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The Neuroscientification of Psychology: The Rising Prevalence of Neuroscientific Concepts in Psychology From 1965 to 2016

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Abstract
The apparent convergence of psychology and brain science has been the subject of both celebration and critique, but it has never been systematically charted. We examined historical trends in the representation of neuroscientific concepts in a corpus of 798,402 psychology journal articles published over the past half century, from 1965 to 2016. A dictionary of 522 uniquely neuroscience-related terms was developed, and the percentage of article abstracts in which at least one term appeared was calculated for each year. This percentage grew from 9.15% to 16.45% over the study period, whereas the percentage containing a subset of 199 terms containing the prefix "neur-" rose much more steeply, from 2.30% to 10.06%. From the mid-1970s, the growing representation of neuroscience in psychology was linear. Proportions were highest among journals covering neuropsychology and physiological psychology and behavioral neuroscience, lowest in those covering social psychology and developmental and educational psychology, and intermediate in those covering experimental and cognitive psychology and clinical psychology. The steepest rises were found in social and clinical psychology journals. Changes in the most salient neuroscientific terms revealed historical shifts in technology, topic, and anatomical focus, which may contribute to our understanding of relationships among mind, brain, and behavior.

Keywords
brain, history of psychology, neuroscience

Psychology, traditionally the science of mind and behavior, is increasingly also a science of the brain. The discipline has had a long-standing tradition of research and practice in neuropsychology, but new subdisciplines of behavioral and cognitive neuroscience have emerged in recent decades, and newer fields of research in social, affective, developmental, educational, and cultural neuroscience have been snapping at their heels. Enabled by advances in neuroimaging technology and promoted by major initiatives such as the American "Decade of the Brain" (Jones & Mendell, 1999), investigations of the neural dimensions of mind and behavior have become much more prominent. Former departments of psychology have been rebranded as departments of psychology and neuroscience or brain science, and the demand for expertise in neuroscientific areas has risen in job advertisements for new psychology faculty (Schwartz et al., 2016).

The reception of these developments within psychology has been mixed. Many psychologists welcome the opportunities that rapid advances in brain science provide and see them as ways to dissolve the vestiges of mind-body dualism in their field. Neuroscience has given researchers new tools such as functional MRI (fMRI) to look "under the mind's hood" (Nobre & van Ede, 2020) and explain its processes mechanistically. Other psychologists have raised concerns about the

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field's permeation by brain science. Just as Eisenberg (1986) complained that "brainlessness" had been replaced by "mindlessness" in psychiatry, critics worry that the rise of neuroscience in psychology may have some negative impacts (Miller, 2010; Satel & Lilienfeld, 2013). Some argue that neuroscientific ideas seduce people into error (Weisberg et al., 2008) and have undesirable social and cultural effects, changing how members of the public understand themselves (O'Connor & Joffe, 2013), eroding their belief in free will (Vohs & Schooler, 2008), leading them to excuse criminal behavior (Aspinwall et al., 2012), and increasing psychiatric stigma (Loughman & Haslam, 2018). Other critics charge that neuroscience promotes reductionist thinking both among the public (Racine et al., 2005) and among researchers. Miller and Keller (2000), for example, argued that the Decade of the Brain "has fostered a naively reductionist view that sets biology and psychology at odds and often casts psychological phenomena as unimportant epiphenomena" (p. 212). Echoing this concern, Schwartz et al. (2016) contended that the rise of neuroscience within psychology will deflect focus away from social influences on behavior, shift funding and hiring priorities, and lower methodological and training standards. Psychology, they urged, must recognize multiple levels of analysis and avoid privileging a single, neurobiological level promoted by the dominant neuroscience paradigm.

The risks and benefits associated with the rising "neuroscientification" of psychology have received significant attention, but to date there has been no systematic investigation of the extent or trajectory of this supposed rise and whether it has been large or small, gradual or abrupt. It is unclear whether neuroscience has in fact become a dominant paradigm in the field, as some critics suggest, although several studies have explored historical shifts in neuroscience-related phenomena in other domains. For example, Reiner (2011) documented a 31-fold increase in references to "neuroscience" or "neuroscientists" in major world English-language newspapers from 1985 to 2009, and O'Connor et al. (2012) demonstrated a near doubling of neuroscience-related articles in United Kingdom newspapers from 2000 to 2010. However, no studies have examined the changing prominence of neuroscience within academic psychology.

Such an examination might explore four key questions. First, to what degree has neuroscience infused contemporary psychology research (e.g., what proportion of psychology research publications have a neuroscientific component)? Second, what is the trajectory of the presence of neuroscience in psychology? Is it steadily upward and linear or has it accelerated in certain periods, such as the Decade of the Brain? Third, how has any rising presence of neuroscience in psychology differed across the discipline's fields? Has it, for example, spread from its heartlands of behavioral neuroscience and neuropsychology into fields such as cognitive, developmental, and social psychology, so that their rises have occurred at different times? It might be expected that neuroscientification is less evident in fields that have an interpersonal rather than intrapersonal focus. Finally, which neuroscientific concepts have been salient at different times during the supposed rise in the prominence of neuroscience within psychology?

