

Left and right brain

Insights from neural networks

ON OPENING up the top of your head, one of the most striking features of the brain's structure is that it is divided into two hemispheres. Delving further, you will notice that the two hemispheres are connected with a bundle of fibres called the corpus callosum. But what role does this architecture of the brain have in terms of how the person makes their way around the world? What influence does it have on perception of events in the world?

The precise role of the left and the right hemispheres of the brain has been a topic of continual interest throughout the last century of psychology. The two hemispheres have been found to process different aspects of information, and the distinction has given rise to pop psychological theories of left-brain and right-brain in learning styles and personality dimensions (for a debunking of the myths and an elegant summary of the evident distinctions, see Corballis, 1999), as well as information-processing theories about asymmetrical processing of (among other things) words, numbers and faces (Ivry & Robertson, 1997).

Yet the difference in processing between the left and right hemispheres of the brain are extremely subtle compared



*At this year's Annual Conference, **PADRAIC MONAGHAN** delivered the Spearman Medal Lecture on an unusual way of studying hemispheric specialisation.*

with, say, the larger differences between the function of the frontal lobes, involved in planning and decision making, and the posterior areas of the brain, involved in early visual processing. Or compared with the distinction between the cortex and the limbic system, or between the right hemisphere and the elbow. Clearly the right cerebral hemisphere is substantially different in its functioning from the nerve endings and motor neurons in the elbow; but there is no (substantial) field of psychology comparing and contrasting the functioning of the elbow and the brain.

This suggests that psychologists' fascination in comparisons between the two hemispheres is due to the nuanced distinctions in their functioning – if they were very different then the match just would not be interesting. Yet the most spectacular asymmetry of all in human brains – the location of language production in the left hemisphere – not only distinguishes it from the right hemisphere, but also from the brains of other apes (Corballis, 1991). Language is one principal property of what makes us human, but why is it a lateralised function, and what effect does this have on functioning in the other hemisphere?

In this article I discuss three main themes concerning hemispheric processing:

1. How does the architecture of the brain, in terms of two hemispheres connected by the corpus callosum, influence the way the brain processes information?

2. What causes hemispheric asymmetries, and what properties of the brain may give rise to behavioural asymmetries?
3. How does the brain interact with the world through which it moves, and how does this interaction influence hemispheric asymmetries?

These questions may productively be addressed using behavioural laboratory experiments, or imaging studies. A further method employs neural network models to study hemispheric function. Neural network models incorporate the neuronal structure of the brain in their processing, in terms of having many interconnected 'neurons', or units. Individual units in these models do not do much on their own, but by changing the strength of the connections between the units, the network can learn to solve complex tasks. A key property of these models is that they learn from experience, and their solution to tasks is constrained and driven by the architecture of the network, in terms of which connections are in place and how those connections change their strength. In our research, neural network models with bi-hemispheric structure are compared with models without this hemispheric distinction. Through this comparison, we can make suggestions about the effect of the brain's structure on behaviour. In the remainder of this article, I review several studies that use this technique to address the questions above.

WEBLINKS

Padraic Monaghan's webpage:

www-users.york.ac.uk/~pjm21

Centre for Connectionist Modelling of Cognitive Processes: anc.ed.ac.uk/cccp

What hits the eye when it reads (video demonstrations): nbr.physiol.ox.ac.uk/nbr_research.html

How the eye connects to the visual cortex: tinyurl.com/0qg6s

Influences of the hemispheric architecture on behaviour

The anatomy of the visual system is such that objects viewed in the left visual field (LVF) are initially processed in the right hemisphere (RH) of the brain, and objects in the right visual field (RVF) are initially projected to the left hemisphere (LH). So, processing within a hemisphere can be investigated by presenting stimuli just within one visual field, and processing between the hemispheres can be promoted by presenting stimuli in both the LVF and the RVF.

Imagine a simple task where two letters are presented, and the participant has to determine whether they are the same shape. So, 'a' and 'a' match, but 'a' and 'b' do not, and neither do 'b' and 'B'. Now, the participant is given the same sets of letters, but this time the task is to say whether the letters have the same name. People are slower and make more errors in this task: 'a' and 'b' do not match but 'a' and 'a', and 'b' and 'B' do. Banich and Belger (1990) found that when the task is easy people responded more quickly when both letters were presented within one visual field. However, when the task was more complex, as in the letter-naming task, responses were quicker when one letter was presented within each visual field. In other words, within-hemisphere processing was best for the easy task, whereas the hemispheres working together was best for the harder task.

