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Neuroimaging of mental imagery: An introduction

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Since the earliest days of scientific psychology, the value of mental imagery in comprehension, memory, and reasoning has been recognised and studied. The massive amount of data collected in this domain of research has revealed that the human mind is often inclined toward the most direct contact possible with the objects of its focus, using mental images in addition to and sometimes instead of indirect or more remote contact based on symbolic, language-like representational systems. In scientific thinking, as in every other form of thinking, imagery is considered an irreplaceable tool, which efficiently supplements more abstract forms of reasoning (Denis, Logie, Cornoldi, de Vega, & Engelkamp, 2001; Shepard, 1988).

This issue of the *European Journal of Cognitive Psychology* addresses this traditional topic in psychology, but does so in a new way—using neuroimaging. It is not surprising that cognitive science has increasingly relied on methods that provide data about the neural substrates of cognition, in particular derived from

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neuroimaging methods. And the study of mental imagery was among the first cognitive domains that inspired significant amounts of neuroimaging research. Two decades after the publication of Roland and Friberg's (1985) pioneering work on the variations of cerebral blood flow that accompany the visualisation of a familiar route, mental imagery is still the focus of a large amount of neuroimaging research. The questions being asked by cognitive scientists are easy to formulate—but the answers sometimes may be difficult to obtain. For example: Does mental imagery share common cortical structures with those known to be active during perception and motor control? How do differences in brain activation inform us about the nature of different types of imagery? How do differences in brain activation inform us about the different strategies people can adopt when using imagery? What do the temporal relations among activations of different brain areas tell us about the course of information processing? How do individual differences in the degree of activation produce individual differences in performance?

These are the types of questions that the contributors to the present special issue of the journal have asked, and have begun to answer in detail in a series of original neuroimaging studies. These studies rely on positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). These techniques are used in the context of a variety of cognitive tasks involving memory, problem solving, and other processes. A strong emphasis is placed on individual differences, which have long been recognized as requiring special attention in order to provide comprehensive accounts of the results of imagery experiments.

Today, we are far beyond the time when cerebral specialisation was conceived only in terms of hemispheric differences. Not only are cerebral regions now carefully differentiated in terms of their functional specialisation, but also imagery tasks are contrasted in terms of their specific requirements (such as representing shape versus spatial relations). Neurofunctional studies of imagery have demonstrated that the activation patterns during imagery depend strongly on the tasks performed (e.g., Thompson & Kosslyn, 2000). One of the merits of the neuroimaging approach to studying mental imagery is that it focuses us on fine-grained analyses of the processes required to perform specific tasks—which leads us to draw distinctions among what previously were lumped together under the general label of ''imagery tasks''.

There is a consensus that retrieving visual representations from memory involves some form of reactivation of the cortical structures that were activated when these representations initially were encoded. In the first paper of the present issue, Todd Handy and his colleagues attempt to establish whether brain activity differs in two circumstances, when a person visualises an object by recalling a recently encoded picture of that object versus when a person visualises an object by retrieving visual information about the object stored in long-term memory. In other words, the aim of this research is to discover whether the activating processes responsible for imagery are affected by the particular strategy one employs. The data collected in a blocked fMRI design show that the left ventral cortex in the fusiform gyrus is activated in both conditions, whereas the frontal cortex is activated differently in the two conditions—which suggests that partly different mechanisms underlie the two retrieval strategies. In addition to apparent differences in the two retrieval mechanisms, the results speak in favour of a common network in the left hemisphere that is activated in both cases.