The current study addressed these four questions by analyzing the presence of a large set of neuroscience-related words ("neuro-terms") in a massive corpus of psychology article abstracts from research published over a half century (1965–2016), a period that coincides with the emergence of neuroscience as a field (e.g., the founding of the Society for Neuroscience occurred in 1969 [Picciotto, 2020], preceded in 1960 by the founding of the Society for Psychophysiological Research). These abstracts represent a substantial majority of all English-language psychology articles published in that period. We chose this source of text because an abstract "summarises the essential contents of a particular knowledge record and is a true surrogate of the document" (Cleveland, 1983, p. 104) and has a relatively compact and consistent format. Abstracts have been studied in previous research on historical trends in scientific research (e.g., Swales & Feak, 2010; Vinker et al., 2015). In keeping with this approach, our study was primarily descriptive. Although the study of the nervous system has always been one focus of psychological research, we expected that the proportion of abstracts containing neuro-terms would rise over the study period, reflecting a process of "neuroscientification." We further expected that this rise would be distributed unevenly across psychology's subdisciplines, that rates in social psychology, for example, would be lower, and that the rise would partly reflect the rapid recent growth in neuroimaging technologies that have driven advances in research.

Method

Development of the corpus

A corpus for examining historical trends in psychology research was constructed by combining samples of psychology abstracts from two databases. In 2017 we downloaded the baseline database from PubMed, which contains metadata for over 25 million abstracts across the health sciences. Using ISSN numbers for a list of 1,095 journals tagged as "psychology" in the SCImago database, we filtered PubMed for matches, extracting entries for 570,857 articles from 758 of the identified psychology journals, of which 439,499 contained abstracts. Abstracts consisting of retraction, correction,

or copyright notices or containing fewer than 85 characters were removed, resulting in 428,936 abstracts published between 1975 and 2017.

To supplement this set of abstracts obtained from a health-focused database, we used the Crossref text-mining application programming interface (API). Using ISSN numbers, we used this API to gather metadata for the same set of 1,095 journals and followed Crossref links to abstracts where they were available. This yielded 740,955 abstracts from 803 "psychology"-tagged journals beginning in 1930, which was reduced to 718,512 after we removed copyright notices, book reviews, non-English abstracts, and editorials. The two sets of abstracts were then merged, removing exact duplicates using Levenshtein's distance (Wagner & Fischer, 1974) to find identical abstracts with slight formatting differences, leaving a combined corpus of 871,340 unique abstracts from 875 journals. This corpus was very sparse in its early decades and data were incomplete for 2017, so a final set of 798,402 abstracts published from 1965 through 2016 was retained for analysis.

Development of the dictionary

A dictionary of neuroscience-related terms for analysis in the abstracts corpus was developed in a two-step process. The aim was to generate a highly targeted set of terms with uniquely or specifically brain- or nervous system-related meanings in the context of psychology research. This set was intended to be conservative, excluding terms that might falsely identify research as having a neuroscientific component. In the first step, we searched the glossary of a major neuroscience survey textbook (Purves et al., 2001) and extracted words with a "neur-" prefix from the corpus. This search process yielded 761 candidate terms that included acronyms and one- to three-word expressions (e.g., "brain," "deep cerebellar nucleus"). In the second step, the 761 terms were independently reviewed by two senior psychology researchers, who were given explicit inclusion and exclusion criteria and two further instructions, as follows:

> *Terms to be included are those that refer to:* 1) brain or broader central nervous system structure, chemistry or functioning, whether at macro (e.g., systemic, regional) or micro (e.g., cellular, chemical) levels; 2) scientific fields that directly study brain or nervous system structure (e.g., brain regions), chemistry (neurotransmitters, neuropeptides) or functioning (systems, processes, cellular phenomena); 3) research methods or technologies that directly study brain or nervous system structure, chemistry or functioning; and 4) pathologies or disorders that specifically relate to the brain or nervous system.
>
> *Terms to be excluded are those that:* 1) do not refer exclusively or uniquely to brain or nervous system structure, chemistry or functioning (i.e., they have non-neuroscience-related senses or uses within psychology); 2) refer to biological or psychobiological phenomena that are not specifically neuroscience- or brain-related (e.g., genetic or hormonal phenomena, or cellular phenomena that are not specific to neurons); and 3) pathologies or disorders that may have a neural dimension but are not narrowly nervous system based in their pathology (e.g., depression, schizophrenia).
>
> For the purposes of this task, there are two other instructions: 1) the default assumption is that most terms beginning with "neur-" will be chosen, unless they clearly do not refer to brain/nervous system phenomena in psychology; and 2) terms that refer to sense organs, including their interface with the nervous system, will normally not be chosen so as not to include terms that are widely used in the psychology of perception with no meaningful focus on brain/nervous system functioning.

The two judges showed strong agreement (89.0%, Cohen's $\kappa = .714$): 522 terms (68.6%) were judged to meet inclusion criteria by both judges (for a list of these 522 terms, see the Supplemental Material available online). These consensus terms composed the neuroscience-term dictionary. Illustrative glossary terms that were excluded for not meeting the criteria included "basal," "consciousness," "declarative memory," "distal," "histamine," and "invertebrate."