Our neural network model of this task incorporated the LVF and RVF connecting to the RH and LH respectively (Monaghan & Pollmann, 2003). The two hemispheres in the model were allowed to interconnect, to simulate the role of the corpus callosum. The model learned to match shapes or names of letters. The model produced precisely the same behaviour as humans. Shape-matching tasks were easier within each hemisphere whereas name-matching tasks were easier for across hemisphere presentations. Constructing a model of this behaviour enabled us to investigate precisely why there was this cross-hemispheric advantage for harder tasks. For the name-matching task, when both letters were presented to one visual field, the model drew on the resources of both its hemispheres. This meant that there was a lot of transfer across the corpus callosum, which slowed processing down. When one letter was presented to each hemisphere, much less transfer had to occur and

performance was quicker and more accurate. Brain imaging data supported the neural network model's insight into hemispheric functioning: for harder tasks both hemispheres of the brain are involved regardless of whether information is presented to just one hemisphere.

Asymmetric properties resulting in behavioural asymmetries

The architecture of the brain enables processing within each hemisphere to occur relatively independently of the processing of the other hemisphere. This can confer an advantage for easy tasks but may slow things down when tasks are hard, as in the above study. Yet, the division in the brain also provides potential for modularity or specialisation of processing within each hemisphere. Such specialisation can be observed by comparing performance for stimuli presented to the LVF or to the RVF. Further

'Why is language a lateralised function? What effect does this have on the other hemisphere?'

insight into hemispheric specialisation can be determined from studies of patients with lateralised brain damage.

Caramazza *et al.* (2000) reported a study of aphasic patients where left-brain damage resulted in impairments to repeating consonants and right-brain damage resulted in damage to reproducing vowels. We investigated this effect in a neural network model that had to reproduce consonants and vowels with two sets of resources – representing the LH and the RH – involved in the task (Monaghan & Shillcock, 2003). After the neural network had learned to solve the task, we damaged one or other side of the model and examined the model's ability to reproduce vowels and consonants. We found that one half of the model became specialised for vowels and the other half always became specialised for consonants. The hemispheric structure of the model promoted modularity of processing and specialisation in different aspects of the task of phoneme reproduction. This study showed that separation of resources can result in modular processing, but it did not determine in advance which half of the model would become specialised for consonants or vowels. Our next studies

attempted to incorporate asymmetries in processing in a neural network model to predict exactly which hemisphere would specialise for a given task.

Neglect refers to an impairment following lateralised brain damage where the patient finds it difficult to orient towards one side of objects. Neglect patients may eat from only one half of their dinner plate, shave only one half of their face, and omit letters from one side of a word. However, damage to the RH very often results in neglect of the left side of objects, but damage to the LH tends to result in considerably less severe neglect (Mennemeier *et al.*, 1997). So what different contributions are the two hemispheres making to the visual processing of objects?

In our neural network model of this behaviour, we included asymmetries in the response properties of the neurons in the LH and RH of the brain, that have been posited to underlie a range of behavioural asymmetries in performance (Monaghan & Shillcock, 2004). The theory was that the LH prioritises processing from neurons that respond to a small region of vision, whereas the RH processes neurons that respond to a much larger region. The model accurately reflected the more severe neglect following RH than LH damage. A further consequence of the model's performance was that neglect for words should be more severe following LH damage than RH damage, even though for other types of object RH damage resulted in more severe impairments than LH damage. Similar effects have been found in patient studies (Monaghan & Shillcock, 2001).

These studies have investigated the potential impact of the hemispheric structure of the brain on development of asymmetric processing, and the type of asymmetries that may generate observable behavioural asymmetries. However, the brain does not occupy a vacuum, and so interactions between the brain and the world provide further possibilities for the development of asymmetries. In the next section I review some potential environmental contributions to the asymmetries observed in the brain.

