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Imaging Imagination: Brain Scanning of the Imagined Future

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'IMAGINATION, n. A warehouse of facts, with poet and liar in joint ownership.'

Devil's Dictionary, Ambrose Bierce

Abstract. In this chapter we review an emerging literature concerning the neuroimaging of various subcomponents of imagination. The preliminary conclusions of this review are two-fold. First, acts of imagination recruit similar networks in the brain to those used for the sensory and motor processing during corresponding actions in, or interactions with the real world (with the important exception that imagined movements do not activate the primary motor cortex). That the majority of studies reviewed have been concerned with visual imagery was inevitable since this is the form of imagination for which most neuroimaging experiments have been conducted. It should be noted that this first conclusion is relevant to all forms of imagination, and not just those of veridical imagery, where there is a 'real world' referent for the imaginary content. Second, the selection processes used in subcomponents of imagination such as anticipation, mindedness, and counterfactual thinking rely on widely distributed subcortical and cortical networks within the brain, consisting of important components such as the cingulate cortex, the dorsolateral prefrontal cortex, the cerebellum and the orbitofrontal cortex. These neural structures play quite different functional roles in the complex interactions of real and imagined acts that constitute human thought and behaviour. Further knowledge of the precise functional roles of the interacting networks can be expected from neuroimaging in the coming years, perhaps through the technical breakthroughs which we imagine in a Coda and which could potentially facilitate and enhance our understanding of imagination in the future.

THE NEUROSCIENTIFIC APPROACH TO THE IMAGINATION

IT HAS TO BE SAID that few neuroimaging studies have deliberately sought evidence for the neural correlates of imagination as such, mainly because of the challenge in constructing unambiguously falsifiable hypotheses about such a broad mental phenomenon. This neglect of imagination might also be a result of its long banishment by behavioural psychology. In fact, many neuroimaging studies have regarded subjects' imagination as experimental noise, i.e. off-task thinking. Nevertheless, over the past decade, imagination, along with consciousness, has emerged as one of the exciting cutting-edge areas of study within neuroscience. Progress, as with all neuroscientific experiments, has relied on the deconstruction of the broad concept, imagination, into investigable components. This, in turn, is not without its conceptual and pragmatic challenges.

Neuroscientific evidence for the brain substrates of imaginative thought has been sought by recording the neural correlates of the six overlapping subcomponents of imagination that Roth identifies in the Introduction to this volume: prediction through anticipation; perceptual, sensory and motor imagery, including pain; pretence; mindedness and empathy (theory of mind); counterfactual thinking including delusion; and creativity (see Figure 14.1). The results of these various experimental approaches therefore offer neuroscientific perspectives on the phenomena discussed by other authors in this volume: prediction (Boyer in Chapter 11); perceptual imagery (Pearson in Chapter 9) pretence (Harris and Koenig in Chapter 5, Whiten and Suddendorf in Chapter 2); mindedness (Currie in Chapter 10, Mithen in Chapter 1, Roth in Chapter 13); counterfactual thinking and pretence (Blackmore in Chapter 3, Boyer in Chapter 11); and creativity (Cook in Chapter 6, Cross in Chapter 7, Mithen in Chapter 1, Nettle in Chapter 12, Roth in Chapter 13, Turner in Chapter 10, Whiten and Suddendorf in Chapter 2).

The main neuroimaging methods at the basis of this chapter are positron emission tomography (PET), functional magnetic resonance imaging (fMRI), event related potential (ERP), electroencephalography (EEG), electromyography (EMG), magnetoencephalography (MEG) and transcranial magnetic stimulation (TMS). We recommend readers not familiar with these approaches to the relevant sections of either the *Oxford Companion to the Mind* (Gregory 2004), the *Handbook of Functional Neuroimaging of Cognition* (Cabeza and Kingstone 2001) or Van Horn's chapter on cognitive neuroimaging in *The Cognitive Neurosciences III* (Van Horn 2004).

There are important caveats to the claims of any neuroimaging research that depends on the strengths and limitations of the method employed. These include: the validity of the various surrogate variables (e.g. haemodynamic

