Is cognitive neuroscience an oxymoron?

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1. Introduction

Cognitive neuroscience research requires a great deal of time and money, and it attracts a great deal of attention. Consequently, there is a subversive temptation to declare it useless. This general grumble comprises many related gripes: Cognitive neuroscience is poorly executed; its costs do not justify its benefits; for a long time we all got along just fine without it, and I still do; it’s just a fad; people are just wowed by pictures of brains; etc.

Still, cognition is the study of mental computations that are performed by a neural machine. It is remarkable to suppose that studying the machine itself would not usefully inform cognitive research. So which is it? Does neuroscience illuminate cognitive research, or is it the moon that never rose? Is cognitive neuroscience an oxymoron?

This essay dodges numerous gripes. It does not address whether most cognitive neuroscience is well executed; whether its benefits typically outweigh its costs; whether neuroscience could ever be necessary to develop a psychological theory; or whether its celebrity outstrips its merit. But it does conclude that neuroscience can play important role in cognitive research. The argument has three parts: A general account of the relationship between neuroscience and cognition, a specific case study of the contribution of neuroscience to the study of visual cognition, and a quantitative analysis of citation records in the journal Cognition.

1.1 What is cognitive research?

Before asking whether cognitive neuroscience contributes to cognitive research, it helps to have a clear image in mind of just what “cognitive research” is. Cognitive theories attempt to describe the functional organization of the mind (Gallistel, 1990). The guiding principle of the cognitive revolution is that we can understand how the mind processes information. Specifically, we can characterize mental activity as a set of representations and computations over those representations. This depends crucially upon an understanding of the function of the mental processes under study (Marr, 1982).

Some classic examples of psychological research questions formulated in this framework are visual object recognition, language production, and theory of mind. In the case of visual object recognition, for instance, it is assumed that the mind begins with a pixel-like representation of the wavelengths and luminosities of light across the retina. It ends with the capacity to categorize objects in the visual scene—e.g., categorizing one as a hat and another as hat. This occurs as successive computations are performed on the early representation, transforming it over a series of representations.

This commitment to characterizing the internal representations that mediate between percept and action is precisely why behaviorists found the cognitive revolution so revolting. Behaviorism is committed, of course, to merely characterizing the relationship between a stimulus and a response. This is a kind of psychological theory. Indeed, it aptly describes the kinds of theories of human behavior applied in some other disciplines. For instance, several key principles of microeconomics do not attempt to mirror the representations or computations involved in choice, except insofar as they appropriately characterize the relationship
between input and output of a human chooser over time. Such theories achieve descriptive adequacy, in the sense that they accurately describe and predict human behavior (Chomsky, 1965). Cognitive theories, in contrast, additionally achieve explanatory adequacy. That is, they aim to characterize the set of internal representations and computations that provide an explanation for the reliability of descriptive relations between input and output. Thus, if neuroscience plays an important role in cognitive research, it must do so by constraining theories of representation and computation.

1.2 What is neuroscience?

Neuroscience is the study of the nervous system, including its physical and biological properties. Like all cognitive theories, many neuroscience theories are motivated by the ultimate desire to explain the functional organization of the mind. Yet theories of neuroscience can be distinguished from cognitive theories in part because they are stated over physical and biological terms (or explicit abstractions from them) rather than over exclusively representational and computational terms.

Neuroscience comprises not only a set of theories, but also a set of methods. A neuroscience method involves either manipulating or measuring neural processes directly. In other words, it either involves an intervention upon neural processes in a manner that is not mediated by ordinary perception (e.g., neural stimulation by electrical or magnetic forces, lesion by natural or artificial means, experimental control of gene expression, etc.), or else it involves measuring neural processes in a manner that is not mediated by ordinary behavior (e.g., EEG, MRI, single unit recording, etc.). In contrast, in “behavioral” methods, the experimenter’s access to mental processes is mediated by ordinary perceptual and behavioral processes.

