Riddle is to conundrum as the frontal pole is to…?

Paul W. Burgess

Institute of Cognitive Neuroscience

UCL (University College London)

17 Queen Square,

London WC1N 3AZ

U.K.

p.burgess@ucl.ac.uk

This article appeared in: BRAIN Volume 139, Issue 6, pp. 1627 - 1630

The following is a commentary on Urbanski et al "Reasoning by analogy requires the left frontal pole: lesion-deficit mapping and clinical implications" BRAIN 2016.

Urbanski et al make a key finding in respect of our understanding of how the prefrontal cortex supports intelligent behaviour. It is one which may help solve a curious conundrum in the research on the functions of rostral prefrontal cortex (PFC). Rostral PFC is a very large brain region for which there are many names (including the "frontal pole"), all of which are rather imprecise, but generally approximate to Area 10 of the human brain. The conundrum is this: Many human lesion studies over the last 60 years or so have suggested that large uncomplicated removals of this region, or damage to the connections to it, can cause little or no impairment on IQ tests (for review see Burgess et al, 2012). Indeed, there are detailed reports of individual patients who have had virtually complete excisions of rostral PFC and yet still score within the top 1% of the population on the most commonly used clinical IQ test (e.g. AP; Shallice and Burgess, 1991). But more recently, several authors have suggested that this brain region is in fact involved in "intelligence" (e.g. Colom, Jung and Haier, 2007; Gläscher et al, 2010), based on evidence from both human lesion evidence and functional neuroimaging. How are these discrepancies to be reconciled?

One possible solution lies in the way that "intelligence" is measured (Duncan, Burgess and Emslie, 1995). There are, in broad terms, two predominant ways of conceiving of intelligence in the study of brain and behaviour. The first is to think of "intelligence" as little more than an average of performance across a wide range of tasks that tap a wide range of abilities, and have little in common with each other. This view is typified by the various instantiations of the Wechsler Adult Intelligence Scale. This is probably the most widely used IQ test in neuropsychological practice, and is the kind of task that patient AP performed so well. However, a completely different way of measuring intelligence is typified by various tests that attempt to measure so-called "fluid intelligence". They rely for their rationale upon belief in an inference made about "positive manifold". Positive manifold is the tendency within a correlation matrix of performances on a wide range of disparate tasks for there to be more positive correlations than would be expected by chance. Fluid intelligence tests tend to use test items that are quite similar to each other (or are selected from a narrow range of them), but have been shown to correlate highly with performance in a wide range of tests that are quite *different* in format. There are many examples of IQ tests in common that have been developed through this second kind of approach, and many of them contain items that require extracting a principle from one set of stimuli and then applying it to a new set of stimuli. For instance, the AH6 IQ test (1970 version) contains many items of the form "Tool is to hammer as animal is to…" with four response option to choose from. Other items, for instance, present a line containing two words on the left, and five on the right, and ask "which one of the five words on the right bears a similar relation to each of the two words on the left". These problems are examples of *analogical reasoning*, which is the process of extrapolating from similarity or regularity in one situation to similarity in another.

So, one potential solution to the conundrum described above that may follow from the Urbanski et al findings is that lesions to rostral areas of PFC can lead to a specific deficit in analogical reasoning, a key component of many "fluid intelligence"-type tests, but not one which not a strong component of IQ tests that measure intelligence as an average across disparate tasks.

FIGURE 1 ABOUT HERE

This possible explanation becomes more plausible when one considers other aspects of the data that Urbanski et al present. They administered, in addition to the experimental tasks of analogical

reasoning, several tests of so-called "executive function" as background tasks (Figure 1). Background tests are administered in these sorts of experiments to show the broader context of the patients' cognitive abilities. The total patient sample performed poorly on them. Urbanski et al also administered a control condition as part of the experimental tasks which required analysis of the same kinds of visual stimuli that were used in the analogical reasoning conditions, and also required such skills as seeing and attending to the stimuli, understanding instructions, making motor responses, and even matching complex stimuli to each other. The entire patient sample, considered as a group, was unimpaired at these control conditions, so we can exclude problems with these more basic processes as an explanation of any deficit.

If the impaired processes that caused these executive difficulties in the total sample are also involved to a significant degree with analogical reasoning, then the method that Urbanski et al use to try to determine brain regions critical to analogical reasoning (VLSM) will be conservative. In VLSM, each voxel from the MRI brain scans is classified according to whether the lesion affects that voxel. Then the analogical reasoning scores for the two groups (lesion present; lesion absent) are compared statistically, and the results are used to build a map of impairment across the brain. This method is conservative in the sense that if analogical reasoning is affected by impairment in a range of processes whose neural substrates are anatomically close to the most critical ones then the chances of finding a neat localisation of brain and behaviour is reduced. In other words, the method is most likely to yield a result where there is strong *functional specialisation* for the mental ability of interest. Not only were Urbanski et al able to identify quite circumscribed parts of the PFC as being critical to deficits in analogical reasoning, they also showed that lesions involving the most important of these *did not* fail the background tasks. Nor did those who were impaired at analogical reasoning fail them either. (There is a complexity in their data as regards Stroop interference in the VSLM group but for current purposes this interesting issue will be put aside.) In other words, patients with lesions in the frontal pole may be impaired at analogical reasoning but not impaired at many other mentally taxing tasks.