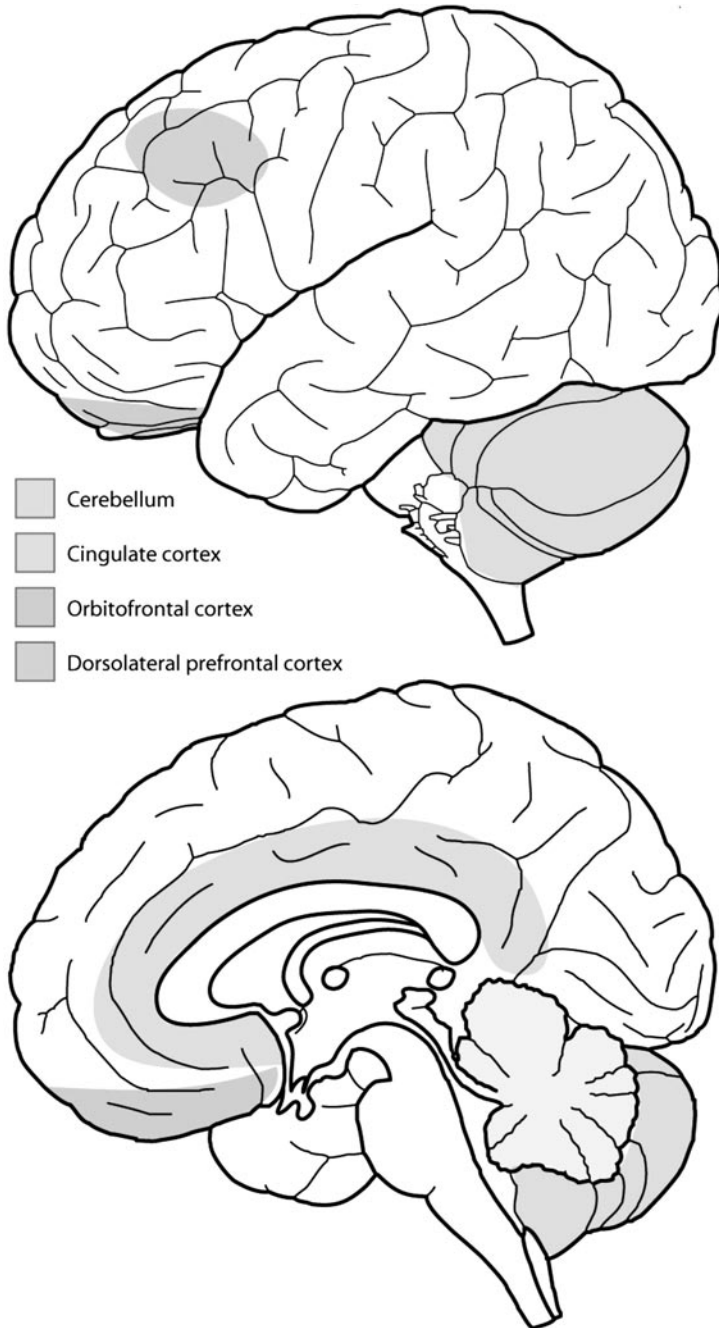


Figure 14.1. Areas of cortex involved in imagination.

fluctuation, relative electric dipole strength) for measuring neural activity; limits to spatial and temporal resolution; the statistical nature of activation data; constraints on the type and extent of tasks that subjects can undertake while being imaged; subject selection and limits on generalizability; and, the subjective experience of being imaged, and its possible effects on imagination.

A more fundamental constraint on interpretation is that, owing to the correlational nature of most neuroimaging data, the mapping between structure and function is not one-to-one, or simple. As Nobel Laureate Sir Charles Sherrington, warned nearly 70 years ago (Sherrington 1938, 181):

To suppose the roof-brain [cerebral cortex] consists of point to point centres identified each with a particular item of intelligent concrete behaviour is a scheme over simplified and to be abandoned. Rather, the contributions which the roof-brain . . . makes toward integrated behaviour will . . . resolve into components for which we at present have no names.

Sherrington's prescience, we suggest, still holds. Understanding just how our brain, through the contributions of its myriad functional centres, enables us to be imaginative is still largely an act of imagination. However, thanks to modern neuroimaging technologies, a convergence of evidence is informing such imaginative endeavour.

CONCEPTUAL AND THEORETICAL CONSIDERATIONS

A broad distinction may be drawn between imagination as a mental product and as a mental process. In the first sense, imagination is a cognitive state stimulated by other cognitive states whether these arise 'internally' or consist of responses to percepts. But, imagination can also be the mental process which creates such 'products', or moreover, mentally manipulates them as required for planning, scheming, or any act of creative thinking. Further, the mental processes required for the latter are likely to extend beyond mental resourcefulness, involving what are often described as 'imaginative insights' or 'leaps of imagination'. To a neuroscientist, these various aspects of imagination are likely to have dissociable neural correlates.

That said, functional and even neuroanatomical dissociation does not necessarily mean that more general hypotheses about imagination must remain uninformed. The most parsimonious general hypothesis is that the brain exploits similar structures and processes in dealing with internally generated mental activity, such as images as it does in dealing with externally generated activation, such as percepts. At first pass, this seems to beg the question of which areas are involved in those forms of imagination which arise 'purely internally': if I dream up a new story in my mind, or mentally

conjure up a fantastical creature, there is not usually or necessarily an external event or activity which corresponds to this. Interestingly, the (albeit limited) evidence indicates that the brain conjures up such images as if they had external referents. In other words, the *Parsimony Hypothesis* can be applied to such cases as well.

