

Original Article

Evolutionary Theory in Cognitive Neuroscience: A 20-Year Quantitative Review of Publication Trends

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Abstract: Evolutionary cognitive neuroscience is an emerging and promising new scientific field that combines the meta-theoretical strengths of an evolutionary perspective with the methodological rigor of neuroscience. The purpose of the present research was to quantify and test evolution's influence in neuroscience and cognitive neuroscience journals over time (1987-2006). In Study 1, analyses from a convenience sample of 10 neuroscience journals revealed that the proportion of neuroscience articles mentioning evolution grew significantly over the last 20 years. Moreover, beginning as early as 1990, the average proportion of neuroscience articles mentioning evolution was significantly different from zero. These effects were not moderated by between-journals differences in impact factor (a citation rate index), suggesting that the observed growth was fairly consistent across journals. In Study 2, analyses from a convenience sample of 4 cognitive neuroscience journals revealed that the proportion of cognitive neuroscience articles mentioning evolution neither differed from zero nor grew significantly over time (1987-2006); however, the change-over-time effect size was large. Compared to other research areas, evolution's penetration into cognitive neuroscience articles grew faster than anthropology, economics, and sociology, but not psychology. The implications of evolutionary psychology's increasing role in science in general, and in cognitive neuroscience in particular, are discussed.

Keywords: evolutionary cognitive neuroscience, evolutionary psychology, history of science, multilevel modeling, publication trends.

Introduction

Whether it is viewed as emerging interdisciplinary science, and integrative theoretical perspective, or a broad sub-discipline of psychology (Cornwell, Palmer, Guinther, and Davis, 2005), one thing is fairly certain about evolutionary psychology: Its influence is growing. In loose evolutionary terms, one could argue that it is currently undergoing the scientific equivalent of adaptive radiation. Evolutionary psychology is not only strengthening its roots in some of its more traditional territory (e.g., social

psychology; Webster, 2007b), but it is also branching out and adapting to new scientific terrain such as cognitive neuroscience (Krill, Platek, Goetz, and Shackelford, 2007; Platek, Keenan, and Shackelford, 2007). For example, in their recent article, Krill et al. reviewed how evolutionary theory has been successfully applied to previous studies in cognitive neuroscience and then highlighted some exciting new frontiers for future research. Krill et al. also mentioned that the emerging symbiosis between evolutionary psychology and cognitive neuroscience might not be entirely seamless. Specifically, they noted that evolutionary perspectives have had some difficulty permeating several cognitive neuroscience journals (e.g., *Cognitive Brain Research*, *Journal of Cognitive Neuroscience*).

The purpose of the present research was to quantify the extent to which evolutionary theory has influenced neuroscience (Study 1) and cognitive neuroscience (Study 2) publications over the last 20 years and to assess evolutionary theory's influence compared to other human science areas (Study 2). Five specific questions were developed:

1. Study 1: Is the proportion of neuroscience articles that mention evolution significantly different from zero as of 2006?
2. Study 1: Has the proportion of neuroscience articles that mention evolution grown significantly for the average neuroscience journal in the past 20 years (1987-2006)?
3. Study 1: Do between-journal differences in impact factor (i.e., frequency of citation) moderate the within-journal change-over-time effects for neuroscience articles that mention evolution?
4. Study 2: Is the proportion of articles that mention evolution in journals that focus on human cognitive neuroscience significantly different from zero as of 2006?
5. Study 2: How does the growth in the proportion of articles that mention evolution in journals that focus on human cognitive neuroscience over the last 20 years compare to the proportion of articles that mention other areas of human science (i.e., anthropology, economics, psychology, and sociology)?

Study 1

Method

Sample

A convenience sample of ten neuroscience journals that were indexed in PsycINFO was obtained (Table 1). This sample of journals was fairly diverse, with 2005 impact factors ranging from 0.68 to 15.46 with a median of 3.05 ($M = 4.45$, $SD = 4.29$). Journal impact factors are a measure of how often the average article in a journal is cited in a given year, and were obtained from the Institute for Scientific Information's Journal Citation Reports: Science Edition website (<http://portal.isiknowledge.com>).

Procedure

PsycINFO keyword searches were performed using the term "evol*" for articles published in each of the ten neuroscience journals from 1987 to 2006. Thus, these searches found articles that mentioned "evolve," "evolved," "evolves," "evolving," "evolution," "evolutionary," or "evolutionarily" in their titles, abstracts, or keywords. The number of articles that mentioned at least one of these terms in a given year was then divided by the

total number of articles published that year to obtain a proportion, and this was done for each journal. Because proportion data often violate the homogeneity-of-variance assumption of regression (Judd and McClelland, 1989, pp. 525-526; cf. Webster, 2007b), an arcsine transformation was applied to the proportions: $\sin^{-1}(\text{proportion}^{1/2})$.

Results

Two types of analyses were performed. First, simple ordinary-least-squares (OLS) regressions were run for each journal with year of publication predicting either raw percentages or arcsine-transformed proportions (Table 1). Second, a series of multilevel random coefficient models (MRCMs) were run using restricted maximum likelihood (RML) estimation. RML methods provide more stable and accurate parameter estimates than weighted OLS methods (Nezlek, 2001; Raudenbush and Bryk, 2002). Detailed examples of the MRCMs used in the present study are discussed below.

