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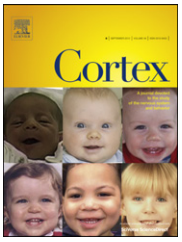

Discussion forum

Using functional neuroimaging to test theories of cognition: A selective survey of studies from 2007 to 2011 as a contribution to the Decade of the Mind Initiative

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1. Introduction

Most current studies in the field of cognitive neuroscience are based on the recording of neuroimages from a participant's brain while that participant is engaged in carrying out some mental activity. The idea is that, by recording the brain activity that accompanies mental processes, we learn where in the brain those mental processes take place. But also it is hoped that such work will shed light on the inner workings of those mental processes, and so tell us something about the mechanisms that produce them.

Six years ago, Max Coltheart opened a Discussion Forum in this journal (Coltheart, 2006a), with the stimulating title "What has functional neuroimaging told us about the mind (so far)?". About 10 different scholars responded to this question by offering examples of situations where, in their view, functional neuroimaging has contributed to understanding human cognitive processes. In Coltheart's Forum rounding off response, followed by the contribution by Page (2006), these opinions were disputed, while their conclusions were summarized by the title "Perhaps functional neuroimaging has not told us anything about the mind (so far)" (Coltheart, 2006b).

Nevertheless, in recent years a number of supposedly new disciplines have emerged which all seek to bring neuroimaging to bear on investigating how the human mind works. As a result, we now have "neuro-economics" (i.e., Camerer et al., 2005), "neuro-sociology" (i.e., Franks, 2010), "neuro-politics" (i.e., Connolly, 2002), "neuro-ethics" (i.e., Farah, 2012), "neuro-philosophy" (i.e., Churchland, 1986) and even "neuro-esthetics" (i.e., Di Dio and Gallese, 2009), "neuro-theology" (i.e., Joseph, 2003) and "neuro-marketing" (i.e., Ariely and Berns, 2010). Clearly, it would make little sense to claim that a new discipline has emerged only because we now have the means for localizing in the brain where the mental processes involved in particular disciplines are located. We could claim to have started a new discipline only if we had acquired a new means of exploring the mental processes involved in that discipline.

Coltheart (2006a,b, 2010; also see Henson, 2005; Loosemore and Harley, 2010 and Poldrack, 2010) has proposed that neuroimaging studies can have three (not mutually exclusive) goals. The first (Goal 1) is the "neuroanatomical localization of cognitive processes". This is no doubt an interesting enterprise but it adds very little to our knowledge of how our mind works. The second goal (Goal 2) consists of "testing theories of cognition". Based on this second goal, neuroimaging studies should be aimed at evaluating theories that are expressed at a purely psychological level. Here we would have grounds for founding new disciplines. The third goal (Goal 3), "testing neural models", is relevant only for exploring how the brain works and will not be considered here.

The aim of the present literature survey is to estimate how many of the studies recently made available in journals devoted to cognitive neuroscience have actually pursued Goal 2, in terms of evaluating theories of cognition. Expressed in another way, the aim of the present paper is to estimate how many recent neuroimaging studies actually comprise relevant ways of exploring the human mind, thus giving rise to new disciplines as a critical contribution to the Decade of the Mind Initiative (Albus et al., 2007).

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2. Method

2.1. Survey of the literature

Journal inclusion criteria.

In our survey, we took into consideration only original research papers concerned with human mental functions, thus excluding review papers. We screened the four journals with the highest Impact Factor according to the ISI Web of Knowledge Journal Citation Reports (JCR) Science 2010: Nature, Nature Neuroscience, Science and PNAS. Also, we added four journals specifically devoted to the study of mind-brain relations, Cortex, Neuropsychologia, Cognitive Neuropsychology, and the Journal of Cognitive Neuroscience.

The papers to be included underwent a two-stage hierarchical process.

In stage 1, we used the following keywords: "fMRI" in every field (title, abstract, text) for each of the eight journals, limiting the search to the period between January 2007 and December 2011. The 809 studies retrieved in this way were passed on to stage 2.

In stage 2, two of the authors, P.E.T. and F.S., independently screened the studies from stage 1, by applying the following inclusion criteria:

- Studies using fMRI with healthy human participants or with patients the aim of which was to contribute to the understanding of the functional architecture of cognitive systems.
- Studies using fMRI to investigate the following human cognitive functions: perception, language, reading, mathematical cognition, memory, attention, and decision-making.