Evidence for the *Parsimony Hypothesis* is found in studies of neural activations in visual cortex arising from seeing a particular object and then visualizing that same object with eyes closed. For example, Kosslyn *et al.* (1999) used PET to show that Area 17 in early visual cortex (V1) was activated when subjects visualized a recently perceived display with their eyes shut. To address the acknowledged limitation to such neuroimaging studies, viz. that the results are correlational and not causal, Kosslyn *et al.* (1999) then employed repetitive TMS on Area 17 to demonstrate the predicted performance impairment indicative of the necessary involvement of Area 17 in all visual information processing, imagined or otherwise. Similarly, Ganis *et al.* used fMRI to map the neural correlates accompanying the act of perceiving or imagining drawings of familiar objects. While concluding that:

visual imagery and visual perception draw on most of the same neural machinery . . . the spatial overlap was neither complete nor uniform; the overlap was much more pronounced in frontal and parietal regions than in temporal and occipital regions. This finding may indicate that cognitive control processes function comparably in both imagery and perception, whereas at least some sensory processes may be engaged differently by visual imagery and perception (2004, 226).

Support for this view comes from Grossman and Blake (2001) who found similar activation patterns in superior temporal sulcus for perceived and imagined motion, although the fMRI (BOLD)¹ activation was weaker for the imagined motion.

Nevertheless, such results, interesting as they are, have little to say about the creative aspects of imagination, in which imaginative mental products may have no 'real-world' correlates. There are several putative global accounts of how the brain is creatively imaginative. One popular cognitive approach is captured by the suggestion that imagination is the outcome of a neural Darwinism—that the brain generates thousands of mental images every second, but only the most salient come to mind or consciousness. However, it is not clear how one could employ neuroimaging to test this directly, although studies of the neural correlates of consciousness might be

¹ Neural activity changes the proportion of oxygenated blood in the brain. By measuring the oxygenated blood using functional magnetic resonance imaging (fMRI), the location and size of the neural activity can be assessed. This technique is called the blood oxygen level dependent (BOLD) signal, or haemodynamic response.

informative. A more recent and neurally specific model of brain function is the Dynamic Workspace Hypothesis (DWH) which is inspired by the research of a number of researchers (most recently Baars 1989; Dehaene *et al.* 1998; Mesulam 1998) (see Figure 14.2). The DWH offers a neural mechanism for the *Parsimony Hypothesis*, in that once perceptual information has been processed, the modules for which it is efferent regard it as the same as imagined information with similar efferents. In most normal cognition, we can distinguish between percepts and mental images by their associated contexts. However, experiments with inattention blindness (Simons 2000) and spontaneous confabulation (Schnider and Ptak 1999) reveal how easily the brain can be deceived in this regard. Moreover, pathologies such as schizophrenia are characterized by symptoms involving an inability to distinguish between internally and externally generated auditory and visual imagery. Importantly in this model, certain parts of the brain have privileged global access to information and these *global workspace* neurons are central to consciousness, and thus also to the subset of consciousness that is imagination.

Some direct evidence for the DWH which is consistent with the predictions of neural Darwinism, has been provided by two related studies of the 'Aha' experience, the sensation of a sudden flash of insight which accompanies successful solution in problem-solving tasks (Jung-Beeman *et al.* 2004). First, fMRI revealed increased activity in the right hemisphere anterior superior temporal gyrus for insight relative to non-insight solutions, i.e. solutions which emerge gradually and without an 'aha' moment. Second, EEG recordings revealed a sudden burst of high-frequency (gamma-band) neural activity in the same area beginning 0.3 seconds prior to insight solutions. The researchers noted that this right anterior temporal area is associated with making connections across distantly related information during comprehension, so 'although all problem solving relies on a largely shared cortical network, the sudden flash of insight occurs when solvers engage distinct neural and cognitive processes that allow them to see connections that previously eluded them' (Jung-Beeman *et al.* 2004, 500).