Data preparation and analysis

Before analysis we tokenized the corpus, removing all numerical values, punctuation, stop-words, and non-English words, and then used SpaCy (https://spacy.io/) to case-fold and lemmatize the text.

Results

Figure 1 presents the percentage of abstracts in each year containing at least one term from the dictionary, and the percentage of abstracts containing at least one term with a "neur-" prefix. A ±2-year smoothing was applied to all data points so the graph ranges from 1967 to 2014. Within this 47-year span, the representation of neuroscience-related terms rose from a base of 9.15%

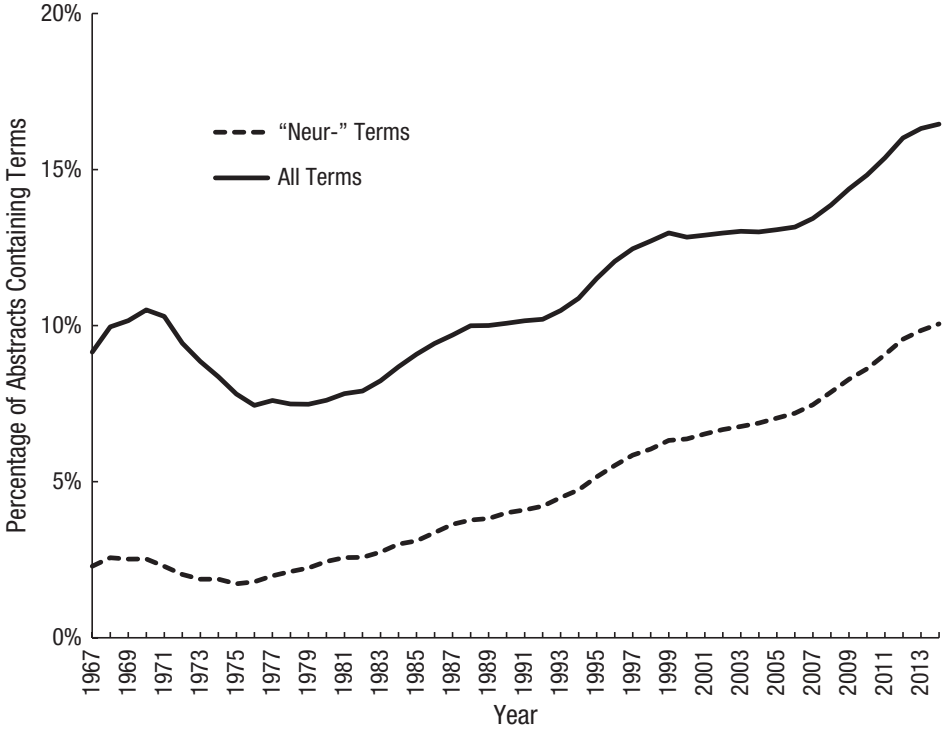

Fig. 1. Percentages of abstracts containing at least one instance of a term from the full set of 522 terms or a word from the subset of 199 "neur-" prefix terms. A ±2-year smoothing was applied to all data points, so the graph ranges from 1967 to 2014.

in 1967 to 1970, fell to a minimum of 7.45% in 1976, and then rose steadily to 2014, where it peaked at 16.45%. In relative terms, this steady increase represents a 121% rise over a 38-year period. Terms with a "neur-" prefix show a similar trajectory: 2.30% in 1967, 1.73% at their nadir in 1975, and 10.06% at their 2014 peak. However, because this parallel trajectory starts from a lower base, it represents a much steeper rise of 482% from the mid-1970s through to the contemporary peak. By implication, the rise in brain- and nervous system-related terms within psychology is especially marked for terms with a "neuro" branding.

Figure 1 suggests that the infusion of neuroscientific concepts into psychology research occurred at a comparable rate during both the 1990s Decade of the Brain and in the 1980s and 2000s. Figure 2 displays the *absolute* difference in the percentage of abstracts containing any neuro-term or any "neur-" prefixed term from the beginning of one decade to the beginning of the next. After the decline in the 1970s, the increase in the 1990s was only slightly greater than in the neighboring decades. Note that the percentage changes relative to the start-of-decade baselines would be much greater (e.g., the absolute percentage increase from 1990 to 2000 in the full term set was 2.76%, but the relative increase was 27.37%).

To address the study's third research question, concerning differences in the neuroscientification between psychology's subdisciplines, we repeated the analysis of the full term set within groupings of journals. These groupings, based on SCImago's classification of journals by field and representing six major subdisciplines as well as a "miscellaneous" group of generalist journals, are overlapping because single journals may receive multiple classifications. Nevertheless, they offer a systematic assessment of differences in the inclusion of neuroscientific concepts into different psychological fields. Figure 3a plots the percentages of abstracts in each journal grouping that contained at least one of the 522 neuro-terms, and Figure 3b rescales those values as a percentage of each field's highest frequency, allowing a clearer view of the rate and timing of its changes.