It is not necessary that neuroscience methods are used exclusively to inform neuroscience theories, or that behavioral methods are used exclusively to inform cognitive theories. This point is crucial: If we defined methods in terms of theory they seek to advance, this would beg the question of whether neuroscience methods (e.g., cognitive neuroscience) can inform cognitive theory. The answer would be guaranteed to be “no” for a trivial reason: Any study using apparent “neuroscience” methods to answer cognitive questions would simply have been “cognitive” research all along, by definition.

1.3 What is “important”?

What does it mean to say that neuroscience has played, or could play, an “important” role in the development of cognitive theories? This question is most interesting if it is reframed pragmatically: If we are interested in developing an accurate model of cognition, is it a useful strategy to seek evidence from neuroscience methods?

Thus, neuroscience could be a useful source of evidence without being sufficient for the development of cognitive theories. In other words, having a complete theory of cognition may require us to know about more than just the brain. A complete cognitive theory of visual processing, for instance, might depend upon information about typical scenes in natural contexts (i.e., the things we see), as well as the functional role of vision in guiding human interactions in the world. Whether cognitive theories must be stated over terms external to the nervous system is a matter of significant philosophical controversy. But, even if we adopt the position that a theory of mental representation and computation must be stated partially over terms external to the nervous system, the neurosciences could still play a useful role in developing those theories.

Similarly, neuroscience could be a useful source of evidence in developing cognitive theories without being a definitive source of evidence. (Indeed, it’s hard to say whether any form of scientific evidence is ever definitive). Presumably neuroscience will constrain cognitive theories via inference to the best explanation. That is, certain cognitive theories will provide a better explanation for the neuroscience evidence, others will provide a worse explanation, and we can use this to inform our assessment of the quality of the cognitive
theories. In this method of reasoning the neuroscience evidence can play an important role in adjusting our assessment of the probability of cognitive theories being correct, even without definitively endorsing or defeating any particular theory.

Neuroscience could also be a useful source of evidence without being necessary for the development of cognitive theories. This point is obvious enough. If I want to know what color my socks are, looking at them would be a useful source of evidence, but it is certainly not a necessary source of evidence. I could buy a camera, hire a film crew to shoot a movie of my socks, show it to my wife and ask her what color she sees. But even if it isn't necessary for me to look at my own socks to determine their color, it could certainly be useful.

Finally, it might be the case that neuroscience is a possible source of evidence without being a practical one. For instance, the film-crew approach is a possible method of attaining evidence about the color of my socks, but it isn't a very practical one. Although practicality is important, I won't address it much further.

2. A priori analysis

The brain is the principal physical substrate of human cognition. Doesn't this guarantee that theories of brain function will be relevant to theories of cognition? In fact it does not, as a simple analogy illustrates. Consider a scholar who wishes to develop a theory of the influence of Uncle Tom's Cabin on American attitudes towards slavery. This novel was distributed in printed books, and so the influence of its content upon readers was fully mediated by physical objects. Would it be useful, then, for the scholar to investigate properties of those objects, such as their material composition (paper and ink) or method of manufacture? Probably not: This approach would fail because general information about the material composition of the book or its method of manufacture are not sufficiently related to the information contained in the book, which is what shaped American attitudes towards slavery.

The same is true for many properties of neural systems when applied to cognitive theory. For instance, there are detailed theories of the cellular mechanisms that enable neuronal firing; however, these are unlikely to be sufficiently related to mental representation and computation to play an important role in cognitive research. Even if every cognitive representation is encoded by the firing of neurons, this does not mean that a theory of the mechanics of neural firing at the cellular level informs a theory of cognitive representation.

Consider a slightly different question, however: If a scholar wishes to understand the influence of Uncle Tom's Cabin on American attitudes towards slavery, would it be useful for her to read the book—i.e., to interact directly with it as a physical object? Presumably it would, simply because this would provide relevant information about its contents, which would in turn inform a theory of its influence. Reading the book might not be necessary. The scholar could rely on indirect sources of evidence about its content, and many of the inferences she would wish to draw about its influence wouldn't depend on knowing its precise contents anyway. Nor, of course, would reading the book be sufficient to answer all the scholar's questions. But if the scholar had never read the book before, and if it sat on her shelf, surely she would be crazy not to pick it up.

