

Method Matters: An Empirical Study of Impact in Cognitive Neuroscience

Lesley K. Fellows¹, Andrea S. Heberlein^{1,2}, Dawn A. Morales¹,
Geeta Shivde¹, Sara Waller^{1,3}, and Denise H. Wu¹

Abstract

■ A major thrust of cognitive neuroscience is the elucidation of structure–function relationships in the human brain. Over the last several years, functional neuroimaging has risen in prominence relative to the lesion studies that formed the historical core of work in this field. These two methods have different strengths and weaknesses. Among these is a crucial difference in the nature of evidence each can provide. Lesion studies can provide evidence for necessity claims, whereas functional neuroimaging studies do not. We hypothesized that lesion studies will continue to have greater scientific impact even as the relative proportion of such studies in the cognitive neuroscience literature declines. Using methods drawn from systematic literature review, we identified a set of original

cognitive neuroscience articles that employed either functional imaging or lesion techniques, published at one of two time points in the 1990s, and assessed the effect of the method used on each article's impact across the decade. Functional neuroimaging studies were cited three times more often than lesion studies throughout the time span we examined. This effect was in large part due to differences in the influence of the journals publishing the two methods; functional neuroimaging studies appeared disproportionately more often in higher impact journals. There were also differences in the degree to which articles using one method cited articles using the other method. Functional neuroimaging articles were less likely to include such cross-method citations. ■

INTRODUCTION

Understanding the relationship between human brain structure and function is a major focus of cognitive neuroscience. The methods available to achieve this goal have undergone significant changes over the last 15 years. In particular, functional neuroimaging is rapidly replacing neuropsychological studies of people with brain lesions as the central method in this field.¹ Functional imaging and lesion studies differ in important respects. The nature of the evidence provided by the two is, in principle, fundamentally different, making them complementary rather than competitive techniques. Indeed, no contemporary book or review of cognitive neuroscience seems complete without an introductory paragraph emphasizing the need for studies using converging methods to compensate for their different strengths and weaknesses (D'Esposito & Devinsky, 2004; Farah, 2004; Rorden & Karnath, 2004; Heilman & Valenstein, 2003; Frackowiak, Friston, Frith, Dolan, & Mazziotta, 1997). In particular, the need for loss-of-function studies to complement the correlational evidence provided by functional imaging has been repeatedly stressed.

As young cognitive neuroscientists training in these methodologically exciting times, we were curious about the comparative impact of the two methods most commonly employed for studying structure–function relationships in the human brain. What influence does the method used have on the impact of a cognitive neuroscience study, and has this changed as functional neuroimaging has gained importance over the last several years? If there are method-based differences in impact, are these primarily driven by evidence-related factors, or other considerations? We examined these questions empirically, using systematic review and bibliometric methods made feasible by another important technical change over the past 15 years: the digitization of the scientific literature (Callaham, Wears, & Weber, 2002; Deville et al., 2002; Cook, Mulrow, & Haynes, 1997).

Lesion and imaging studies have both shared and unique inferential pitfalls. They share the problem of individual differences in neuroanatomical organization: Differences in individual experience or biology could lead to unique structure–function relationships, complicating the interpretation of both lesion and functional imaging data. Another shared problem concerns assigning a single cognitive process to a neural region. A region may participate in multiple computational processes, perhaps by virtue of involvement in

¹University of Pennsylvania, ²Children's Hospital of Philadelphia, ³California State University Dominguez Hills

different neural circuits. Indeed, it may even be the case that the same population of neurons can support different cognitive functions. Thus, activity of a region in two or more tasks, or impairment on multiple tasks due to a single, small lesion, might be explained either by a common underlying function or by multiple functions (Duncan & Owen, 2000; Farah, 1994; Shallice, 1988; Rumelhart & McClelland, 1986). Finally, both lesion method and functional imaging share a reliance on *ceteris paribus* assumptions: that a single variable is being manipulated and all other things are equal. *Ceteris paribus* assumptions create problems that are method-specific, but the underlying philosophical issue is one that all methods share. For example, in lesion studies, a lack of reorganization is generally assumed: All other neural regions in a lesioned brain are assumed to be performing the same tasks they performed prior to lesion acquisition, and not acquiring the functions of the lesioned area. (This assumption almost certainly does not hold in chronic-stage lesion patients; Farah, 2004.) In functional imaging studies, it is assumed that two tasks that differ theoretically in a single cognitive process do not differentially recruit neural regions for theoretically shared task components (Posner, Petersen, Fox, & Raichle, 1988). (This assumption is also unlikely to hold; Friston et al., 1996.)