Figure 3a demonstrates striking variability in the representation of neuro-terms across psychology fields. Unsurprisingly, journals in the neuropsychology/physiological psychology and behavioral neuroscience journal groups had the highest percentage of abstracts containing neuro-terms in recent years, both peaking in 2014 at more than 55%. The experimental/cognitive psychology journal group had the next highest percentage (24.4%), followed by clinical psychology (17.6%) and developmental/educational psychology (13.7%)

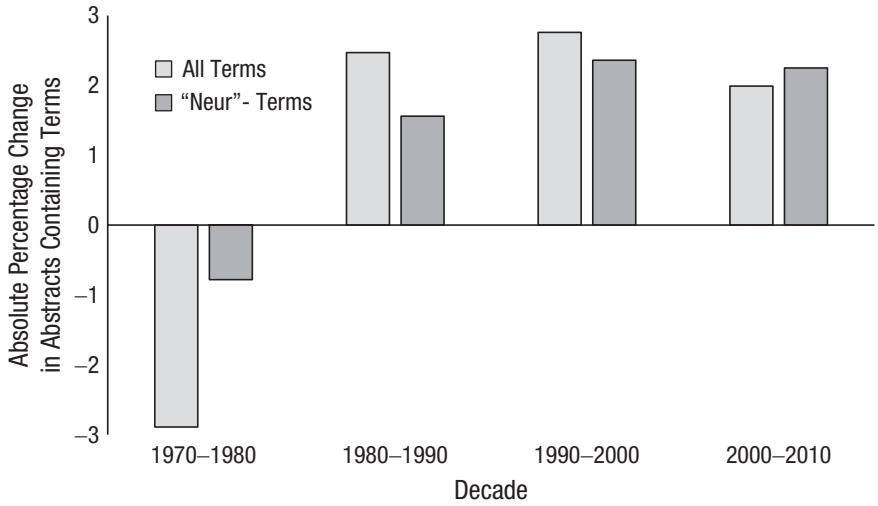

Fig. 2. Decadal change in absolute percentage of abstracts containing at least one term from the full term set and the "Neur-" prefix subset.

journals. The miscellaneous journal group rose from 3.2% at its lowest point in 1976 to 9.5% in 2014. Social psychology abstracts were consistently the least likely to contain neuro-terms; rates fell as low as 0.4% in the 1970s to a modest peak of 3.4% at the end of the study period.

Figure 3b demonstrates that the rate and timing of increases in the presence of neuro-terms differ sharply between fields. Relative to the mid-1970s low point, the steepest rate of increased presence of neuro-terms was found in social psychology, followed by clinical psychology, neuropsychology/physiological psychology, miscellaneous, and developmental/educational psychology; behavioral neuroscience and especially experimental/cognitive psychology showed the most modest increases. Neuropsychology/physiological psychology and behavioral neuroscience demonstrate relatively steady and sustained rises over this period, but other fields displayed their steepest increases at different times: experimental/cognitive psychology especially in the 1980s, clinical psychology and developmental/educational psychology in the 1980s and 1990s, and social psychology in the 2000s and 2010s. Miscellaneous journals increased most steeply in the 1990s and 2000s, implying that neuroscientific ideas garnered much wider visibility within general psychology at this time.

To summarize, the representation of neuroscientific concepts in psychology research, and its rate of change, are very unevenly distributed across subdisciplines. Terms representing these concepts appeared at relatively high rates in the more biological and cognitive fields of psychology, where they underwent relatively modest increases over the past half century. They were substantially rarer in other fields but rose steeply from relatively low bases in all of these, but the timing of greatest rise differed somewhat across fields.

Thus far, our analysis has examined neuroscience-related terms as a set rather than examining the historical trajectories of specific terms. Table 1 helps to clarify shifting trends in the use of specific terms by presenting the 20 most frequently appearing terms (according to the number of abstracts in which they appeared) in each 5-year period starting in 1965 through 1969. For simplicity and to avoid redundancy in the table, four high-frequency noun/adjective neuroanatomical term pairs (and their frequencies) were combined and are represented in the table by their noun form (i.e., cerebrum/cerebral, cortex/cortical, hippocampus/hippocampal, hypothalamus/hypothalamic). Several general trends can be observed. First, consistent with the pattern documented in Figure 1, terms beginning with "neur-" become increasingly prevalent in the top 20, composing four or five of these terms from 1965 through 1994 but nine from 2005 through 2016. Second, neuroanatomical terms declined in representation. Third, disciplinary terms rose to prominence at different times, including "neuropsychological" from the late 1970s and "neuroscience" from the early 2000s. Likewise, "neurocognitive" rises steeply from the late 2000s.

Different neuroanatomical terms changed in their relative prominence, indicating changes in psychology's preoccupations with shifting locations within, and models of, the brain. For instance, "hypothalamus" declined in prominence after its 1960s and 1970s heyday. "Hippocampus" underwent a similar early drop only to rebound from the early 1990s, the same pattern occurring for "amygdala," which reappeared in 2005 through 2009 after a 20-year absence from the list. "Prefrontal