These findings may suggest that it would be useful to disentangle the notion of "fluid intelligence" from that of analogical reasoning. If analogical reasoning is a key component of fluid intelligence, and fluid intelligence underpins performance on virtually all mental ability tasks, then Urbanski et al's patients who had analogical reasoning deficits should have been expected to fail a wide range of tasks. But they did not. So, how might analogical reasoning ability be correlated with a wide range of mental abilities in the healthy brain, and yet be impaired relatively independently in neurological patients? One possibility is that analogical reasoning may be an ability whose development might be facilitated by development of other processes, but thenceforward is not directly causally related to them. In other words, there is correlation not causation. Whatever, the implications of the Urbanski et al study reach beyond our understanding of analogical reasoning alone.

One issue that the Urbanski et al study did not address however concerns the critical processing impairment in those who fail the analogical reasoning task. Volle et al (2010) have shown, using fMRI, that within lateral rostral PFC is activated by an analogical reasoning task both during study of the source (i.e. before the source could be compared with a target) and also when the target appeared. Hence the processing contribution made by at least some rostral PFC structures appears not to be specific to one particular problem-solving stage. Burgess et al (2007) give one possibility for a process of this kind in the "gateway hypothesis". This holds that rostral PFC supports a brain region involved in "XN control", which is the ability to voluntarily alter the degree to which we either attend to the environment (known as stimulus-oriented attending), or to the thoughts in our heads (known as stimulus-independent attending). Such an ability might be required both in attending to analogical stimuli and extracting important features from it, and then in making a "workspace" in our heads to try out various hypotheses we generate about the possible matches to the target

stimuli. This explanation has been shown to be plausible for deficits in prospective memory following rostral PFC lesions (Benoit et al, 2012). However, its plausibility for explaining analogical reasoning deficits remains to be determined. The analogical reasoning test that Urbanski et al present in this study may prove not only useful for that purpose, but also may add very usefully to our ability to detect in the clinic the kinds of impairments that follow rostral PFC damage.

References

Benoit, R.G., Gilbert, S.J., Frith, C.D., and Burgess, P.W. Rostral prefrontal cortex and the focus of attention in prospective memory. Cereb. Cortex 2012; 22 (8): 1876-1886.

Burgess, P. W., Dumontheil, I., & Gilbert, S. J. The gateway hypothesis of rostral prefrontal cortex (area 10) function. Trends Cog. Sci. 2007; 11: 290-298.

Burgess, P. W. & Wu, H-C. (2013) Rostral prefrontal cortex (Brodmann area 10): metacognition in the brain. (2013) Chapter 31 in: Principles of Frontal Lobe Function, 2nd edition (Editors: Donald T. Stuss & Robert T. Knight) pp. 524-534. New York: OUP

Colom, R, Jung, R.E., & Haier, R.J. General intelligence and memory span: evidence for a common neuroanatomic framework. Cognitive Neuropsychology 2007; 24(8): 867-78.

Duncan, J., Burgess, P. W., & Emslie, H. Fluid intelligence after frontal lobe lesions. Neuropsychologia 1995; 33: 261-268.

Gläscher, J., Rudrauf, D., Colom, R., Paul, L. K., Tranel, D., Damasio, H., & Adolphs, R. Distributed neural system for general intelligence revealed by lesion mapping. Proc. Nat. Acad. Sci. USA 2010; 107(10): 4705–4709.

Shallice, T. and Burgess, P. W. Deficits in strategy application following frontal lobe damage in man. Brain 1991; 114**:** 727-741.

Volle, E., Gilbert, S. J., Benoit, R. & Burgess, P. W. Specialisation of the rostral prefrontal cortex for distinct analogy processes. Cereb. Cortex 2010; 20(11): 2647-2659.

Glossary

Executive functions: A collective term used to refer to a set of processes that are involved with dealing with novelty, behavioural adaptation, and organisation of behaviour over long time periods. These include planning processes, inhibition, prospective and other sorts of high-level memory abilities, complex problem-solving, and are also strongly related to many forms of social cognition and metacognition such as self-judgement, mentalizing, and judging the most appropriate way to behave. Most executive functions are thought to be supported at least in part by structures within the frontal lobes. There are a large number of executive functions, and many may operate independently of each other.

Functional specialisation: The degree to which a particular part of the brain, or system within it, can be identified as supporting a particular mental ability.

Fluid intelligence: A hypothetical construct held to be involved in most mental abilities. Its invention is tightly linked to the UK scientist Charles Spearman and his followers (e.g. Raymond B. Cattell). Its existence has been hotly debated for over 70 years.

LEGEND FOR FIGURE 1

Schematic representation of the Urbanski et al study and the principal findings.