Simple Ordinary-Least-Square Regressions

Table 1 shows the results for a series of simple, within-journal regression analyses of publication year predicting either the raw percentages (left columns) or arcsine-transformed proportions (right columns) of articles that mention evolution. Three journals (viz., *Brain*, *Brain and Cognition*, and *NeuroReport*) showed significant increases over time in the percentage of articles mentioning evolution. Also, three-fifths of the journals published in 2006 contained 1% or more articles referring to evolution in one form or other. The results for arcsine-transformed proportions were similar, with two additional journals (viz., *Cognitive Brain Research* and *European Journal of Neuroscience*) showing marginally significant ($ps < .10$) increases in proportion of articles mentioning evolution over time. Notably, in none of these analyses did mentions of evolution significantly (over even marginally) decrease over time.

Multilevel Random Coefficient Models

The present data structure was inherently hierarchical, with time (years) nested within journals. To this end, a two-level longitudinal growth model was employed (cf. Raudenbush and Bryk, 2002; Singer and Willett, 2003) using the HLM 6 program (Raudenbush, Bryk, Cheong, and Congdon, 2004). In multilevel modeling terms, within-journal (temporal) variance was modeled at level 1, and between-journal variance was modeled at level 2. The level-1 model was:

$$\sin^{-1}(\text{proportion}^{1/2})_{ij} = \pi_{0j} + \pi_{1j}(\text{Year} - 1996.5)_j + e_{ij}.$$

In this model, arcsine-transformed proportions of articles mentioning evolution are modeled as a function of publication year (mean-centered at 1996.5). The intercept, π_{0j} , represents the predicted mean proportion at time t (i.e., the midpoint of 1996) within journal j . The raw, unstandardized slope, π_{1j} , represents the simple change-over-time (publication year) in proportions across t times within journal j . The random error term, e_{ij} , represents the residual within-journal variance.

Table 1. Simple, ordinary-least-squares regression results: Change over time in the raw percentages and arcsine-transformed proportions of neuroscience articles that mention evolution.

Journal	No. yrs.	Raw percentages			Arcsine proportions		
		2006 mean	Slope	<i>t</i>	2006 mean	Slope	<i>t</i>
<i>Behavioral Neuroscience</i>	20	0.76	0.015	0.52	0.08	0.0026	1.20
<i>Brain</i>	13	3.74	0.316	2.80*	0.20	0.0158	2.95*
<i>Brain and Cognition</i>	20	1.85	0.092	2.38*	0.13	0.0062	2.44*
<i>Cognitive Brain Research</i>	14	0.94	0.061	1.47	0.09	0.0067	2.01†
<i>Cognitive Neuropsychology</i>	20	1.03	-0.012	-0.15	0.06	0.0005	0.13
<i>European J. of Neuroscience</i>	7	1.38	0.195	1.73	0.13	0.0178	2.21†
<i>International J. of Neuroscience</i>	17	1.60	0.043	0.48	0.09	0.0015	0.34
<i>J. of Cognitive Neuroscience</i>	18	0.92	-0.132	-1.55	0.10	-0.0024	-0.60
<i>Nature Neuroscience</i>	9	1.27	-0.089	-0.61	0.10	-0.0031	-0.34
<i>NeuroReport</i>	17	0.95	0.065	3.03*	0.10	0.0067	3.71*

Note. Arcsine proportions = $\sin^{-1}(\text{proportion}^{1/2})$. No. yrs. = Number of years with available data (1987-2006). 2006 mean = predicted mean for 2006. *J.* = *Journal*.

†*p* < .10. **p* < .05.

The level-1 intercepts (means) and slopes were then modeled at level 2 as a function of their means:

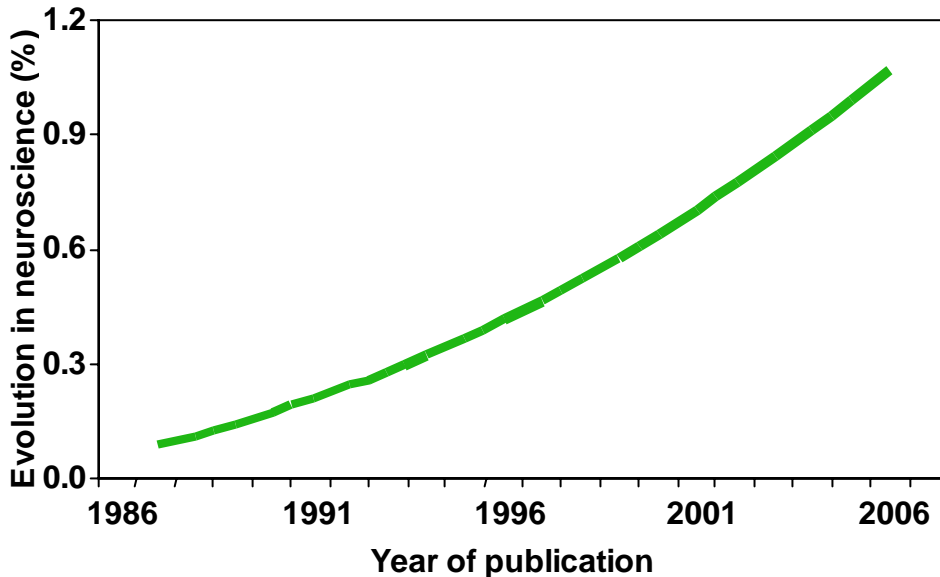
$$\begin{aligned}\pi_{0j} &= \beta_{00} + r_{0j}, \\ \pi_{1j} &= \beta_{10} + r_{1j}.\end{aligned}$$