In addition to these shared inferential issues, there is an important difference in the kinds of inferences that can be drawn from functional imaging and lesion methods. In contrast to lesion studies, functional imaging studies are necessarily correlational. Such studies correlate differences in brain activity (most commonly indexed by changes in blood flow) in specific regions with changes in cognitive task performance to infer a structure–function relationship. However, functional imaging cannot show that such a relationship is causal. Although the cognitive processing underlying a task might induce blood flow change in a certain region, this relationship does not guarantee that the region is necessary for performing the task. It is this crucial inferential difference that is the usual basis for emphasizing the need for converging methods.

In addition to their weaknesses, lesion and functional imaging methods have unique strengths. Lesion studies can provide stronger evidence for necessity claims: When a brain area is damaged and we then observe that a behavior is not present, we can tentatively conclude that the brain area is necessary for the behavior and its underlying cognitive processes. On the other hand, functional imaging studies allow us to study neurologically healthy brains, and thus are not subject to worries about reorganization. Moreover, studying the activity of the whole brain while a subject performs a cognitive task can provide insights into the network properties of different neural regions, even within single subjects.

With these issues in mind, this study was designed to address two main questions:

1. How has the advent of functional imaging altered the methodological landscape of cognitive neuroscience in the past 15 years, in terms of the sheer number of studies published using functional imaging and lesion methods?
2. Given the differences in the inferential strength of lesion compared with functional neuroimaging techniques, does the method used in a structure–function study influence its impact? We hypothesized that, despite the increase in the number of functional imaging studies, articles using lesion methods would be cited disproportionately more, because they can establish a causal role for a structure in a behavior, whereas functional imaging studies cannot.

We chose to answer these questions by examining articles published in four topic areas within cognitive neuroscience at three time points spanning the rise in use of functional neuroimaging. Bibliometric methods have been applied in other areas of science to provide empirical support for the claim that citation counts bear some relationship to the quality of evidence in an article. For example, review articles in clinical medicine that use inferentially stronger techniques have been shown to be cited more often than reviews using weaker approaches (Montori, Wilczynski, Morgan, & Haynes, 2003), and higher-quality peer review has been shown to be related to higher citation counts (Laband & Piette, 1994). We employed a similar method here, assuming that cognitive neuroscientists would “vote with their bibliographies,” so that citation counts would bear some relationship to the inferential strengths of the cited studies.

We identified a pool of original cognitive neuroscience articles using search methods developed for systematic reviews (Deville et al., 2002; Cook et al., 1997). We then sorted these articles by method used, and first compared the number of lesion and functional neuroimaging articles at each of three time points (between 1994 and 2001). Second, we compared the number of citations of studies using lesion as compared to functional neuroimaging, as an index of the relative influence of each method. Finally, in an effort to explore the influences that drive citation patterns in more detail, we evaluated the extent of “cross-method citation,” that is, how often researchers cite studies using complementary methods.

RESULTS

Cognitive Neuroscience Methods are Changing

Using literature search methods developed for systematic reviews, we identified original research articles addressing structure–function relationships in the hu-

man brain, published in English in 1993, 1997, or 2001, in four areas of cognitive neuroscience: language, memory, executive function, and emotion (see Methods). As shown in Figure 1, the number of original articles using functional neuroimaging methods rose sharply over the period we examined. Such studies constituted an increasing proportion of the dataset as a whole (23%, 47%, 62% for the years 1993, 1997, 2001, respectively).

Does Method Influence Citation Count?

Citation counts from date of article publication to September 2003 were gathered for articles published in 1993 and 1997. Figure 2 shows the citation rate for articles, split by method and by year of publication. The initial analysis was performed on the whole sample. Descriptive statistics showed that the distribution of citation counts was highly positively skewed, so further analyses were performed with log transformed data. The average citation count for lesion articles was 32 ($SD = 39$; median = 19; IQR 26), and for imaging articles was 89 ($SD = 116$; median = 50; IQR 103). The average citation count for imaging articles was significantly higher than lesion articles [ANOVA, $F(1,267) = 26.4$, $p < .0001$]. As is obvious from Figure 2, citation counts diverged early postpublication and remained significantly different throughout the period we examined. The same pattern was discernible in all four topic areas, and for both 1993 and 1997 when these publication years were analyzed individually (not shown).