The exclusion criteria we applied were:

- Studies related to other mental functions, e.g., motor control, emotion regulation, etc. For instance, we did not include the study by Miall et al. (2009) in which the main topic was the brain activation related to drawing.
- Studies related to the investigation of neural mechanisms, e.g., brain areas targeted by dopamine neurons, coupling between the high- and low-frequency bands of ongoing electrical activity, cerebral plasticity, etc. An example is the study by Elkana et al. (2011), the aim of which was to investigate spontaneous functional recovery after insult to the language-dominant hemisphere.
- Studies related solely to investigating the neural correlates of specific neurological disorders (e.g., "Impaired recognition of musical emotions and facial expressions following anteromedial temporal lobe excision", Gosselin et al., 2011; "Examination of focal brain lesions in childhood", Jacobs et al., 2011).
- Studies combining fMRI with other methods (e.g., EEG, TMS, computational models) when the main conclusions reached were based on these supplementary methods. An example is Turkeltaub et al. (in press), which was a study of a patient that combined fMRI with Transcranial Magnetic Stimulation.

All studies were then classified, according to Coltheart's (2010) proposal, as belonging to Goal 1, that is "neuro anatomical localization of cognitive processes", or to Goal 2, that is, "testing theories of cognition".

To be assigned to Goal 1, the main aims and conclusions of the study must have made explicit reference to establishing what brain regions or systems exhibit altered activity in response to the engagement of particular cognitive, emotional, or sensory processes.

To be assigned to Goal 2, the main aims and conclusions of the study must have made explicit reference to testing theories of cognition by using neuroimaging data. Studies belonging to this category could have been concerned with a particular theory expressed in cognitive terms and in trying to collect evidence in support of that theory. Other studies in this category could have been concerned with competing theories expressed in cognitive terms and in trying to adjudicate between such theories. In this phase we did not consider whether or not a study was properly designed – whether, for example, it committed the consistency fallacy (Mole and Klein, 2010). This fallacy consists in claiming that some study supports some theory solely because the data from that study are consistent with the theory, without providing any evidence that the study could plausibly have yielded any pattern of data that would have counted against that theory.

3. Results

3.1. Goal 1 and Goal 2 descriptive statistics

Overall 199 papers were identified from stage 2. One-hundred and seventy-nine were assigned to Goal 1[1]; the remaining 20 were assigned to Goal 2.

3.2. Raters' agreement

The percentage of independent agreement between the two raters was 170/199 = 85.4%; Kappa = .51; .95 CI = .42–.60 (Martin and Femia, 2004). The remaining 29 studies that had yielded a discrepancy between the raters were subsequently submitted blind to a third rater[2] who independently classified them within the two categories. Using the majority vote, eight studies were assigned to Goal 2 and the remaining 21, to Goal 1.

In Table 1 we list the 20 studies assigned to Goal 2.

The overall percentages of Goal 1 and Goal 2 studies are 88.8% and 11.2% respectively. Their range across all the journals is 0–13.3%.

Although in terms of raw numbers there was a small increase in studies belonging to Goal 2 across the five years, the percentage of all studies that belong to Goal 2 has not increased over this period. This percentage was 16.7% in 2007 and 8.3% in 2011.

However, even though the number of functional neuroimaging studies aimed at the clarification of how mental processes work is low, it may still be interesting to see to what

[1] The complete list of references assigned to Goal 1 and a supplementary figure and table, are available upon request to the first author.

[2] We acknowledge the collaboration of Dr. David Giofrè for this role.

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Table 1 – List of studies assigned to Goal 2 in alphabetical order.

Authors
1. Ahveninen et al., 2011
2. Bartolucci and Smith, 2011
3. Basten et al., 2010
4. Bozic et al., 2007
5. Caplovitz and Tse, 2010
6. Cappell et al., 2010
7. Delgado et al., 2008
8. Greene and Paxton, 2009
9. Hare et al., 2011
10. Herrmann et al., 2010
11. Izuma et al., 2010
12. Kompus et al., 2009
13. Marklund et al., 2007
14. Sahin et al., 2009
15. Sala and Courtney, 2007
16. Stokes et al., 2009
17. Tombu et al., 2011
18. Tricomi et al., 2010
19. Vilberg and Rugg, 2007
20. Zhou et al., 2010

extent the few studies belonging to Goal 2 have contributed to such knowledge. Within the 20 studies that were concerned with Goal 2, 11 (papers 3, 4, 6,7, 9,11,13,15,16,18 and 20, see Table 1) explicitly conceded that they merely supported previous cognitive models by using neurophysiological findings as converging evidence. Thus all 11 suffered from the consistency fallacy, described above and defined by Mole and Klein (2010). The remaining nine studies made use of neuroimaging data with the intention of adjudicating between two competing theories concerning functional and/or anatomical mental processes.