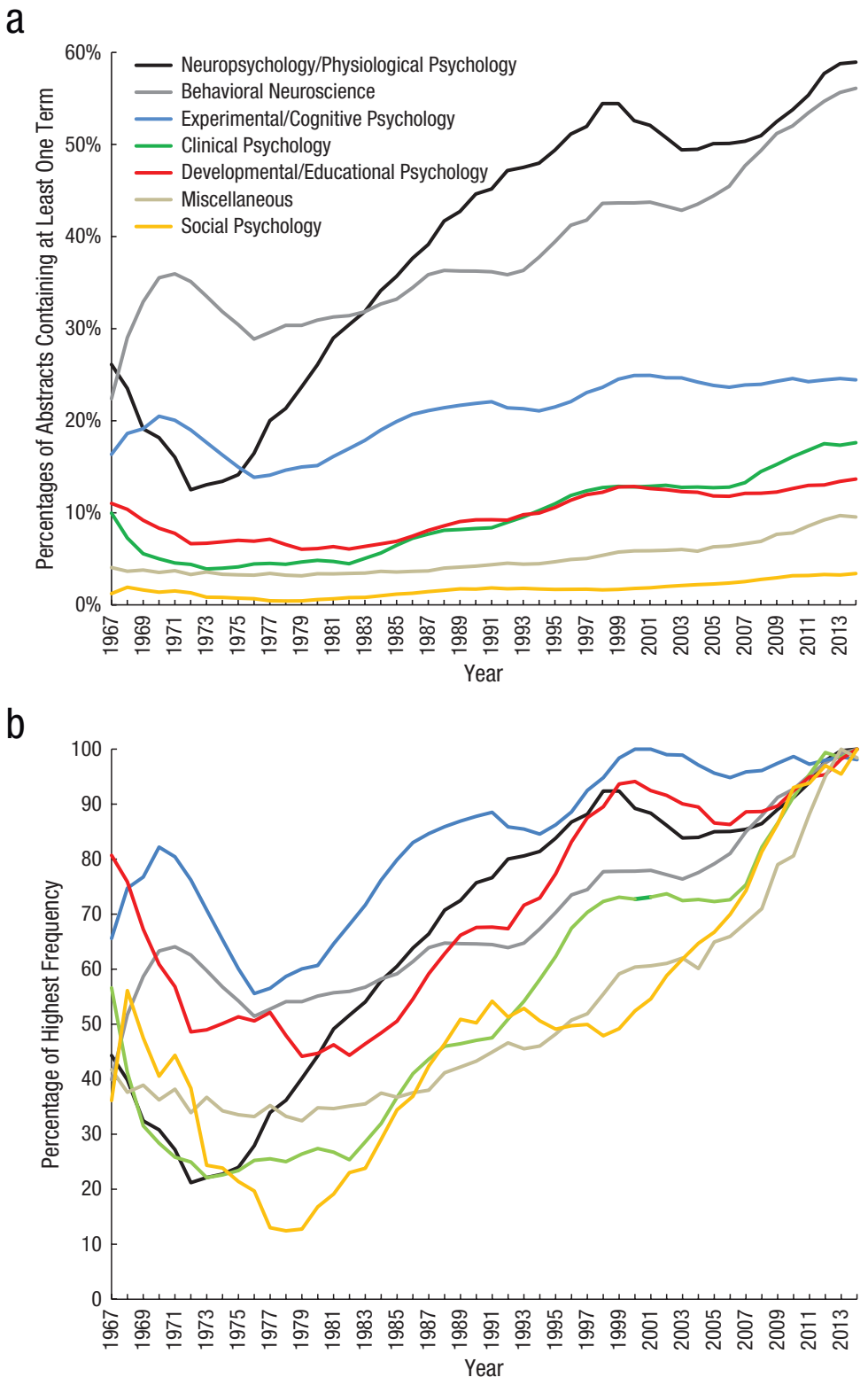

Fig. 3. Percentage of abstracts containing at least one term for (a) all abstracts and (b) each grouping's highest frequency, separately for each subdiscipline.

Table 1. Twenty Most Frequent Terms in Each 5-Year Period Ranked by Number of Abstracts in Which They Appear

Rank	1965–1969	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999	2000–2004	2005–2009	2010–2014	2015–2016
1	brain	brain	brain	brain	brain	brain	brain	brain	brain	brain	brain
2	cortex	hypothalamus	hypothalamus	cerebrum	cerebrum	neuropsych	neuropsych	cortex	neural	neural	neural
3	hypothalamus	cortex	EEG	cortex	neuropsych	cortex	cortex	neuropsych	cortex	cortex	cortex
4	EEG	EEG	cortex	hypothalamus	cortex	cerebrum	Alzheimer	neural	neuropsych	Alzheimer	neuropsych
5	neural	hippocampus	cerebrum	EEG	hypothalamus	Alzheimer	neural	Alzheimer	Alzheimer	neuropsych	Alzheimer
6	hippocampus	neural	neural	neural	neural	neural	cerebrum	hippocampus	hippocampus	hippocampus	hippocampus
7	cerebrum	cerebrum	hippocampus	neuropsych	neurological	neurological	hippocampus	cerebrum	fMRI	fMRI	PFC
8	nerve	amygdala	neurological	neurological	EEG	EEG	EEG	neurological	cerebrum	PFC	fMRI
9	amygdala	neurological	amygdala	hippocampus	aphasia	hypothalamus	neurological	neuron	PFC	neuroimaging	EEG
10	neurological	nerve	contralateral	lateralization	Alzheimer	aphasia	neuron	EEG	neuron	neuron	neurocog
11	catechol	olfactory bulb	nerve	catechol	dopamine	hippocampus	frontal lobe	neuronal	neuroscience	cerebrum	neuroimaging
12	CNS	forebrain	neuron	aphasia	lateralization	frontal lobe	aphasia	serotonin	neuroimaging	neuroscience	neuroscience
13	neurophys	contralateral	dopamine	dopamine	hippocampus	temporal lobe	neuronal	PFC	neurological	neuronal	neurological
14	neuronal	cholinergic	neuropsych	amygdala	serotonin	neuron	serotonin	neuroimaging	neuronal	EEG	amygdala
15	thalamic	neuron	CNS	neuron	neuron	dopamine	hypothalamus	frontal lobe	amygdala	neurological	cerebrum
16	neuron	neuronal	catechol	contralateral	contralateral	ERPs	temporal lobe	hypothalamus	EEG	amygdala	MRI
17	forebrain	CNS	serotonin	serotonin	CNS	CNS	CNS	aphasia	dopamine	neurocog	neuronal
18	epinephrine	catechol	VMH	nerve	catechol	nerve	dopamine	temporal lobe	hypothalamus	MRI	neuron
19	cholinergic	retic form	ipsilateral	CNS	temporal lobe	lateralization	ERPs	neuroscience	neurocog	neurobio	neurobio
20	ANS	afferent	lateralization	neurophys	CNS^2	serotonin	neurophys	ERPs	neurobiological	ERPs	cingulate cortex