Journals vary in their influence, and this in turn can affect the citation rate of an article published in a particular journal. Unsurprisingly, the impact factor of a journal (according to ISI Journal Reports) was correlated with citation count in the present data ($R = .56$, $p < .0001$). In addition, functional neuroimaging studies were disproportionately more likely than lesion studies to appear in the highest impact journals (*Science*,

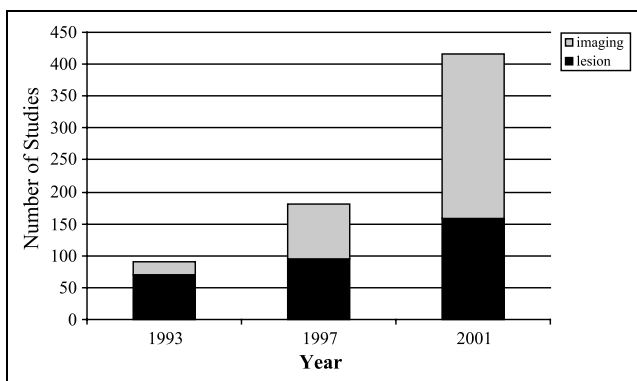


Figure 1. Number of original cognitive neuroscience publications using either lesion or functional neuroimaging methods published in 1993, 1997, and 2001. See text for details of inclusion and exclusion criteria.

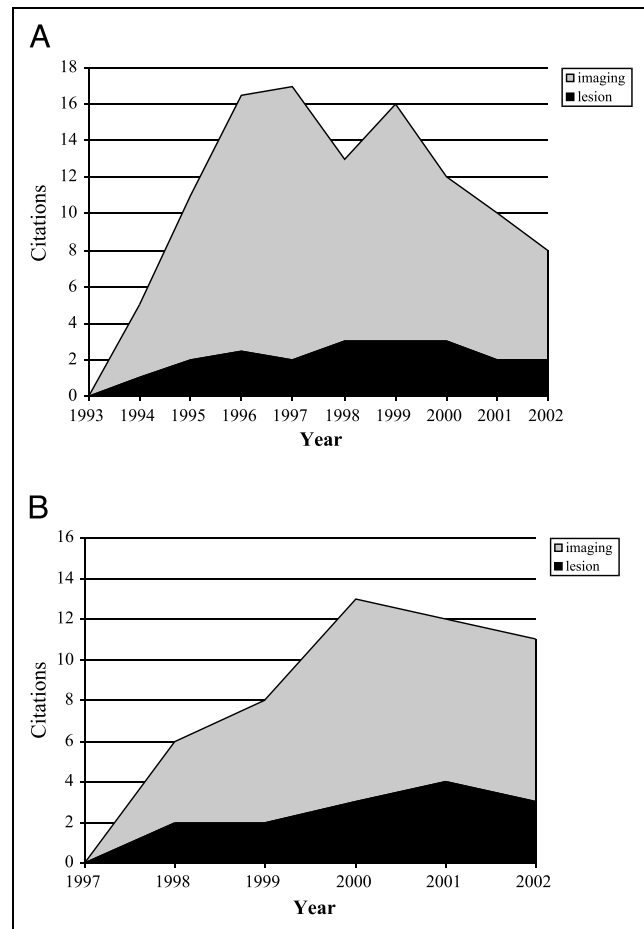


Figure 2. Median citations per year from date of publication to September 2003 for articles published in 1993 (A) and 1997 (B), according to the method used in the cited articles.

Nature, *Proceedings of the National Academy of Sciences*) ($\chi^2 = 13.9$, $p < .001$). The ANOVA was repeated with (log-transformed) journal impact factor included as a covariate to examine its influence on the higher citation count of functional neuroimaging articles. Journal impact factor accounted for a large portion of the variance when entered into the regression model [$F(1,259) = 87.1$, $p < .0001$], although method used continued to have an independent effect [$F(1,259) = 5.3$, $p < .05$]. The interaction between journal impact factor and method was not significant [$F(1,258) = 2.5$, $p = .11$].