IMAGINATION AS PREDICTION

Perhaps the simplest form of imagination is prediction—the mental representation of possible future events or experiences. There is a considerable literature on predicting or anticipating the next stimulus in a particular sequence of, say, movements or rewards. Sophisticated predictions are performed by the cerebellum which has been proposed to function like a Smith-predictor (Miall *et al.* 1993). A number of recent neuroimaging papers have investigated the role of cerebellum in predicting not only motor sequences

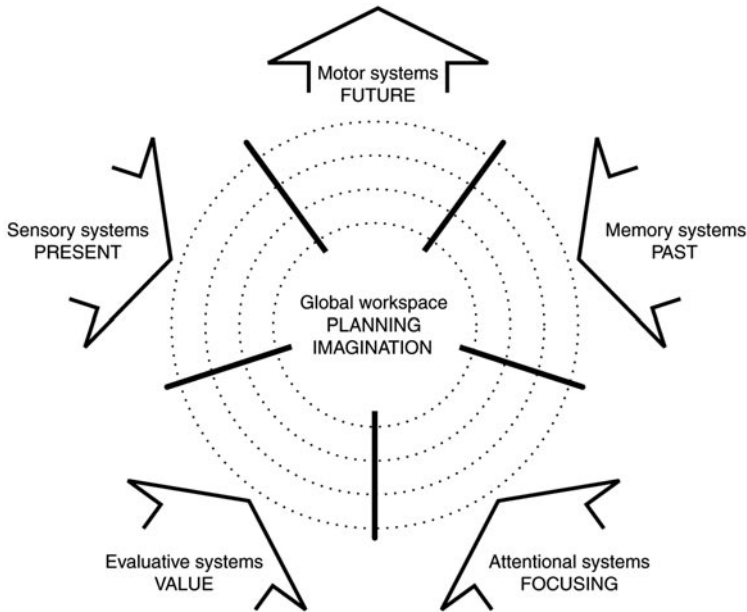


Figure 14.2. Tentative model of the global workspace. The figure represents the five main types of processors connected to the global workspace: sensory, memory, attentional, evaluative, and motor systems. Each concentric ring represents a different synaptic level and the connections from one zone to another are reciprocal. The binding of the various processors is accomplished through effortful processing and long-range workspace connectivity which establishes coherence between two or more informationally distributed workspace regions. The activation of the global workspace may lead to activation of motor systems but may also lead to the projecting, imagining, of such possible futures without a direct motor component. Inspired by Baars (1989), Mesulam (1998) and Dehaene *et al.* (1998).

but also in the prediction of other higher cognitive and emotional functions (Dreher and Grafman, 2002; Nitschke *et al.* 2003; Tanaka *et al.* 2004). Behaviourist studies of prediction of rewards and punishments have classically concentrated on the role of various structures within the basal ganglia. Recently, it has been proposed that dopaminergic neurons and the orbitofrontal cortex are involved in a network for reward prediction (Schultz *et al.* 1997) and this proposal has received support from human neuroimaging experiments (Ploghaus *et al.* 2000; Berns *et al.* 2001; Pappata *et al.* 2002; Tanaka *et al.* 2004; Tricomi *et al.* 2004). It should be noted, however, that real-life prediction and anticipation processes are anything but simple and it is unlikely that simple-minded behaviorism will elucidate the richness of neural mechanisms involved in prediction (Kringelbach 2004a).

Some of these studies suggest that prediction is largely subliminal or non-conscious rather than conscious. Consistent evidence for such a claim has been provided by several studies into the placebo effect, where the effect of the placebo is based on a *false belief*. In a PET study, Petrovic *et al.* (2002) found that not only was activity in rostral anterior cingulate cortex (ACC) and lateral orbitofrontal cortex correlated with pain relief through analgesia, but that similar activations were found in placebo responders (and not, crucially, in placebo non-responders). The authors conclude that there are related neural mechanisms for real and placebo analgesia, a finding in support of the Parsimony Hypothesis. Other evidence that real and imagined percepts are supported by common neural structures comes from two fMRI studies into the anticipation of pain (Wager *et al.* 2004). Here, the administration of placebos was related to decreases in activation in various parts of the pain network, including the thalamus and insula, and increases in activation of prefrontal areas including the ACC, associated with pain anticipation.

That anticipation or prediction is usually unconscious should not be surprising. Unconscious processing is attributed to the ventral information processing stream in the brain, which is temporally privileged over the dorsal information stream required for conscious processing (e.g. Goebel *et al.* 1998). In other words, unconscious processing happens faster than conscious thought. If this were not so, it could be noted, then musical improvisation within a group, as in jazz or rock music, would not be possible. Nor, for that matter, would most conversation or spontaneous speech.

This is not to say that all imaginative experience is unconscious. We now consider the case of imagination as the generation of mental imagery—a process that is often conscious.