This analogy highlights the utility of distinguishing between neuroscience theory and neuroscience methods. A general theory of “books” as a physical object might be stated over terms irrelevant to the informational content of any given book—e.g., principles of chemical bonding, methods of manufacture, etc. Such theories would typically be useless to a scholar interested in their informational content. Yet, the “method” of interacting physically with particular books (i.e., reading them) is obviously a very useful method of understanding their informational content. Similarly, it might be the case that theories of neuroscience typically generalize over properties of neural systems that are not particularly informative about mental organization at the level of representation and computation. Yet, interacting directly with the physical substrate of a neural system might be a very useful method of learning about the
representations and computations instantiated in one.

Of course, reading the brain is not as easy as reading a book. If your uncle Tim is acting oddly and you want to understand why, it probably makes more sense to use behavioral methods (i.e., observing the relationship between perceptual inputs and behavioral outputs) than to crack open his head and take a close look at his brain. In order for the “direct” investigation of the neural system to usefully inform psychology, we must have theories capable of relating physical data to cognitive theories, and instruments capable of collecting that data. Given such theories and instruments, however, it is hard to see how neuroscience methods could fail to be informative for cognitive research.

3. A case study

A classic cognitive research problem is to understand the information processing that enables vision. Somehow, we transform a dynamic two-dimensional projection of light onto the retina in each eye into a three dimensional representation of space, a categorization of objects within that space, and a representation of the motion of those objects over time. In cognitive terms, the goal is to understand the nature of the information represented on the retina, and then to specify the series of computations that transform this information across a series of representations, resulting finally in representations of three dimensional space, object identity, motion, etc.

Such a cognitive theory can be neutral with respect to neural mechanism. For instance, consider the hypothesis that a key step during object recognition is the discovery of object boundaries by computing local luminosity gradients. By itself, such a hypothesis is not committed to any particular neural mechanism; indeed, it applies as naturally to visual processing on a laptop computer as it does to visual processing in a brain. Yet, over a period of about 20 years, neuroscientists actually did drive pioneering advances in our understanding of the earliest stages of visual processing. Now several decades past, we are in a good position to appreciate the historical significance of this work, which is an ideal case study of the potential for neuroscience to advance cognitive research.

Feed-forward visual processing begins when light hits a photoreceptor in the retina. These photoreceptors relay through another layer of cells to eventually activate retinal ganglion cells, which transmit information from the eye to the brain. In the years surrounding World War II, a number of researchers performed single-unit recordings of the evoked response of retinal ganglion cells during the presentation of brief visual stimuli to the eye (Barlow, 1953; H. Hartline, 1940; H. K. Hartline, 1938; Kuffler, 1953). This line of investigation lead to a pivotal characterization of a type of receptive field common to many retinal ganglion cells: “center surround” (Figure 1).

![Fig. 1 A reproduction of an illustration from Kuffler (1953) showing the receptive field of a retinal ganglion cell. In the diagrammed receptive field, the innermost portion responds preferentially to the onset of light, while the outermost portion responds preferentially to the offset of light.](image)

An immediately subsequent stage of processing was characterized in a classic series of experiments by Hubel and Weisel (1962). This stage takes as input representations with a center-surround format. By computing the spatial relations among cells of this type, it derives a representation of local linear contrast boundaries and their orientation (Figure 2). Here, again, the experiments that established the representational content of early visual processing were single-unit recordings, in this case taken from the lateral geniculate nucleus and cortical area V1.
These experiments had a transformational impact on the field because they provided a case study of the mapping between neural function and cognitive organization (Gordon, 2004; Wurtz, 2009). Experimental evidence characterized the representational content of three successive stages of visual processing, specifically in terms of the activation of photoreceptors and the receptive fields of individual neurons across two populations. And, a biologically plausible model showed how connections between cells and their individual response properties could instantiate the computation of the later representations from earlier ones. Perhaps most importantly, it was immediately obvious that this element of visual processing constituted useful progress towards the functional purpose of object recognition. Specifically, a retinal map of luminosity was being transformed into elements useful for the detection of object edges in natural scenes (which often involve local high-contrast boundaries). Later cognitive theories posited that this process of edge detection plays a crucial role in object identification and the construction of a three dimensional representation of space (Marr, 1982).