Method-based Citation Bias

One marker of how extensively converging evidence is discussed in a given study is the extent to which the study cites articles that used other methods (“cross-method citations”). We performed an exploratory analysis in a randomly selected subset of the original set of articles to examine this practice. We determined the

methods used in the articles that had cited the articles in our index group, and counted how many such citations were “within method” and how many were “across method.” In other words, when an article in our subset was cited, how often was it cited by an article that shared the same method, and how often by an article that used the other method? We found that within-method citation occurred 417 times in the 12 selected imaging studies, and 139 times in the 12 selected lesion studies. Across-method citations occurred 48 times in imaging studies, and 30 times in lesion studies. An ANOVA of these data revealed a significant main effect of the within/across-method factor on citation count [$F(1,22) = 5.2, p < .05$]. Notably, there was also an interaction of this factor with the lesion/imaging method factor [$F(1,22) = 5.8, p < .05$], indicating a greater bias away from across-method citations in the functional imaging literature.

DISCUSSION

The field of cognitive neuroscience is undergoing rapid methodological changes. We used systematic review and bibliometric methods to study the effects of these changes. We first quantified the dramatic increase in the use of functional imaging in the study of structure–function relationships in the human brain. Such studies have become much more numerous over the past decade, and now represent the single most common method used in all four subtopics of cognitive neuroscience that we examined.

Given the different strengths and weaknesses of functional neuroimaging and lesion methods, we then compared their relative impact as estimated by citation counts. We found that the method used influenced the number of citations garnered by an article to a surprising degree. Imaging studies were cited at approximately thrice the rate of lesion studies. This was true for articles from two publication years (1993 and 1997) and held across the entire decade we examined.

This phenomenon appears to be largely related to systematic differences in the prestige of the journals publishing these articles. Imaging studies appeared more often than lesion studies in high-impact journals than would be expected given the relative representation of these methods in the literature as a whole. Similarly, when journal impact factor was included as a covariate in the analysis, it explained much of the variance in citation count between the two methods. Journal impact factor is calculated based on citation counts for all articles published in a given journal. Consequently, this value is not independent of citation count for the specific articles we examined. Nonetheless, the vast majority of the journals represented in our sample publish work using any of a variety of methodologies, so journal impact factors are unlikely to be primarily determined by the citation of imaging or lesion

studies. The predominant influence of journal impact factor in determining citation counts is not peculiar to cognitive neuroscience: for example, a study of the emergency medicine literature found that journal prestige was the single most powerful predictor of citation count, and furthermore was not systematically related to other measures of study quality, such as study design or methodology (Callahan et al., 2002).

These data suggest that sociological factors, such as method novelty and the undeniably arresting concept of “seeing into” the normally functioning brain, rather than considerations of inferential strength, have disproportionately influenced publication patterns in cognitive neuroscience. The magnitude of this apparent publication bias is striking.

Although citation counts are an imperfect measure of impact (Najman & Hewitt, 2003), they are commonly used in a variety of settings (Mela, Martinoli, Poggi, & Derchi, 2003; Haggblom et al., 2002; West & McIlwaine, 2002; Lichtman & Oakes, 2001; Dracos & Cognetti, 1995; Laband & Piette, 1994), and have been shown to be related to the quality of reported evidence in some fields (Montori et al., 2003; Laband & Piette, 1994). The design we employed did not permit us to judge the quality of a given study independent of citation counts, so we are unable to directly test another possible explanation for this finding: that the quality of the studies using the two methods was consistently different. However, it does seem unlikely that such a large and pervasive difference could be explained entirely by study quality.

Other factors beyond journal impact factor significantly influence citation counts by method. We explored one putative factor in our third analysis, focusing on the articles that cited a subset of studies from our initial dataset. We found a tendency for studies to be cited more often by other studies that use the same method. This “within-method bias” was present in both lesion and functional imaging studies, but was disproportionately more prominent in functional imaging studies. Several explanations might be offered for this pattern: There may be a greater need for methodological citations in imaging articles, given the complexity and ongoing refinement of the techniques (although lesion studies are also applying more complex and evolving techniques; Rorden & Kornath, 2004). If so, this alone might explain the interaction we observed. However, it also seems plausible that there is a citation bias arising from a greater familiarity with the literature in the method one uses, a bias that is somehow exacerbated in functional imaging research. The direction of this effect is surprising, given that in principle, the interpretation of functional neuroimaging findings relies particularly heavily on converging evidence from loss-of-function work.