Hemispheres and the environment

We have seen that visual stimuli presented in the RVF initially project to the LH, and stimuli presented in the LVF project to the

RH. But what happens when stimuli are presented in the centre of vision? The same principle applies: parts of stimuli to the left of centre are projected to the RH, and parts to the right of centre project to the LH. This prompted my colleague Richard Shillcock to an extraordinary insight. When staring closely at the centre of an object, half of what is seen of the object is initially processed by the LH and half by the RH. The brain does an extremely good job of tying up the division, so you can't see the join, but it is there nonetheless. For most objects in the world this division of visual information does not have a big impact, as much of what we look at is roughly symmetrical (for example, trees, tigers – when they are running directly towards you – or pizzas), but for some objects one side is not predictable from the other. A prime example of this is written words. Given the letters 'pe' at the start of a word, then it could end with 'n', 'ck', 'nguin', 'regination', and numerous others. When we read, we tend to look slightly to the left of centre, meaning that about half the word initially goes to each half of the brain.



A tiger may be roughly symmetrical, but most words are not

What influence does this asymmetry in the reading environment have on processing in the brain?

We constructed a set of neural network models to investigate the impact of this division of word information on language processing in the LH and RH. We found that the point in the word where people prefer to look when they're reading

(slightly to the left of centre) corresponds to the point at which information about the word's identity is balanced between the LH and RH (Shillcock *et al.*, 2000). This is because there is slightly more information near the beginning of the word than the end about the word's identity. Our modelling suggested that the preferential viewing position of words is an optimal method of

reading because it neatly divides up the quantity of information in the LH and RH – a situation the studies on shape- and name-matching tasks, above, indicated was most efficient for the brain.

These asymmetric visual properties of words were also found to be sufficient to create asymmetries in processing the meaning of words in a neural network. The LH is most sensitive to words that are related in terms of dominant or closely related meanings, whereas the RH is more sensitive to words that are more distantly related. Thus, the LH responds to 'money' as the dominant meaning of bank, whereas the RH is more sensitive to 'river', a less often used meaning of 'bank'. Similarly, the LH is sensitive to the relation between 'sofa' and 'chair', and the RH is more sensitive to the relation between 'sofa' and 'lamp' (Chiarello *et al.*, 1990). The neural network model learned to make the match between the written forms of words and their meanings (Monaghan & Shillcock, 2004). We found that, purely as a consequence of asymmetries in the word – more information and variability on the left – the RH of the model became more sensitive to more distant meaning relations than the LH. Thus, the hemispheric asymmetry in representing the meaning of words was purely an interaction between the environment and the bi-hemispheric structure of the brain.

It is a moot point to what extent the hemispheric asymmetries we observe in language processing are a consequence of the environment, and to what extent they are due to latent processing preferences in the two hemispheres. Hebrew is the reverse of English, in that there is more information on the right of the word. Readers of Hebrew indeed actually show less asymmetry in language processing than do readers of English (Brysbaert & Nazir, 2005). This suggests that the RH propensity for more distantly related meanings is at least partially a consequence of the properties of the lexicon interacting with inherent processing distinctions in the brain.

The view of words being initially divided between the two hemispheres of the brain also resonates with long-standing claims about the connection between reading difficulties and impaired hemispheric transfer (Orton, 1925). We tested a neural network model learning to produce the spoken forms for visually presented words when transfer between the

LH and RH of the model was impaired. The model with impaired callosal transfer demonstrated difficulties in reading, particularly for irregularly pronounced words such as 'pint' or 'bind'. These words have been found to cause particular difficulties for surface dyslexics (Shillcock & Monaghan, 2001).

Conclusion

There are structural concordances between the LH and RH for all brain regions. This, together with the fact that the two hemispheres operate in parallel, has created substantial and sustained interest for the role of the two hemispheres in psychological processes. The differences between the two hemispheres are subtle, but occasionally very substantial, such as the facility for language production in the LH. Comparing how the two hemispheres process information provides insight into the potential range of solutions available to the brain for solving tasks. In addition, such studies illuminate the value of modularity of processing in the brain and the importance of slightly different but complementary ways of processing information.

The use of neural networks that implement the coarse anatomical

DISCUSS AND DEBATE

Which differences between left- and right-brain functioning stand up to scientific scrutiny?

How independent is processing within the two hemispheres of the brain?

What insights into modularity are given by examining hemispheric processing?

What are the limitations of neural network modelling as a research methodology in psychology?

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distinctions of the two hemispheres enables insight into several aspects of hemispheric processing. The studies reported here indicate that the divided architecture has a profound impact on the way our brain learns to solve cognitive tasks, and that this learning is a complex and rich interaction between asymmetries that are out there in the world and those that are internally determined.

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