Notably, in this case the neural evidence preceded the development of a cognitive theory. Researchers had not specified a hypothesis of visual processing that included representations of center surround receptive fields. To the contrary, similar experiments performed on the frog's retinal ganglion identified representational contents that long confounded any attempt to relate to the functional demands of vision (a problem famously addressed in Lettvin, Maturana, McCulloch, & Pitts, 1959).

During this formative period of the study of visual processing, then, neuroscience methods drove breakthroughs in cognitive theory. Hubel and Wiesel's experiments were examples of neuroscience methods because their dependent measure was a physiological signals produced by the brain, rather than behavior. Yet, these same experiments were designed to build a cognitive theory of vision. Their basic strategy, which was to characterize the response profile of neurons (i.e., their receptive fields) is reflected across a vast subsequent literature, and encompasses not just single unit recording, but also EEG, PET, MRI, etc. (DiCarlo, Zoccolan, & Rust, 2012).

Indeed, an immediate impact of Hubel and Weisel's research was to prompt new directions in behavioral and computational research on early visual processing. The receptive fields of some LGN and V1 neurons characterized by Hubel and Weisel resemble a local sinusoidal contrast gradient. These are distributed at variable orientations and over variable spatial frequencies (i.e., variable “widths” of the sine wave). It was soon noted that a population of neurons with receptive fields of this type would be capable of representing a visual scene by approximating a Fourier decomposition of the spatial frequency of luminosities. Eventually this line of inquiry established a correspondence between the receptive fields of complex cells and Gabor wavelets, a mathematical object that enables an efficient compression of the information contained in natural scenes. In fact, the basic strategy of decomposing natural scenes into summaries of local spatial frequency is shared with common image compression algorithms for computers, such as the JPEG format.

As this computational interpretation of the neuroscience was developed, a number of clever behavioral paradigms were devised to demonstrate their validity (e.g. Campbell & Robson, 1968). Thus, in all likelihood, the same cognitive theory could have been developed without constraint or inspiration from neuroscientific evidence. Even if a suitably precise cognitive theory of visual processing could be developed without evidence from
neuroscience, however, it is easy to grasp how pivotal the role of neuroscience evidence was in this case. A characterization of the receptive fields of individual neurons across multiples stages of representation enabled Hubel and Weisel to posit an account of the representations and computations contained in early visual processing that had not really been entertained in any serious way by prior theorists. In other words, they made a big step, relatively fast, and there is little indication that the step would soon have occurred without reliance on neuroscience.

Above, I introduced the conceptual distinction between neuroscience theory and neuroscience methods. The key contribution of Hubel and Weisel’s research to a cognitive theory of visual processing appears to have been their use of neuroscience methods, not their development of a general theory of neuroscience. In other words, the information they obtained about neural responses did not influence cognitive theory by way of some general theory of the nervous system—i.e., a theory that generalized over physical rather than informational properties of the brain. Hubel and Weisel instead moved directly from data about the neural system, collected by neuroscience methods, to theory of information processing. Although their theory of information processing could also be construed as a “neuroscience theory”—after all, it described the implementation of an algorithm in terms of the firing of and connections between neurons—it was no less a theory of cognition. By marrying an algorithmic specification of cognitive processing to a biological plausible neural implementation (Marr, 1982) it was, without irony or contradiction, an instance of true “cognitive neuroscience”.