Two major journals have recently highlighted converging approaches to structure–function models of human cognition (*Neuroimage*: Fink, Marshall, Noth,

& Zilles, 2003; *Journal of Neuroscience*: Raichle, 2003). Some theorists have raised the bar still higher, arguing that mere convergence between two methods is insufficient. For example, Shallice (2003) has expressed the view that functional imaging and lesion-based results cannot be used to directly constrain each other, but instead must each be used to constrain formal process models of cognition. Horwitz, Friston, and Taylor (2000) make a similar claim: Models require support from these two methods in conjunction with evidence from other methods such as animal studies, computational modeling, and electrophysiological techniques.

Despite such exhortations for increased inferential rigor, our findings suggest that there is no ongoing, intensive use of converging methods, at least as indexed by citation patterns. Nor are articles using these two core methods equally likely to appear in influential journals. The findings of this study instead indicate both an imbalance in cross-citation between cognitive neuroscience literatures, and a striking predominance of functional neuroimaging articles in higher impact publications.

In our view, these findings raise important questions for the field as whole. Is lesion work making less of an impact than its inferential weight suggests it should because of sociological factors? Is relevant and high-quality lesion work not being done? Are there practical barriers to integrating findings across methods? The first possibility needs to be critically scrutinized by those in the field. The latter two possibilities may require specific, practical interventions. Funding bodies and editorial boards may want to examine their practices in terms of encouraging the pursuit of converging evidence. There may also be a need to reduce barriers to the use of such evidence. As the field grows larger and methods become increasingly sophisticated, active efforts to facilitate cross-method literacy may be necessary. Such efforts could occur in training programs, ensuring that cognitive neuroscientists are adept in the interpretation of studies that use a variety of methods. In addition, journals and databases could implement the use of common terminology across methods (e.g., in describing neuro-anatomical regions or behavioral phenomena) to make these literatures accessible to readers of all methodological backgrounds. Such journal-driven efforts to improve scientific communication have been successful in other areas, such as improving abstract content in clinical medicine (Haynes, Mulrow, Huth, Altman, & Gardner, 1996).

In summary, we found a strikingly large effect of the method used in a cognitive neuroscience article on its impact. This appeared to be mediated in large part by systematic differences in the prestige of the journals in which the two methods are published. In contrast to our hypothesis, the theoretically greater inferential weight of lesion findings did not translate to greater impact as measured by citation count, nor (relatedly) to publication in higher impact journals. We believe that these findings should challenge cognitive neuroscientists to

critically evaluate the nature of the evidence we are acquiring in support of theories relating human brain function and structure.

METHODS

Systematic Review

Original articles in four areas of cognitive neuroscience were identified using systematic literature review methods (Deville et al., 2002; Cook et al., 1997). Four research areas (memory, language, executive function, and emotion) were chosen as a convenience sample to limit the scope of the search, and simply to reflect our interests. Three years, 1993, 1997, and 2001, were selected to cover the “decade of the brain” (www.loc.gov/loc/brain/) at intervals suitable for tracking citation counts. This 4-year interval was chosen to provide an adequate measure of citation counts based on a pilot study that examined the temporal pattern of citations for two well-known, but otherwise arbitrarily selected, cognitive neuroscience articles published in the early 1990s (Desimone & Duncan, 1995; Pardo, Pardo, Janer, & Raichle, 1990).