The next paper summarises studies that explore the neural correlates of a spatial imagery task. A nice feature of neuroimaging studies is that they provide an opportunity to revisit classic imagery paradigms. Here, Luigi Trojano and his colleagues recorded fMRI measures while participants compared mentally the angles formed by the two hands of a clock, an adaptation of the ''mental clocks'' task originally designed by Allan Paivio (1978). The results of the studies document the role of the cortical areas in the posterior parietal cortex in spatial mental imagery, even in the absence of any visual stimulation. Furthermore, the comparison of tasks involving the categorical and coordinate processing of spatial mental images reveals that both types of processing share a common region of activation in the superior parietal lobule, but that the two sorts of processing are not identical. Another interesting finding bears on an issue that has elicited much controversy during the past decade, namely the circumstances in which imagery induces activation in early visual areas—especially in cases where abstract or schematic patterns are imagined, without requiring the inspection of fine-grained visuospatial representations.

This controversy is directly addressed in the following paper. Taking advantage of a database of nine PET experiments conducted in their laboratory, Angélique Mazard and her colleagues directly compare spatial and object imagery tasks, with the aim of discovering which brain areas are activated in common and which are not. Their meta-analysis reveals both common and distinct areas that are activated during the two sorts of imagery. In some respects, the most illuminating result concerns a crucial difference during spatial versus object imagery: These researchers report that spatial imagery activates the superior part of the parietal cortex, whereas object imagery engages the anterior part of the ventral pathway. More specifically, the early visual cortex tends to be activated by object imagery, while it is deactivated by spatial imagery. This analysis strongly suggests that the early visual cortex plays a role in the visualisation of figural information, although large interindividual variations are also evident in the activity of this region. Thus, this meta-analysis contributes to the ongoing debate about the role of early visual areas in visual mental imagery (e.g., Roland & Gulyas, 1994).

A further attempt to delineate the subprocesses serving imagery is found in the experiment reported by Stephen Kosslyn and his colleagues. They used PET to monitor brain activity while participants performed four tasks: forming high-resolution images, generating images from distinct segments, inspecting images to parse them, and rotating images. The innovative feature of this study is that rather than compare a test condition to a baseline, as is the convention in neuroimaging research, these researchers rely on multiple regression analyses. In these analyses, variations in response times and error rates are regressed onto variations in regional cerebral blood flow, with the goal of discovering in which areas variations in blood flow predict variations in performance. This method is an alternative to the subtractive method, in that it does not inform us about the brain areas that underlie performance, but rather about those regions that underlie *variations* in performance in specific tasks. The results revealed not only that different areas predict performance in different tasks, but also that the number of brain areas that predicts performance lines up with the complexity of the tasks.

Other challenging issues are introduced in the following three papers. Mental rotation and the meaning of parietal activation in functional neuroimaging are the subjects of Vinoth Jagaroo's theory-driven review. The discussion is grounded in the widely recognised fact that the posterior parietal cortex is activated during mental rotation. This activation may be interpreted as reflecting a specialised parietal function that underlies the transformational process itself, or this activation could reflect the role of the parietal lobe in directing eye movements. By highlighting the centrality of coordinate transformations in the process under study, the author suggests some interesting lines of future work on functional imaging of mental rotation.

The next paper addresses the issue of sensory integration and intermodal differences. The neuroimaging literature has focused on visual imagery and the question of shared mechanisms for visual perception and visual imagery. This study by Marta Olivetti Belardinelli and her colleagues used fMRI to record brain activation while participants generated images in eight modalities (visual, auditory, tactile, olfactory, gustatory, kinaesthetic, visceral, and abstract). The newest piece of information reported here is that the posterior portion of the middle-inferior temporal cortex is recruited by all imagery modalities, indicating that this region is not specific to visual imagery, as previously assumed by the authors of studies that focused solely on visual imagery. Parietal and prefrontal areas show a more heterogeneous pattern of activation for the modalities considered. The data converge on the idea that the generation of images involves high-level processes that are independent of modality-specific representations.