4. Quantitative analysis

If neuroscience is important to the development of cognitive theories, then cognitive research that is directly informed by neuroscience will tend to be of a superior quality. How can we test this hypothesis by quantitative analysis? A common proxy for the quality of scientific research is its citation index. And, cognitive research that is “influenced” by neuroscience will, of course, tend to cite that very neuroscience. Thus, we might ask whether cognitive research that cites neuroscience is subsequently more cited. This evidence would be consistent with the hypothesis that cognitive research that is influenced by neuroscience is of a higher quality (or at any rate more influential), although it is also consistent with some alternatives.

Of course, it is crucial that this hypothesis is tested on papers that are unambiguously devoted to the development of cognitive theory. It is possible, for instance, that neuroscience research is more cited that cognitive research, but this is not the question. Our goal is not to establish whether neuroscience is influential in general. Rather, the goal is to assess whether neuroscience improves cognitive research. Thus, we want to consider only articles that are cognitive research, asking whether those that cite neuroscience (i.e., are influenced by it) are subsequently more cited (i.e., are of a higher quality, or more influential).

We assessed this question in a sample of articles drawn from the journal Cognition. This journal publishes articles almost exclusively on cognition. It publishes almost no research employing neuroscience methods (e.g. fMRI), and the few articles that do employ neuroscience methods are designed to address theories of cognition. Indeed, among the sample of articles that we targeted, a search on the Thomson Reuters Web of Science did not reveal any that included “fMRI” in its title or abstract. The audience of Cognition is primarily psychologists, and it is among the more influential and widely read journals specific to the field of cognitive psychology.

This analysis focuses on articles published during the calendar years 2008, 2009 and 2010. This affords a large sample of published articles (N = 540) for which we could obtain adequate citation information from the Web of Science. We chose this range of dates because it seemed late enough for the published articles to have potentially benefited from the explosive growth of cognitive neuroscience in the preceding decade, but early enough to have amassed a meaningful number of citations representative of their quality.
For each article we recorded the number of Web of Science indexed citations (hereafter “citations”) through August 2015 (the date at which this manuscript was initially prepared); this is our measure of the article’s quality and influence. We used an automated text extraction algorithm to identify the references cited in each article PDF (hereafter, “references”). This algorithm identified 21,159 references, including many to the same sources. We then categorized references targeting “neuroscience” (versus not) by assessing whether each referenced article was published in any of 62 neuroscience journals, or whether its title contained word stems associated with neuroscience (e.g. “Neur”, “Brain”, etc.).

The sample of articles we analyzed were cited an average of 31 times each. Out of 540 total articles, 311 (58%) referenced at least one neuroscience article, while 229 (42%) referenced none. Articles that contained at least one neuroscience reference received an average of 34 citations, while those that contained no neuroscience references received an average of 26 citations, which is a statistically significant difference $t(538) = -2.88, p < .005$. In other words, articles that referenced neuroscience tended to receive about eight more citations on average than articles that did not, an increase of 31% in the frequency of citation. A comparison of the most cited to least cited articles helps to illustrate this trend. Among the 20 most cited articles (mean = 148 citations), 17 contained at least one neuroscience reference. In contrast, among the least cited articles (mean = 3 citations), only 9 contained at least one neuroscience reference.

This analysis can be improved in a few simple ways. First, citations are not distributed normally across this sample of articles; rather, the distribution is highly right skewed, violating an assumption of the parametric statistical tests we employed to analyze our data. A log transformation of citation counts produces an adequately normally distributed dependent variable. Second, as might be expected, articles published earlier (e.g. 2008) tended to receive more citations than articles published later (e.g. 2010), while the likelihood of neuroscience references also increased over this range in our sample. This pattern of correlations may obscure the predicted effect of neuroscience references on subsequent citations, and so it is important to statistically control for the effect of time. Third, articles that contained more references overall were more likely to contain at least one reference to neuroscience, and also to receive more citations (e.g., perhaps because of variable rates of citation across subdisciplines, reciprocity among authors, a correlation between an exhaustive literature review and article quality, etc.). This pattern of correlations may artificially inflate the predicted effect; again, it is important to statistically control for it.