4. Conclusion

Following a proposal by Coltheart (2010), we assumed that the only neuroimaging studies that can be instrumental in increasing our understanding of how the human mind works are those that can be assigned to Goal 2, that is, those studies that aim to support some psychological theory or to discriminate between competing psychological theories. A better understanding of how the human mind works might, in turn, justify the founding of new disciplines, such as, for example "neuro-economics", and many other newly founded disciplines of the "neuro+" type.

Surprisingly enough, our survey of the relevant literature of the latest five years showed that comparatively few studies could be assigned to Goal 2. Much more numerous were studies belonging to Goal 1 that is, studies aimed at localizing mental functions in specific brain regions rather than aimed at understanding how the human mind works.

Even if we do not reject Goal 2 studies that commit the consistency fallacy, our survey nevertheless still makes it clear that very few resources are currently being devoted to using neuroimaging data to test theories about cognition. If neuroimaging research on localization of cognitive functions is ever to have any impact on cognitive theorizing, the investigator must be willing to make proposals about the mapping of mind to brain that involve both sensitivity (a claim that brain region X will always be active when cognitive process C is being executed) and specificity (the claim that brain region X will not be active except when cognitive process C is being executed). Whether it is possible even in principle to formulate and substantiate such proposals in the future, remains to be seen.

We hope this evidence makes researchers interested in the Decade of the Mind Initiative reflect on how to contribute to the knowledge of the human mind in ways that will avoid merely duplicating the Decade of the Brain Project.

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Table : Number of studies related to Goal 1 and Goal 2 and their ratio for each journal.

Journal	Goal 1	Goal 2	Goal2/Goal1%
Nature + Nature Neuroscience	19	2	10.5
Science	19	2	10.5
PNAS	60	8	13.3
Cortex	36	3	8.3
Journal of Cognitive Neuroscience	10	1	10
Neuropsychologia	31	4	12.9
Cognitive Neuropsychology	4	0	-
Total	**179**	**20**	**11.2**

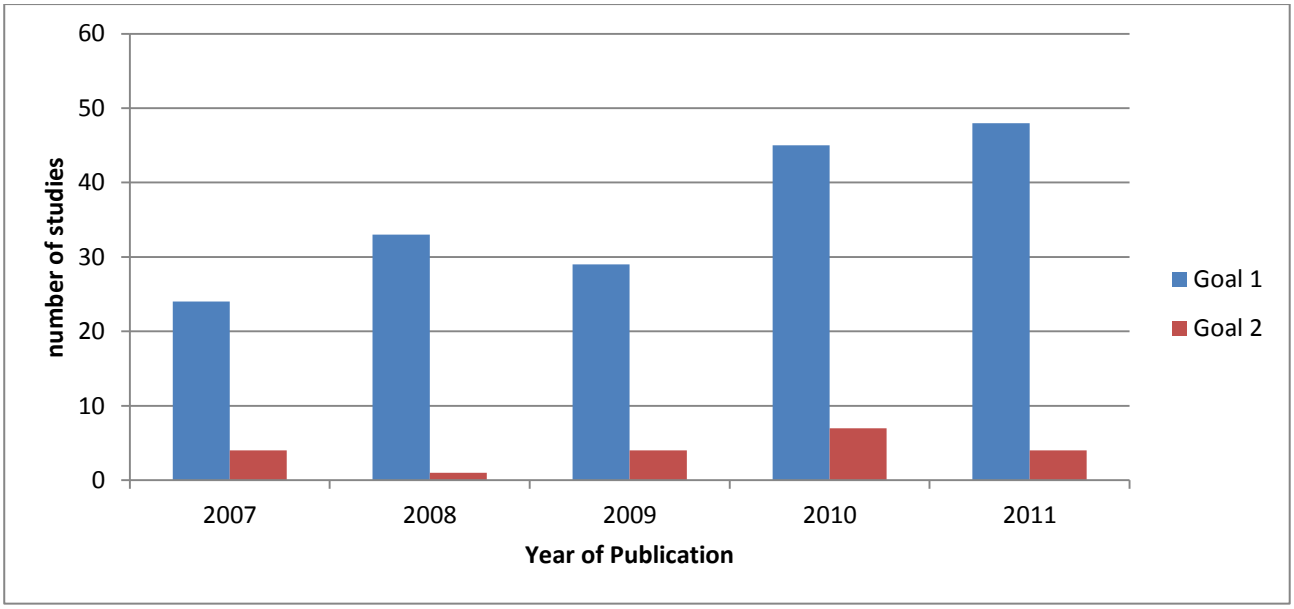

Figure: Raw number of studies assigned to Goal 1 and Goal 2 from 2007 to 2011