IMAGINATION AS IMAGERY

Mental imagery as defined by Roth (in the Introduction to this volume) is quasi-perceptual experience in the absence of external stimuli, colloquially seeing things in the mind's eye. We can imagine in all sensory modalities, and within (at least) visual, auditory, and motor domains, images can be novel, creative, or even fanciful, as well as remembered. However, it is the latter imagery that has been the main focus of neuroimaging studies as it is hoped that the associated neural correlates might be informative of the elusive structures and functions involved in memory storage and recall. To this end, visual imagery for remembered stimuli is both psychologically privileged and the easiest to facilitate in a brain scanning environment. Ishai *et al.* (2002) employed fMRI to study the neural correlates of short- and long-term

memory for perceived and imagined complex visual images (famous faces). The imagined faces (long-term memory) activated a subset of the network of regions activated by the perceived images (short-term memory), which included the areas known to be involved in facial recognition such as the lateral fusiform gyri. However, the imagined faces activated additional areas including the hippocampus (the subcortical organ that have been implicated in laying down spatial memories), and the inferior frontal gyrus, an area implicated in studies of selection for action and working memory. This finding, consistent with the more recent fMRI study of real and imagined drawings reviewed above (Ganis *et al.* 2004), suggests that the Parsimony Hypothesis might be rather too parsimonious.

Nevertheless, convergent evidence for the coincidence of neural structures involved in imagery and perception comes from several studies into imagined motion. Goebel *et al.* (1998), in an fMRI study comparing perceived and imagined motion, found that the Area MT/MST in V1, known to be involved in motion detection, was also activated during motion imagery, along with areas in lateral prefrontal cortex. Consistent with the DWH they concluded that 'a complex cortical network of motion-sensitive areas driven by bottom-up and top-down neural processes' (Goebel *et al.* 1998, 1563) is necessary for both objective and imagined motion detection. Lamm *et al.* (2001) used fMRI and ERPs to show that imagined dynamic imagery activated a network of cortical regions, importantly the premotor areas, but also including the occipital and parietal cortices, and dorsolateral prefrontal cortex, and that the activations persisted until the imagined task was completed.

Mental rehearsal of motor sequences has become a central feature of sports psychology: athletes, notably gymnasts and high-divers, now spend a lengthy period of inwardly focused attention immediately pre-performance. Kuhtz-Buschbeck *et al.* (2003) combined fMRI and TMS to examine the relationships between imagined mental rehearsal and execution of simple and complex motor tasks. Premotor, posterior parietal, and cerebellar regions, a network involved in motor performance, were more active during mental rehearsal of the complex task. A similar network was delineated by Binkofski *et al.* (2000) with fMRI in subjects while they executed a series of motor instructions, with imagery of the task-activating inferior prefrontal areas. The precise location of these frontal activations was found to lie in Broca's area, a region known to be involved in speech production. This finding is interpreted as evidence for a human analogue of the mirror-neurons found in non-human primates (e.g. Rizzolatti *et al.* 1996). In turn, this could suggest that imagination is not exclusive to human cognition, i.e. that the higher mammals, including monkeys and apes, dogs and cats, all enjoy an imaginative life. More recent studies have suggested that mirror neurons in many other areas of the brain support sympathetic imagination in humans, i.e. our

capacity for putting ourselves in other people's shoes (for a review see Adolphs 2002).

An extreme form of involuntary mental rehearsal of motor execution is apparent with the experience of phantom limbs. To investigate the neural correlates of phantom limb movement and associated pain, Lotze and co-workers (2001) used fMRI to compare the real and imagined movements of upper limbs of healthy controls and upper-limb amputees. While imagining movement of their phantom hand, amputees showed higher activations in contralateral primary motor and sensory-motor areas than controls when imagining their own hand movements. This difference was not apparent when amputees imagined movements of their intact hands. Evidence for a greater degree of cerebral reorganization, contra the Parsimony Hypothesis, was seen with phantom limb pain which activated neighbouring areas in motor cortex for facial musculature.

A more common form of mental rehearsal is observed in professional musicians whose performances, particularly solo roles such as playing concerti, are often from memory. Lotze *et al.* (2003) compared EMG activation maps of professional and amateur violinists during actual and imagined performance of the first 16 bars of Mozart's violin concerto in G major (KV216). Compared with the amateur violinists the professional musicians showed higher activity in auditory cortex and sensorimotor cortex, among a suite of areas, but only during execution but not during imagination. The researchers interpreted these findings as evidence that in professional musicians, 'a higher economy of motor areas frees resources for increased connectivity between the finger sequences and auditory as well as somatosensory loops, which may account for the superior musical performance' (Lotze *et al.* 2003, 1817). However, motor and auditory systems only became co-activated in real performance situations. That is, in this case the neural processes underpinning imagined and real performances are dissociable.

Whereas relatively few of us are professional musicians, we all must, from time to time, have to navigate around complex urban or rural environments from memory. Perceived but unremembered features of the landscape can be surprising, as can be the efficacy of the feeling that, despite incomplete certainty, one is heading in the right direction. To investigate the neural correlates of such remembered visuo-spatial imagery, Rosenbaum *et al.* (2004) used fMRI to scan subjects while they undertook a series of mental navigation tasks in their familiar urban environment (downtown Toronto). A suite of areas was activated, including medial and posterior parietal cortex, and regions of prefrontal cortex associated with working memory load. Again, these findings are supportive of the DWH account of complex neural processing. Interestingly, activity in the right medial temporal lobe did not include the hippocampus, the subcortical

organ involved in laying down memories, suggesting that imagined spatial layouts might be dependent on a network of other regions involved in topographic information processing.