Searches were conducted in two literature databases: MEDLINE and PsycINFO. The goal of the search was to identify articles that met three criteria: (1) were original research articles with empirical evidence; (2) investigated the neural substrates or correlates of cognitive function; and (3) were in one of the four research areas listed above. One general search strategy was developed to identify articles that used “brain” (and a variety of brain-related terms, including terms related to the major cognitive neuroscience methods) as key words or subject headings. This search was made as broad as possible. Four topic-specific search strategies were also developed to identify articles in each research area. The topic searches were then each combined (using “and”) with the general “brain” search. These four searches were then limited to journal articles concerning human subjects, with abstracts, in English, and to the three years of interest. Review articles were excluded. In keeping with standard systematic review practices, the completeness of this initial search strategy was checked by hand searching selected journals for 1993 and 1997. Two very high-impact cross-disciplinary journals (*Nature* and *Science*) were chosen to ensure that we had not inadvertently biased the sample away from high-impact articles. We also searched one journal that published a breadth of material using both methods (*Journal of Cognitive Neuroscience*) to ensure comprehensive coverage of our selected topics. All articles that fulfilled the aforementioned criteria were identified, and if necessary, the search terms were adjusted so that the computerized search strategies captured all relevant articles. The full search strategies are available in the Appendix.

The results of the automated searches were hand-reviewed by two investigators independently to identify the articles that met the three criteria listed above. The same investigators then classified the selected articles, according to the principle method used, as one of the following: (1) lesion study; (2) functional imaging (including functional magnetic resonance imaging, positron emission tomography, and single-photon emission computed tomography); (3) electrophysiological (event-related potentials, electroencephalography, magneto-encephalography, intracranial recording); (4) neurochemical-level studies (pharmacological agents, Parkinson's disease, genetic studies of receptors, etc.); (5) combinations of these; and (6) other. The results of this independent selection and classification were compared, and differences were resolved by consensus between the two reviewers. The present work focuses solely on lesion and functional imaging studies. A total of 91 articles published in 1993 and 178 articles published in 1997 formed the dataset on which further analyses were performed.

Impact Assessment

In keeping with common practice, citation counts were used as a marker of the impact of each publication. Citation counts, tracked by year, were obtained from the ISI Citation Indexes (<http://isi6.isiknowledge.com/portal.cgi>) from each article's publication date through September 2003. To explore the possibility that the journal of publication might have an independent influence on citation rate, we also included journal impact factor (as of September 2003, drawn from the ISI website: <http://isi6.isiknowledge.com/portal.cgi/jcr>) as a variable in the analysis.

Evaluating Method-based Citation Patterns

In an effort to examine the use of converging evidence, we examined the extent to which a subset of our pool of articles was cited by articles using other methods ("across-method citations"). Twelve articles from 1993 and 12 articles from 1997 were randomly selected from the original pool of 269 articles, with the constraint that half of this subsample were lesion studies and half were functional imaging studies. The articles that cited each of these 24 articles were identified using the ISI Citation Indexes, and were classified as lesion, functional imaging, or other study. The number of times that each of the 24 articles was cited by articles in these three categories was then determined.

Statistical Analysis

The dependent variables were all positively skewed, and so were log-transformed prior to being submitted to parametric analyses.

APPENDIX

A. Brain-related, or Cognitive Neuroscience Method-related Search for MEDLINE

1. brain.mp. or exp BRAIN/
2. exp NEURONS/
3. cerebral.mp. or exp CEREBRAL CORTEX/
4. (frontal adj lobe).mp. [mp = title, abstract, cas registry/ec number word, mesh subject heading]
5. exp Frontal Lobe/
6. (temporal adj lobe).mp. [mp = title, abstract, cas registry/ec number word, mesh subject heading]
7. exp Temporal Lobe/
8. (parietal adj lobe).mp. [mp = title, abstract, cas registry/ec number word, mesh subject heading]
9. exp Parietal Lobe/
10. exp PREFRONTAL CORTEX/ or prefrontal.mp.
11. (prefrontal adj cortex).mp. [mp = title, abstract, cas registry/ec number word, mesh subject heading]
12. Broca.mp.
13. Wernicke.mp.
14. cerebellum.mp. or exp CEREBELLUM/
15. exp Basal Ganglia/
16. (basal adj ganglia).mp. [mp = title, abstract, cas registry/ec number word, mesh subject heading]
17. amygdala.mp. or exp AMYGDALA/
18. exp Hippocampus/ or hippocamp\$.mp.
19. thalamus.mp. or exp THALAMUS/
20. exp Thalamic Nuclei/ or exp Gyrus Cinguli/ or cingulate.mp.
21. (nucleus adj accumbens).mp. [mp = title, abstract, cas registry/ec number word, mesh subject heading]
22. exp Nucleus Accumbens/
23. exp Corpus Striatum/
24. striatum.mp.
25. exp BIOGENIC AMINE NEUROTRANSMITTERS/ or neurotransmitters.mp. or exp AMINO ACID NEUROTRANSMITTERS/ or exp NEUROTRANSMITTERS/
26. exp DOPAMINE/ or dopamine.mp.
27. exp SEROTONIN/ or serotonin.mp.
28. norepinephrine.mp. or exp NOREPINEPHRINE/
29. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28
30. (brain adj death).mp. [mp = title, abstract, cas registry/ec number word, mesh subject heading]
31. exp Brain Death/
32. 30 or 31
33. 29 not 32
34. exp Brain Mapping/
35. exp Magnetic Resonance Imaging/ or exp Tomography/
36. (functional adj magnetic adj resonance adj imaging).mp. [mp = title, abstract, cas registry/ec number word, mesh subject heading]