Thus, we performed a regression that predicted the natural logarithm of the number of citations received by each article in our sample. We included three predictors: a dichotomous variable that coded whether each article contained any references to neuroscience, a variable coding the year of publication, and the total number of references contained in each article. Again, we found a statistically significant effect indicating that articles that referenced neuroscience were more likely to receive subsequent citations, $p < .005$, after controlling for the other two predictors.

Although we find clear evidence in this model that referencing any neuroscience is correlated with a higher citation index, we do not find evidence that referencing more neuroscience helps. Specifically, after controlling for the presence versus absence of any neuroscience reference, there is no further statistical relationship with the specific number of neuroscience references ($p > .50$) or the proportion of neuroscience references out of all references ($p > .50$). On the other hand, this provides some evidence against the hypothesis that articles referencing neuroscience are cited more only when they actually contribute to the neuroscience literature (i.e., report neuroscientific results, address neuroscientific theories, etc.). Were this the case, presumably an article that cites many neuroscience findings (and thus more likely contributes to the neuroscience literature) would receive more citations than an article that cites only one or two neuroscience findings (and thus likely does not contribute to the neuroscience literature). On the other hand,
if neuroscience improves cognitive research, it is surprising that we do not find evidence that more neuroscience is associated with greater improvement.

Although the evidence described above is consistent with the possibility that neuroscience improves cognitive research, there are several important alternative explanations for the observed effect. One possibility is that it may be explained by variability across sub-disciplines of cognitive research. For instance, research into cognitive development may infrequently refer to neuroscience (e.g., because little neuroscience is performed on infants and children) and also receive fewer citations (e.g., because the pace of research is relatively slow), compared with other subdisciplines. This would produce a spurious confound between neuroscience references and subsequent citations.

We conducted a quick and rough test of this account, testing for the presence of the basic “neuroscience advantage” already identified, but now within four separate categories of research. We identified articles belonging to each research category by searching for keywords or word stems in the titles of articles contained in our sample. For instance, twelve articles contained the word “moral” in the title, and thus presumably focused on moral cognition. Eight of these articles referenced neuroscience, and these received an average of 92 citations each; four did not reference neuroscience, and these received an average of 13 citations each. Among 25 articles with the word “face” in the title, those referencing neuroscience received more citations (mean = 29) than those that did not (25). Among 60 articles with the word stems “ling” or “lang” in the title, those referencing neuroscience again received more citations on average (42 vs. 22). The same trend emerged among 58 articles with the word stem “child” or “infant” in the title (35 vs. 32). These are the only categories we analyzed; clearly, further and more systematic approaches could be taken to address this question. Yet, while the magnitude of the “neuroscience advantage” is variable across categories, in each case there is a trend in the same direction. This provides some preliminary evidence that the overall effect is not spuriously driven by features specific to different subdisciplines.

Another explanation for the observed pattern of results is that references to neuroscience impart a false aura of quality. In other words, people may cite articles that reference neuroscience because they have the impression that the research or theory is more cutting-edge, valid, interdisciplinary, plausible, etc., but in fact those articles may not differ in any of these respects. This explanation is difficult to rule out because of our use of citation as a proxy for quality. It may be amplified by our reliance on a sample of recently published articles; perhaps the “early returns” of citations are driven relatively less by actual research quality than by heuristic approximations of it. The foundations of this argument are more than hypothetical: Perhaps ironically, the sixth-most-cited article in our sample is titled, “Seeing is believing: The effect of brain images on judgments of scientific reasoning” (McCabe & Castel, 2008). It shows that college students are more likely to accept a scientific argument as valid if it is accompanied by an uninformative fMRI activation map. (On the other hand, other research provides some evidence that scientific experts are immune to this effect (Weisberg, Keil, Goodstein, Rawson, & Gray, 2008)).