Note: ANS = autonomic nervous system; catechol = catecholamine; CNS = central nervous system; CNS^2 = CNS (i.e., the acronym "CNS"); EEG = electroencephalogram; ERPs = event-related potentials; fMRI = functional MRI; neurobio = neurobiological; neurocog = neurocognitive; neurophys = neurophysiological; neuropsych = neuropsychological; PFC = prefrontal cortex; reticular form = reticular formation; VMH = ventromedial hypothalamus.

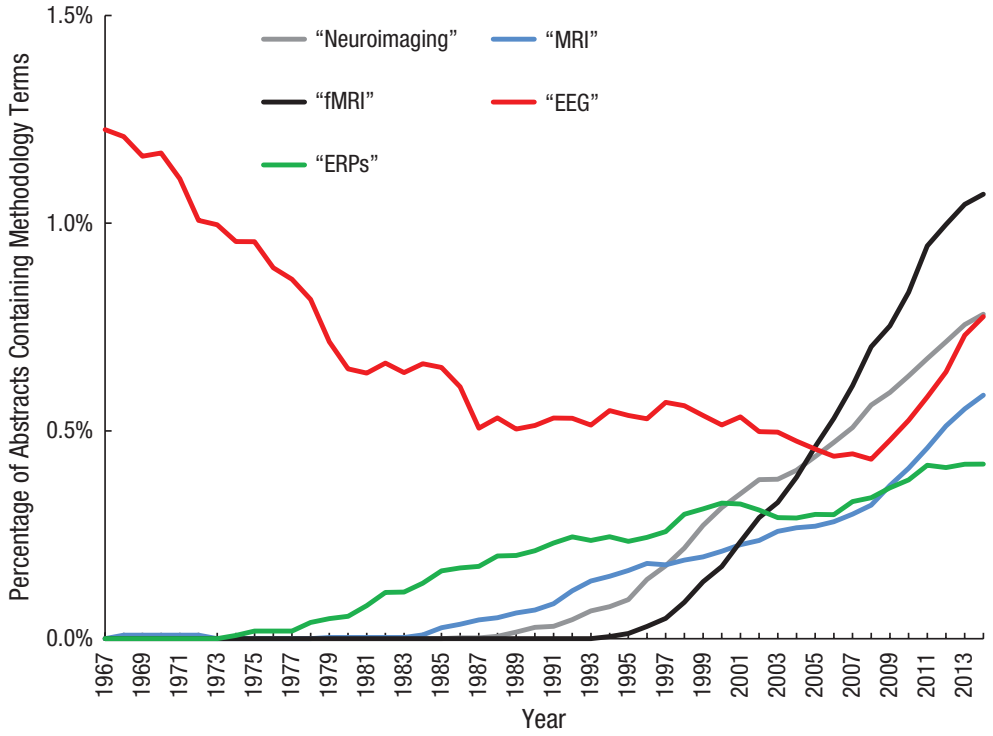

Fig. 4. Percentage of abstracts containing specific research methodology-related terms.

cortex" became salient from the early 2000s. References to "lobes" ("frontal" and "temporal") enter the top 20 only between 1985 and 2004. Likewise, terms related to brain lateralization (e.g., "lateralization," "contralateral") appear in Table 1 only between 1970 and 1994, peaking in the 1980s.