- 37. (functional adj MRI).mp. [mp = title, abstract, cas registry/ec number word, mesh subject heading]
- 38. fMRI.mp.
- 39. exp Tomography, Emission-Computed/
- 40. (positron adj emission adj tomography).mp. [mp = title, abstract, cas registry/ec number word, mesh subject heading]
- 41. exp Evoked Potentials/
- 42. (event-related adj potentials).mp. [mp = title, abstract, cas registry/ec number word, mesh subject heading]
- 43. exp *Electroencephalography/px, mt [Psychology, Methods]
- 44. 34 or 35 or 36 or 37 or 38 or 39 or 40 or 41 or 42 or 43
- 45. 33 or 44

B. Frontal/Executive Topics Search for MEDLINE

- 1. exp Decision Making/
- 2. (decision adj making).mp. [mp = title, abstract, cas registry/ec number word, mesh subject heading]
- 3. decision-making.mp.
- 4. planning.mp.
- 5. exp THINKING/
- 6. (problem adj solving).mp. [mp = title, abstract, cas registry/ec number word, mesh subject heading]
- 7. problem-solving.mp. or exp Problem Solving/
- 8. exp MORALS/
- 9. moral\$.mp.
- 10. exp JUDGMENT/
- 11. executive.mp.
- 12. gambling.mp. or exp GAMBLING/
- 13. risk-taking.mp. or exp Risk-Taking/
- 14. uncertainty.mp. or exp UNCERTAINTY/
- 15. lexical.mp.
- 16. (1 or 2 or 3) not 15
- 17. strategy.mp.
- 18. supervisory.mp.
- 19. 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18
- 20. exp Organ Procurement/
- 21. exp Tissue Donors/
- 22. exp Palliative Care/
- 23. exp DEATH/ or death.mp.
- 24. 20 or 21 or 22 or 23
- 25. 19 not 24

C. Language Search for MEDLINE

- exp LANGUAGE/
- 47. exp MEMORY/
- 48. lexical.mp.
- 49. exp READING/
- 50. synta\$.mp. [mp = title, abstract, cas registry/ec number word, mesh subject heading]

- 51. semantics.mp. or exp SEMANTICS/
- 52. exp WORD PROCESSING/
- 53. 46 or 48 or 49 or 50 or 51 or 52
- 54. 53 not 47

D. Memory Search for MEDLINE

- 46. memory.mp. or exp MEMORY/

E. Emotion Search for MEDLINE

- 46. emotion\$.mp. or exp EMOTIONS/
- 47. affective.mp.
- 48. mood.mp. or exp Affect/