A final alternative explanation for this effect is that articles referencing neuroscience are more likely to be cited by the neurosciences, but not by other branches of cognitive science. Why might this be? An unlikely possibility is that articles in the journal Cognition that reference neuroscience are being cited by neuroscientists not because of their contributions to cognitive theory, but rather because of contributions to non-cognitive theories of neuroscience—e.g., a model of network dynamics, or neurotransmitter receptor types, etc. This possibility is unlikely because Cognition just doesn’t publish articles with this kind of content. (Recall that not a single article in our sample contains “fMRI” in the title or abstract).

A second possibility is that cognitive neuroscientists are more likely to cite articles (or authors) who cite them, perhaps via an implicit or explicit reciprocity, or because they find it easier to relate such work to their own interests.
This hypothesis is more likely, and also harder to rule out based on our data. Because the citation advantage that we observe is not eliminated when controlling for the total number of citations, we can at least provide some evidence against a pure effect of peer-to-peer reciprocity in citation (assuming that neuroscientists are no more prone to such reciprocity than non-neuroscientists), but other versions of the hypothesis are not addressed by this analysis.

There is a third version of this alternative that is perhaps the most likely, but is friendly to the overall claim that cognitive research is improved by engagement with the neurosciences. Possibly, cognitive research that engages seriously and directly with neuroscience is also more useful to neuroscientists who are working on cognitive questions—i.e., cognitive neuroscientists. For instance, research that uses behavioral methods to investigate early visual representations would likely benefit from research on this topic using neuroscience methods; in turn, it is especially likely to inform future research using neuroscience methods. In this case, our effect might be driven by citations from neuroscientists, and yet it would still be diagnostic of the underlying quality and broad applicability of the research for the development of cognitive theories.

Based on the set of citation records available to us we could not develop a reliable method to directly assess whether our effect was due entirely to enhanced rates of citation by neuroscience for those articles in our sample that referenced neuroscience. The most relevant evidence we found targets a different, but related question: Are references to neuroscience related to increased citation from articles that are not neuroscience? In order to assess this, we analyzed the number of citations for each article in our sample, focusing exclusively on subsequent articles also published in Cognition. In other words, we asked, “For three years’ worth of articles published in Cognition, if they referenced neuroscience, were they then more likely to be cited by subsequent articles also published in Cognition?” In this case we found no significant difference in citation rates; indeed, if anything the citation rates trended in the opposite direction (i.e., more citations for articles that did not refer to neuroscience). This analysis, however, is compromised by a marked reduction in statistical power.

In summary, our analysis provides strong evidence that references to neuroscience articles are associated with higher citation rates for cognitive research in Cognition. Yet, this data is compatible with a number of rival hypotheses and does not provide exclusive support the conclusion that neuroscience has an important influence on cognitive research.

5. Conclusion

Cognitive neuroscience aims to characterize the interface between computation and biology, and it is not an oxymoron. A priori, there is good reason to believe that cognitive neuroscience will advance cognitive theory. Although it is not clear whether “theories” of neuroscience will often play this role, there is every reason to believe that neuroscience methods will be pivotal. This depends, of course, on the existence of theories that map between physical properties of the brain and computational properties of the mind. A case study of an early advance in cognitive neuroscience, the mapping of receptive fields in the retinal ganglion and early visual cortex, shows that this approach can succeed in practice. This case study underscores the utility of neuroscience methods for describing representations and computations that are many stages of processing removed from behavior and, thus, difficult to characterize by behavioral methods alone. Of course, this case study may be anomalous. Yet, in an analysis of a sample of articles developing cognitive theories, we find that references to past neuroscience research are associated with a greater impact as measured by citation index. This is at best an indirect proxy for the underlying “quality” of cognitive research, however, and the evidence presented here is consistent with several alternative hypotheses.

Each of the methods used above—a priori analysis, case study and quantitative analysis—has its own drawbacks. Together, however, their complementary strengths provide a unified account of the important role that evidence from
the neurosciences can play in advancing cognitive research.

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References