Among neurophysiological and neurochemical terms, there is evidence of a shift in attention away from general catecholamines to specific neurotransmitters (i.e., "dopamine" and "serotonin"), although no neurotransmitters feature in the top 20 after 2009. Among the neurological disorder terms, "aphasia" is salient in the 1980s and 1990s but "Alzheimer's disease" becomes a major focus of attention in the late 1980s and holds its high rank to the present. Among the methodology-related terms, "fMRI" enters in 7th position in the 2005 through 2009 period, and "EEG" gradually declines until 2005 through 2009 only to rebound after this. This pattern is further clarified by Figure 4, which shows how different methodological tools emerged at different times to drive research innovation. "EEG" was dominant from the beginning of the study period, steadily declining until a rebound in the late 2000s, and "ERPs" (event-related potentials) started to be mentioned in psychology articles beginning in the mid-1970s and rose gradually thereafter. "MRI" begins to appear in the mid-1980s and "fMRI" in the mid-1990s, the latter rising steeply to reach a peak in 2014, when it appeared in just over 1.0% of psychology abstracts. The term "neuroimaging" began to appear around 1990 and quickly became widely used.

Discussion

Our analysis of almost 800,000 journal article abstracts illuminates the shifting relationship between neuroscience and psychology over the past half century, during which neuroscience has rapidly become a major intellectual force. As indexed by changes in the frequency with which scientific abstracts referred to a large set of neuroscience-related terms, we were able to chart the infusion of brain science into the science of mind and behavior in quantitative and qualitative detail.

On our first research question, which addressed broad historical trends, our findings clearly demonstrate that neuroscientific concepts have become substantially more prevalent within psychology research over the study period. At the end of this period, one in six psychology article abstracts contained a uniquely neuroscience-related term, more than double the proportion in the mid-1970s. These figures may be interpreted in contrasting ways. On the one hand, as the rate of increase over the past 4 decades equates to a 2% (compounding) annual rise, it would be unreasonable to suggest that psychology is being overrun or dominated by brain science. On the other hand, the rise in "neur"-prefixed

terms is much steeper than that of the whole term set (4.6% annual increase) and indicates that psychology is indeed undergoing a rapid reshaping. We believe that a sensible middle view is to recognize that neuroscientific concepts are gaining traction in research published in psychology journals, but with 83.5% of article abstracts at the end of the study period containing no mention of a single neuro-term, they fall well short of becoming a dominant paradigm in the discipline's foreseeable future. The fact that only a small minority of psychology articles contains a salient neuroscientific element implies that there is likely to be inertia or entrenched resistance to the adoption of new neuroscientific approaches in the field, whether they involve somatic approaches to clinical treatment, neural network analyses of cognitive tasks, or neurobiological models of personality traits.

Our second research question concerned the shape of the trajectory of neuroscience's evolving presence within psychology. For most of the past 50 years, that trajectory is close to linear. However, this simple trend is complicated by the rise and then fall from 1965 to 1975, which resulted in an aggregate decline in the proportion of neuroscience-related terms during the 1970s. This bump may reflect the enthusiasm generated by early behavioral neuroscientific work on appetite and motivation, often conducted with animals and exemplified by the frequent references to the hypothalamus in this period. This may have been counteracted by the rapid growth in research and new journals in the less brain-invoking fields of clinical, cognitive, and social psychology in the 1970s. Since that time, the overall trajectory of neuroscientification is a steady rise that shows no sign of slowing or accelerating. The pre-1975 corpus contains abstracts from only one of the databases (Crossref, not PubMed), and it is possible that this explains the 1965 through 1975 bump. However, the presence of a discernible nonlinearity entirely within that decade and the very large journal overlap between the databases counts against this possibility.

The moderate level and steady increase of the representation of neuroscientific concepts in the corpus of psychology abstracts reflect aggregate patterns over a broad discipline. Our third research question addressed variations between its subdisciplines, which our findings indicated were stark. At one end of the spectrum, abstracts from journals classified as covering behavioral neuroscience, neuropsychology, and physiological psychology contained neuroscience terms at unsurprisingly high rates. At the other end, social psychology publications, and to a slightly lesser extent those in developmental and educational psychology, very rarely referred to neuroscientific concepts. Although social and developmental neuroscience have been touted as emerging cross-disciplinary research domains (e.g., Cacioppo, 2002) and have generated important scientific advances, neuroscientific ideas feature prominently in very small—albeit rapidly growing—proportions of articles in social and developmental psychology journals.

The fields of cognitive or experimental psychology and clinical psychology are both intermediate in their degree of penetration by neuroscientific concepts, but they show differing trajectories. The former displays the smallest rate of increase in the representation of neuro-terms in abstracts over the past half century, perhaps because the multidisciplinary field of cognitive science encouraged an integrative approach to the study of cognition from the outset. Clinical psychology, in contrast, shows a rapid incorporation of neuroscientific concepts, quadrupling the rate of abstracts containing a neuro-term from the 1970s to the 2010s. This emphatic change may partly reflect the influence of an increasingly neurobiological psychiatry discipline on the research agenda of clinical psychologists (Haslam & Lusher, 2011; Miller, 2010). It coincides with the vigorous promotion of neuroscience-based approaches to psychiatric classification such as the National Institute of Mental Health's Research Domain Criteria (RDoC), which aims to integrate psychological and neurobiological processes (Kozak & Cuthbert, 2016).