A common experience for all of us is how remembered imagery can often be invoked cross-modally, e.g. the recall of a visual image triggered by associated percepts in other domains, such as sounds or smells. Lundstrom *et al.* (2003) used fMRI to study the retrieval of imagined visual images through word associations. Significant activations in both the posterior precuneus and left lateral prefrontal cortex suggested that explicit retrieval of item–context associations requires a functional network, similarly to Goebel *et al.* (1998), and much as the DWH predicts. Consistently, Bensafi *et al.* (2003) measured nasal airflow in human subjects while they imagined sights, sounds, and smells. Only during olfactory imagery did subjects spontaneously sniff, with imagery of pleasant odours involving larger sniffs than imagery of unpleasant odours. Bensafi *et al.* (2003) argued that the motor activity of sniffing assists in the creation of imaginary olfactory percepts.

Although such intra-domain associations might not be unexpected, for those who experience the phenomenon of synaesthesia, *perception* in one modality can be invoked by stimulation in another (Ramachandran and Hubbard 2003). For example, common words, numbers or letters are often reliably associated with experiences of particular colours. The study of synaesthete subjects offers an opportunity to gain evidence for the neural substrates of some aspects of imagination, in a parallel way to the investigation of other modes of cognition where concomitant evidence for neural causality has been traditionally sought in cognitive dysfunction, particularly with clinical subjects suffering brain lesions (Ramachandran and Hubbard 2001). In an earlier study, Paulesu *et al.* (1995) used PET to study the neurophysiology of colour-word synaesthesia. In addition to the expected ‘language areas’, synaesthetes showed activations in the visual association areas of the inferior temporal and parietal cortices, and in the right prefrontal cortex, but not in the early visual areas. This suggests that in synaesthetes, colour-word visual experience occurs without activation of the visual cortex, but rather in areas associated with language. This finding, while supportive of the DWH, is evidence against the Parsimony Hypothesis. However, more recent and extensive neuroimaging research *has* shown activation of colour areas of visual cortex with synaesthetic experience, in direct support of the Parsimony Hypothesis (Hubbard *et al.* 2005). Interpretation of these data of synaesthetes might be interestingly informative of the neuro-typical case where the perceptual experience of early infants is typically synaesthetic, and normal development is regarded as a growth away from synaesthesia, but which is incomplete in some people for reasons not completely understood (Ramachandran and Hubbard 2003).

Another comparison subpopulation is composed of those who have suffered from some post-natal sensory deprivation, such as blindness onset in childhood. What differences in imagination might these people have? To begin to address this question, Morris *et al.* (2001) studied the responses to fearful faces by a partially blindsighted patient, i.e. someone whose conscious experience is that of being blind in one hemifield. Co-activated responses in a subcortical network including the amygdala, thalamus, and superior colliculus demonstrated that fear-related stimuli can be processed independently of conscious visual awareness. By way of follow-up, researchers at Oxford have studied late-blind individuals who have retained synaesthetic colour perception (Steven and Blakemore 2004; Steven *et al.* 2005). Most had been without any form of colour vision for more than a decade. All perceived colours when they heard or thought about letters, numbers, and time-related words (days of the week and months of the year). One saw Braille characters as coloured dots when he touched them. These results suggest that: 'the neural activity underlying synaesthesia occurs after the establishment of a visual representation. . . . Synaesthesia can persist for very long periods with little or no natural experience in the referred modality and therefore does not depend solely on continuing associative learning' (Steven and Blakemore 2004, 855).

Sadly, until the objective evidence for the synaesthetic experience was secured, many self-reports by synaesthetes were not believed. Similar scepticism is aroused by those other forms of imagination which feature conscious or unconscious pretence: imbuing entities or events with imaginary properties, or even fantastical phenomena, e.g. a childhood belief in fairies. Religious experience falls into this category of imagination, and several neuroimaging studies have sought associated neural correlates. One investigation employed PET to measure the relationship between serotonin receptor density and self-ratings on a personality scale measuring religious behaviour and attitudes (Borg *et al.* 2003). The authors concluded that: 'the serotonin system may serve as a biological basis for spiritual experiences [and] . . . that the several-fold variability in [serotonin] receptor density may explain why people vary greatly in spiritual zeal' (Borg *et al.* 2003, 1965). Excessive religious zeal, of course, can be disabling. Puri *et al.* (2001) also used PET to study the neural correlates of religious delusions in psychiatric patients. Religious delusions were associated with high levels of activation in the left temporal cortex, and reduced activation in the left occipital cortex. Interestingly, similar activations in the temporal cortex have been associated with false memories of alien abduction (Holden and French 2002).