F. Brain or Cognitive Neuroscience Method Search for PSYCINFO

- 1. brain.mp. or exp BRAIN/
- 2. exp NEURONS/
- 3. cerebral.mp. or exp CEREBRAL CORTEX/
- 4. (frontal adj lobe).mp. [mp = title, abstract, heading word, table of contents, key concepts]
- 5. exp Frontal Lobe/
- 6. (temporal adj lobe).mp. [mp = title, abstract, heading word, table of contents, key concepts]
- 7. exp Temporal Lobe/
- 8. (parietal adj lobe).mp. [mp = title, abstract, heading word, table of contents, key concepts]
- 9. exp Parietal Lobe/
- 10. exp PREFRONTAL CORTEX/ or prefrontal.mp.
- 11. (prefrontal adj cortex).mp. [mp = title, abstract, heading word, table of contents, key concepts]
- 12. Broca.mp.
- 13. Wernicke.mp.
- 14. cerebellum.mp. or exp CEREBELLUM/
- 15. exp Basal Ganglia/
- 16. (basal adj ganglia).mp. [mp = title, abstract, heading word, table of contents, key concepts]
- 17. exp Hippocampus/ or hippocamp\$.mp.
- 18. thalamus.mp. or exp THALAMUS/
- 19. exp Thalamic Nuclei/ or exp Gyrus Cinguli/ or cingulate.mp.
- 20. (nucleus adj accumbens).mp. [mp = title, abstract, heading word, table of contents, key concepts]
- 21. exp Nucleus Accumbens/
- 22. exp Corpus Striatum/
- 23. striatum.mp.
- 24. exp DOPAMINE/ or dopamine.mp.
- 25. exp SEROTONIN/ or serotonin.mp.
- 26. norepinephrine.mp. or exp NOREPINEPHRINE/
- 27. (brain adj death).mp. [mp = title, abstract, heading word, table of contents, key concepts]
- 28. exp Brain Mapping/
- 29. exp Magnetic Resonance Imaging/ or exp Tomography/

30. (functional adj magnetic adj resonance adj imaging).mp. [mp = title, abstract, heading word, table of contents, key concepts]

31. (functional adj MRI).mp. [mp = title, abstract, heading word, table of contents, key concepts]

32. fMRI.mp.

33. (positron adj emission adj tomography).mp. [mp = title, abstract, heading word, table of contents, key concepts]

34. exp Evoked Potentials/

35. (event-related adj potentials).mp. [mp = title, abstract, heading word, table of contents, key concepts]

36. exp Electroencephalography/

37. exp Amygdaloid Body/ or amygdala.mp.

38. exp NEUROTRANSMITTERS/ or exp Brain Stimulation/

39. exp Tomography/

40. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37 or 38 or 39

41. 40 not 27

G. Executive/Frontal for PSYCINFO

1. exp Decision Making/

2. (decision adj making).mp. [mp = title, abstract, heading word, table of contents, key concepts]

3. decision-making.mp.

4. planning.mp.

5. exp THINKING/

6. (problem adj solving).mp. [mp = title, abstract, heading word, table of contents, key concepts]

7. problem-solving.mp. or exp Problem Solving/

8. exp MORALS/

9. moral\$.mp.

10. exp JUDGMENT/

11. executive.mp.

12. gambling.mp. or exp GAMBLING/

13. risk-taking.mp. or exp Risk-Taking/

14. uncertainty.mp. or exp UNCERTAINTY/

15. lexical.mp.

16. (1 or 2 or 3) not 15

17. strategy.mp.

18. supervisory.mp.

19. 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18

20. exp Palliative Care/

21. exp Death Attitudes/ or exp Organ Transplantation/ or exp Tissue Donation/ or exp Grief/

22. 20 or 21 or 15

23. 19 not 22

H. Language for PSYCINFO

42. exp LANGUAGE/

43. exp MEMORY/

44. lexical.mp.

45. exp READING/

46. synta\$.mp. [mp = title, abstract, heading word, table of contents, key concepts]

47. semantics.mp. or exp SEMANTICS/

48. word processing/ or word recognition/ or exp "words (phonetic units)"/

49. 42 or 44 or 45 or 46 or 47 or 48

50. 49 not 43

I. Memory for PSYCINFO

42. exp MEMORY/ or memory.mp.

J. Emotion for PSYCINFO

42. emotion\$.mp. or exp EMOTIONS/

43. affective.mp.

44. mood.mp. or exp Emotional States/

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Reprint request should be sent to Lesley K. Fellows, Montreal Neurological Institute, 3801 University Street, Rm. 276, Montreal, QC, Canada H3A 2B4, or via e-mail: lesley.fellows@mcgill.ca.

Note

1. We recognize that there are numerous other cognitive neuroscience methods that provide evidence about structure–function relationships. We chose to focus on these two methods first because they are the two most common, particularly over the time period we studied, second because they are clearly different in the nature of the evidence that they provide, and third, to restrict the dataset to a tractable size.

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