosciences can help us in the endeavour to use individuals with brain damage to try to understand healthy cognitive functions. The most likely position, and one that most cognitive neuropsychologists would agree with, is that in Figure 1.9c, which admits that neuroscience can help us understand aspects of cognition but that there are many aspects of the field that do *not* require knowledge of neurons, pathways in the brain, etc.

Turning to the relationship between cognitive and clinical neuropsychology, this grew with the birth of cognitive psychology with there being clear links between the two. At an informal level, *depending on the country*, cognitive neuropsychologists are not trained clinicians but simply scientists who happen to work with patients with brain damage for their research. On the other hand, many clinical neuropsychologists do not conduct research since all their time is taken up with the assessment and care of their patients. However, some will work with scientists to conduct research. In terms of training, clinical neuropsychology is a specialist training that occurs within a health setting and is often done after formal studies (at Bachelors or Masters levels) have been completed. The pathways and the amount of time varies considerably in different countries. So for example, in the United States and Australia, it is possible to enter a doctoral clinical neuropsychology programme after completing the relevant undergraduate or postgraduate studies. In the UK, however, it is necessary first of all to complete a doctoral training in clinical psychology to get an overall grounding as a clinician and then, after that, to specialise in clinical neuropsychology.

Chapter Summary

- Early thinkers in the field were known as localisationalists because they believed that particular mental functions were situated in specific locations in the brain.
- The diagram-makers formulated the earliest models of mental processing by synthesising the ideas of the localisationalists in 'box and arrow' models.
- The field decreased in popularity at the beginning of the twentieth century but this was rekindled by the birth of the information processing approach and cognitive psychology.
- The development of more advanced techniques such as standardised research methodologies and brain-imaging technology further developed the field towards the end of the twentieth century.

Important Researcher

Paul Broca

Paul Broca (1824–1880) was a French polymath who was a physician, anatomist, and anthropologist, publishing research across all these areas. The event that has secured his place in history is the revolutionary thinking he proposed when he studied patient Tan.

While similar thoughts may have been around at the time, it was Broca who meticulously documented his observations and spoke about it through the various intellectual groups and salons that he was very involved in. If Broca's suggestions about Tan had not been heard by others and promoted similar lines of enquiry in other doctors working with patients with brain damage, then we may never have heard of Broca or Tan, or at the very least the pace of understanding would have been extremely slow. This demonstrates that science requires excellent quality work but it also requires communication to other audiences; this can be through written papers and scientific conferences. In the modern world public engagement with science is particularly valued, bringing science to the general population so that they can think about it and maybe even contribute to the debate. So Broca was important not only for his scientific work but also for his prolific communication of his ideas that spread quickly to other neurologists such as Carl Wernicke and Ludwig Lichtheim. Interestingly, as well as his medical career, Broca, founded a society of free thinkers who were very impressed with Charles Darwin's theories on evolution which had just been published in 1859. Broca, who was an atheist, is quoted as saying, 'I would rather be a transformed ape than a degenerate son of Adam'.

Important Research Study

Patient Tan

Tan was the name given to Louis Victor Leborgne when he was admitted to a hospital in Paris having lost the ability to speak at the age of 30; the name was simply because that was the only guttural sound he could make. He had suffered from **epilepsy** for much of his life and spent the next 21 years at the hospital. Although some of the details about the specific brain area that Paul Broca suggested was the centre of spoken language have been disputed (see Chapter 10), Tan will go down in history because of the incredible contribution to science that his condition gave through the observations that Broca made.

Questions for Reflection

- Why was it necessary for the cognitive revolution to happen before the amazing observations by the nineteenth century diagram-makers were rediscovered in the creation of the field of cognitive neuropsychology?
- In what ways is cognitive neuropsychology different from cognitive neuroscience?

Go Further

Dr Jansari's YouTube Videos

Why do we know less about the human brain than the dark side of the moon? (Parts 1 and 2)

Go on a guided tour of the functioning of the human brain, dispelling some of the many myths about the grey stuff while also revealing some true wonders. The fascinating field of cognitive neuropsychology is explored through examples of patients with very selective disorders. How these findings can help others with brain damage is shown and the exciting techniques for improving functioning in healthy adults are described. Finally, in a coming-together of Eastern philosophy and neuroscience, the incredible impacts of mindfulness meditation both on the physical body and the brain are introduced.

Further Reading

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