IMAGINING OTHER MINDS

Informative as the preceding studies might be for understanding how our brains are imaginative, their relevance pales when compared with the importance of using our imagination for conceiving the thoughts and feelings of others. In navigating around our social environment, prediction, anticipation, pretence, and sometimes delusion are all aspects of our imaginative repertoire. Not surprisingly, then, the majority of neuroimaging studies about imagination have been concerned with understanding the neural functioning of mindedness or theory of minds (ToM). For example, both Fletcher *et al.* (1995) and Gallagher *et al.* (2000) found ToM correlates in the left medial prefrontal cortex when comparing fMRI activations induced by stories involving mental attributions as compared with stories involving physical attributions. In contrast, Saxe and Kanwisher (2003) showed that similar reasoning about the mental states of other people produced higher fMRI (BOLD) activations in the temporo-parietal junction. Moreover, Ferstl and von Cramon (2002) showed with fMRI that the role that the medial prefrontal cortex plays in coherent language processing is independent of concomitant ToM processes. Some resolution between these different findings has been provided by studies into the neural correlates of the distinctive roles of self and other as the basis of human self-consciousness by Vogeley *et al.* (2001) and Ruby and Decety (2003). Using fMRI and PET respectively, these investigations supported the predicted neural dissociations between perceptions of self, with activations in the temporo-parietal junction, and perceptions of other, with activations in the left temporal cortex. Both perceptions activated the frontal region of the anterior cingulate cortex.

In a follow-up fMRI study, Vogeley *et al.* (2004) investigated the neural dissociations between taking a first-person perspective centred upon one's own body as opposed to a third-person perspective taking the viewpoint of someone else. Common activations were seen in a network of occipital, parietal, and prefrontal areas. Differences in activations induced by third-person perspective over first, and first-person perspective over third, were found in distinct subregions of the temporal, parietal and pre-motor cortices, laterally and sometimes bilaterally. Vogeley *et al.* concluded that: 'the data suggest that in addition to joint neural mechanisms, for example, due to visuospatial processing and decision making, third-person and first-person perspectives rely on differential neural processes' (2004, 817). Such a conclusion builds on earlier work by Zacks *et al.* (1999) which used fMRI to reveal distinct functional areas near the parietal-temporal-occipital junction for egocentric and object-based spatial transformations.

This not unexpected functional modularity of personal perspective raises the interesting question of what neural correlates might be associated with

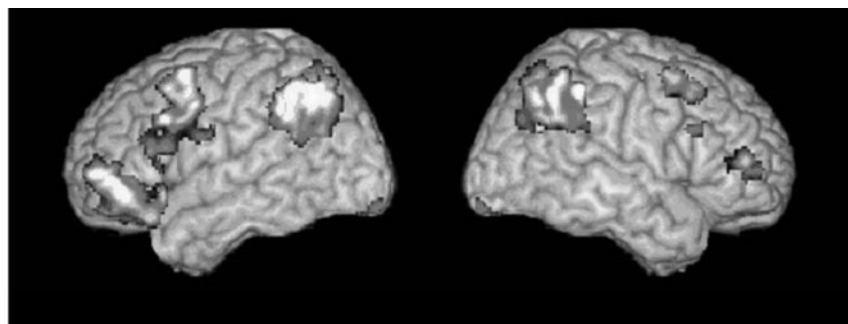
various social interactions between self and other. Is it simply a matter of interaction between the separate neural associates of self and other, or do other neural functions and structures become additionally involved to enable the interaction? One experimental approach (across fMRI, PET, and MEG) has been to investigate the simpler but crucial non-linguistic interactions involved in responding appropriately to various facial expressions (Kringelbach 2004b; Kringelbach and Rolls 2003). Interestingly, the neural correlates of changing behaviour in response to changes in another's facial expression were not found in the fusiform gyrus facial recognition area, but in the frontal areas involved in decision making: the orbitofrontal and anterior cingulate/paracingulate cortices (Kringelbach and Rolls 2004). Emotional attribution was further investigated by Decety and Chaminade (2003) by comparing subjects' responses to sad stories told by actors with either congruent or incongruent emotional expressions. PET activations of emotional mismatch were seen in the ventromedial prefrontal cortex and the superior frontal gyrus, suggesting that feelings of sympathy rely on separate networks for shared experience and affect. The explanatory efficacy of these findings to predict the aetiology of various neuro-psychiatric disorders was reviewed by Blair. He argued that:

in autism . . . the basic response to emotional expressions remains intact but that there is impaired ability to represent the referent of the individual displaying the emotion. In psychopathy, the response to fearful and sad expressions is attenuated and this interferes with socialization resulting in an individual who fails to learn to avoid actions that result in harm to others. In acquired sociopathy, the response to angry expressions in particular is attenuated resulting in reduced regulation of social behaviour (2003, 561).