Our findings also point to qualitative changes in the neuroscientific concepts that feature in the abstracts corpus over recent decades. There appears to have been a shift from a focus on motivation to one on cognition and especially executive functions. This shift has been accompanied by decreasing reference to (a) neuroanatomic structures at the level of lobes and (b) to the lateralization of cognitive functions and an increasing focus on neurocognition and, by implication, on the networks that are involved in specific functions as captured by fMRI. New neuroimaging technologies have also been clinically influential in the past 2 decades, and population aging is a likely source of the rising attention to the neuroscience of dementia. Finally, there has been a growing vogue for terms with a "neur-" prefix, rates of which have increased much more rapidly than other brain science-related concepts. This shift toward a specific framing of brain science concepts arguably represents the intellectual and cultural success of the neuroscience "brand." This trend was observed by Miller (2010), who noted that what had previously been described as "cognitive testing" was increasingly referred to as "neurocognitive testing" without the tests themselves changing.

Limitations of the study

Several limitations of our work must be acknowledged. In particular, somewhat different conclusions about the degree to which neuroscientific concepts permeate

psychology research might have been reached if we had defined those concepts or that research differently or examined alternative datasets. First, with regard to the operational definition of neuroscientific concepts, it is possible that by employing a tightly circumscribed set of neuroscientific terms we may have underestimated the degree to which neuroscience-involving concepts feature in psychology research. "Neuroscientific concept" is itself an intrinsically fuzzy concept, and our efforts to delimit it in a restrictive way so as to minimize "false positives" may have led us to miss some articles that would be judged to have a neuroscientific component on closer inspection. In addition, sampling the candidate neuro-terms from a neuroscience text's extensive glossary may have missed selected concepts with particular relevance to psychology. "Psychophysiology," for example, was not listed in the glossary and therefore could not be included in the main analysis, although follow-up analyses showed the frequency of its cognate terms would not have substantially influenced findings. Despite the unavoidable ambiguity in defining the set of neuro-terms, we believe our approach was solid and principled.

Second, with regard to data sources, it is possible that abstracts are not ideal sources of data for judging whether articles have a neuroscientific component, and full-article texts might be preferable. We would argue that the enormous challenges involved in accessing full text for such a massive research corpus, and the problems full text poses for extracting consistent information from all items (e.g., great differences in size and nontextual features between articles), justify our use of relatively standardized abstracts. It could further be argued that if no neuroscientific concepts feature in an abstract, then the research it summarizes is unlikely to have a significant neuroscientific component, even if one or more such concepts were to appear elsewhere in the article's full text. Nevertheless, combined with the potentially conservative definition of neuroscientific concepts, the reliance on abstracts may contribute to an underestimation of the prevalence of neuroscientific concepts in psychology research, although such a bias would be unlikely to change the broad historical trends we observed.

Even if abstracts were the ideal data source for a large-scale analysis of historical change within psychology, our abstract sample, although very large, was not exhaustive, and the journal set did not match perfectly before and after 1975, when the inclusion of the PubMed database added a modest number of new journals. In addition, defining which journals count as psychology outlets is open to question, and defining those journals more exclusively or inclusively would certainly alter the proportion of abstracts containing neuro-terms. Relying on the "psychology" categorization employed by a body dedicated to evaluation of scientific journals (SCImago) is preferable to making subjective classifications, but results of the analysis might differ if the journal set were more restrictive. Finally, it could be argued that by weighing all abstracts equally (at least within each time period) the analysis may have failed to capture accurately the salience of neuroscientific concepts in the literature. These concepts might be more or less prevalent than average in the most influential, renowned, or prominent journals. Weighting abstracts by journal was not practical in the present study, but it is possible that some journals serve as vanguards and contribute disproportionately to historical shifts.

A third limitation concerns the definition of psychology research. Our study defines it as investigations published in designated psychology journals. An alternative approach might define psychology research as research conducted by psychologists or by researchers affiliated with departments or institutes of psychology, regardless of where that research is published. Many researchers working in university psychology departments publish outside recognized psychology journals, perhaps especially if their research has a neuroscientific orientation and is publishable in neuroscience journals. If this were the case, our findings are likely to underestimate the proportion of research conducted by psychology researchers that has a neuroscientific component. As the proportion of researchers identifying professionally with the psychology discipline but publishing frequently in neuroscience journals is likely to have risen in recent decades, that underestimation may be greater more recently. It is therefore important to distinguish between the representation of neuroscientific concepts in the psychology research literature, the explicit focus of the present study, and the representation of neuroscientific concepts in the research literature generated by psychologists. The level and rate of historical increase of the latter may be significantly higher than our analysis of the former suggests, a possibility that future studies might address. We would note that growth in the representation of research conducted by psychologists in neuroscience journals would arguably reflect the psychologization of neuroscience at least as much as the neuroscientification of psychology.

Conclusions

The results of this study imply that although it is reasonable to suggest that psychological science is undergoing a process of neuroscientification, the extent of

that process should not be exaggerated. The representation of neuroscientific concepts in journal article abstracts has been growing for the past 4 decades, but that growth has generally been gradual. It has barely influenced some research fields and touches only a small proportion of contemporary research publications. For those inclined to see the rise of neuroscience within psychology as a disciplinary threat, our findings should offer some qualified reassurance. For those who see it more as an opportunity, hoping for psychology to become part of an encompassing neuroscience that illuminates phenomena from cells to societies, the findings indicate that this is a distant aspiration.

Transparency

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