The final contribution to this special issue reports one of the first attempts to collect PET data in people engaged in a high-level type of problem solving, namely, chess playing. By examining the brains of experts during blindfold chess, it is possible to access the neural representations of mental images constructed during this very complex task. Pertti Saariluoma and his colleagues compared performance in a memory task (which requires spatial information storage) and problem solving (which in addition calls for access to long-term memory and planning) in experienced chess players, using their performance in an attention task as a baseline. The findings clearly show that the pattern of brain activation is different in these two tasks. In particular, the memory task activates the temporal areas, whereas problem solving activates several frontal areas. This research opens the door to the speculation that experts' chess-specific images may not necessarily be represented in the brain in the same way as ordinary mental images.

The explosion of interest in neuroimaging methods among researchers who study cognition cannot be explained solely by the appeal of seeing pretty pictures of brain activity. Rather, these sophisticated methods force scientists to relate theories of mental processing to the brain itself, and invite scientists to develop detailed models of cognition that do more than explain behaviour—that also specify the underlying mechanisms in biologically plausible terms. Cognitive scientists, and in particular those who focus on the study of mental imagery, have no excuse for ignoring the value of these techniques. But the techniques are not a ''magic bullet''. They are only useful if combined with clearly focused questions that are rooted in theoretical issues. Moreover, researchers must take care not to fall into the trap of assuming that the pretty coloured pictures provided by today's impressive machines are the direct reflections of *mental images*, but instead must keep in mind that they are viewing evidence of underlying *neuronal activity*—which is not the same thing as a mental representation, let alone the experience that a type of representation may evoke. The challenge is to use this information to build theoretical models of the cognitive processes that are supported by cerebral activations.

Consistent with a general trend in the papers published in psychology journals, the reader will notice that the lists of co-authors of the published papers tend to be increasingly long. This reflects the fact that neuroimaging is a highly collaborative and interdisciplinary domain. This trend probably also suggests that some disciplinary borders will soon have to be reconsidered in the field of human cognition. Needless to say, this collaborative endeavour goes along with extensive international cooperation, which is reflected here by the fact that the seven papers involve authors from a total of eight different countries.

The present special issue of the *European Journal of Cognitive Psychology* is an outgrowth of the Eighth European Workshop on Imagery and Cognition (EWIC), which was organised in Saint-Malo, France, in April 2001, by Michel Denis and Maryvonne Carfantan. Since the launching of the EWIC meetings in 1986, the presence of neuroimaging methods in research on mental imagery has steadily increased. The 2001 edition of EWIC included a special session on Neuroimaging Investigations of Mental Imagery, whose content served as a starting point for shaping this special issue of the *European Journal of Cognitive Psychology* on the neuroimaging of mental imagery. A call for papers was widely circulated. Some of the original papers presented at the workshop were published elsewhere, while newly submitted papers were accepted, thus forming a set of seven original papers. The invited co-editors appreciated very much the enthusiastic response of Claus Bundesen, Editor, to their proposal of devoting a full special issue to neuroimaging investigations of this major topic within cognitive psychology. We hope that this special issue will be a source of inspiration for further research on a fascinating facet of human cognition.

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REFERENCES

Denis, M., Logie, R. H., Cornoldi, C., de Vega, M., & Engelkamp, J. (Eds.). (2001). *Imagery, language, and visuo-spatial thinking*. Hove, UK: Psychology Press.

Paivio, A. (1978). Comparisons of mental clocks. *Journal of Experimental Psychology: Human Perception and Performance*, *4*, 61–71.

Roland, P. E., & Friberg, L. (1985). Localization of cortical areas activated by thinking. *Journal of Neurophysiology*, *53*, 1219–1243.

Roland, P. E., & Gulyas, B. (1994). Visual imagery and visual representation. *Trends in Neurosciences*, *17*, 281–287.

Shepard, R. N. (1988). The imagination of the scientist. In K. Egan & D. Nadaner (Eds.), *Imagination and education* (pp. 153–185). New York: Teachers College Press.

Thompson, W. L., & Kosslyn, S. M. (2000). Neural systems activated during visual mental imagery: A review and meta-analyses. In A. W. Toga & J. C. Mazziotta (Eds.), *Brain mapping: The systems* (pp. 535–560). San Diego, CA: Academic Press.