Appropriate reciprocation as the behavioural indicator that one has correctly inferred another's mental states is important for mutually beneficial cooperation. In antagonistic situations, such as when playing games, counter-factual thinking—imagining what might have been or what if—clearly becomes important. To this end, SciFi buffs who yearn for a robot-mediated future will be interested in three fMRI studies which all showed that prefrontal regions, but no other brain regions, were more active when subjects interacted (played games) with other human subjects than when they interacted with a computer (McCabe *et al.* 2001; Rilling *et al.* 2004; Gallagher *et al.* 2002). From these findings, it could be concluded that in these interactional situations, the perceived capacity for intentionality is critical for the activation of those brain regions involved in imagining of other minds.

CREATIVE IMAGINATION

Whereas we may prefer not to attribute mental states to computers, what about the imagined mental states of characters in fiction, especially those of our own creation? As a 'higher' process of imagination, creativity involves 'the generation of highly novel and original ideas and cultural products' (Roth, Introduction to this volume). Perhaps not surprisingly, the difficulties in framing controlled measures of creativity in experimental environments have restricted neuroscientific progress in this area until very recently. Nevertheless, neural correlates of creative thinking have been sought and found. Jung-Beeman *et al.*'s (2004) fMRI and EEG study of the 'Aha' experience showed right temporal involvement in insight, a component of creative thinking. Investigating a separate component of creativity, Bechtereva *et al.* (2004) found PET activations in the left parieto-temporal cortex of subjects engaged in verbal creation tasks. In an fMRI study to investigate the neural correlates of creative intelligence operationalized as fluid analogy making, Geake and Hansen (2005) found a network of activations in prefrontal and parietal areas for deep compared with shallow fluid analogies, consistent with the DWH (Figure 14.3). A further ROI analysis showed a linear correlation between subjects' intelligence measures and fMRI (BOLD) activation in prefrontal areas involved with working memory.



Anterior ← LH → Posterior

Posterior ← RH → Anterior

Figure 14.3. Significant clusters of neural activation, as determined by fMRI, associated with fluid analogizing tasks (Geake and Hansen 2005). These active clusters, associated with creative thinking, form a network of frontal and other cortical regions.

SUMMARY

Imaging and other neuroscientific techniques offer a potential handle on the architecture of the imaginative mind, helping to show how the neural bases of imaginative activities are organized. There is no one 'module' for imagination; nor even a series of modules for the different forms of imagination discussed. Rather, imaginative processes are highly distributed activities which recruit many different brain areas and networks. The complex relationships within and between these various networks are captured by the Dynamic Workspace Hypothesis (Dehaene *et al.* 1998). In any event, some common operating principles underlie different forms of imagination. These include parsimony, obviously relevant to cases where imaginative activity has corresponding referents in the 'outside world', but interestingly applicable to wholly imagined mental phenomena.

IMAGINING IMAGING

We conclude with a Coda featuring an indulgence of our own imagination, *Imagining Imaging*. In the future, could neuroimaging becoming an everyday diagnostic and even recreational tool for expanding human imagination and consciousness, as Roth (2004) conjectured? Geake and Cooper (2003) imagined an educational future in which imaging technology becomes more powerful yet miniaturized and cheap, in a parallel manner to the development of computer technology, so that schools acquire class sets of personal neuroimagers for the diagnosis of learning difficulties. Remediation is then effected through biofeedback provided by real-time neuroimaging. Such a scenario has been recently explored by deCharms *et al.* (2004). Subjects were able to learn to voluntarily control neural activations in their somatomotor cortices from feedback provided by real-time fMRI. Similar EEG-based feedback research has been undertaken with musicians (Egner and Gruzelier 2003). Importantly, this learning effect was shown to be additional to improvement due to practice-based neural plasticity. In other words, neuroimaging can be used, not just to measure imagination, but also to influence it. As for Geake and Cooper's conjectured future developments of miniaturized imaging technologies, the first releases of near infrared encephalography (NIEG) wireless headsets are now commercially available. Despite its considerable limitations to spatial resolution, this new neuroimaging technology can be used in natural settings, making it more user-friendly than current laboratory-based equipment. Furthermore, the DWH predicts that the most important neural correlates are network connectivities rather than spatial modularizations. To this end, diffusion tensor imaging (DTI) and its concomitant analysis are

now allowing researchers to begin to construct neural connectivity maps. Perhaps the future of imaging our imagination is closer than we imagine?

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