In this model, both the within-journal intercepts (π_{0j} s) and slopes (π_{1j} s) are modeled as functions of their respective intercepts (β_{00} , β_{10}). For example, the unstandardized coefficients of interest here are β_{00} and β_{10} . First, β_{00} describes the extent to which the arcsine-transformed proportion for the average journal is different from zero at the midpoint of the year distribution (i.e., 1996.5). The effect of β_{00} can be tested at different years simply by re-centering the year variable. For example, testing whether the arcsine-transformed proportion for the average journal is different from zero during the 2006

publication year simply involves re-centering the year variable by subtracting 2006 from each value and re-evaluating the model. Second, β_{10} describes the extent to which the within-journal change-over-time slopes in proportions are different from zero for the average journal (i.e., “Has the proportion of articles mentioning evolution increased over time for the average neuroscience journal?”). The error terms, r_{0j} and r_{1j} , represent the between-journal residual variances for their respective intercepts (π_{0j} s) and slopes (π_{1j} s).

The multilevel model described above revealed that both the intercept ($\beta_{00} = 0.067$, $t_9 = 7.04$, $p < .001$) and the change-over-time slope ($\beta_{10} = 0.0039$, $t_9 = 2.60$, $p < .03$, $r = .65$) were significantly different from zero (Figure 1). Simple effects tests revealed that the average proportion of neuroscience articles mentioning evolution was (a) not significantly different from zero in 1987 ($\beta_{00} = 0.030$, $t_9 = 1.39$, $p = .20$), (b) was significantly different from zero by 1990 ($\beta_{00} = 0.042$, $t_9 = 2.40$, $p < .05$) and every year thereafter, and (c) was substantially different from zero for the most recent data in 2006 ($\beta_{00} = 0.10$, $t_9 = 9.46$, $p < .001$). In addition, the change-over-time slopes were fairly consistent across journals: A random effects test indicated there was a non-significant amount of variance in the journals’ change-over-time slopes ($\chi^2_9 = 14.38$, $p = .11$).

Figure 1. Predicted mean percent of neuroscience articles mentioning evolution.



To test whether differences in journals’ impact factors moderated the change-over-time slopes, the level-1 intercepts (means) and slopes were modeled at level 2 as a function of their means and their between-journal differences in mean-centered impact factor:

$$\pi_{0j} = \beta_{00} + \beta_{01}(\text{Journal impact factor}) + r_{0j},$$

$$\pi_{1j} = \beta_{10} + \beta_{11}(\text{Journal impact factor}) + r_{1j}.$$

In this model, both the within-journal intercepts (π_{0j} s) and slopes (π_{1j} s) are modeled as functions of their respective intercepts (β_{00} , β_{10}) and between-journal differences in impact factor (β_{01} and β_{11} , respectively). For example, the unstandardized coefficients of interest here are β_{01} and β_{11} . First, β_{10} describes the extent to which the arcsine-transformed

proportions for the average journal at the midpoint of the year distribution (i.e., 1996.5) are moderated by between-journal differences in impact factor. Second, β_{11} describes the extent to which within-journal change-over-time slopes in proportions are moderated by between-journal differences in impact factor (i.e., “Do journals of different impact have different change-over-time slopes?”). The error terms, r_{0j} and r_{1j} , represent the between-journal residual variances for their respective intercepts (π_{0j} s) and slopes (π_{1j} s).

When impact factor was added as a between-journal predictor (as shown in the model above), it moderated neither the within-journal intercepts ($\beta_{01} = 0.0038$, $t_8 = 1.06$, $p = .32$) nor the change-over-time slopes ($\beta_{11} = -0.00014$, $t_8 = -0.22$, $p = .83$). Thus, growth in mentions of evolution in neuroscience articles over time was fairly constant across journals, at least insofar as differences in their impact factors were concerned.

Discussion

The simple, OLS, within-journal regressions suggested that at least half of the ten neuroscience journals sampled experienced at least marginally significant growth in mentions of evolution over time ($ps < .10$), but only three showed significant growth ($ps < .05$). More importantly, the MRCMs revealed that mentions of evolution in the average neuroscience journal had been significantly different from zero from 1990 onward and had grown significantly over time between 1987 and 2006. Further, this growth was fairly uniform across journals, and was not differentiated by journal impact factor. Thus, unlike previous studies in which impact factors moderated temporal publication trends in article length in psychology journals (Webster, 2007a), the present study showed no appreciable moderating effect of impact factors on the change-over-time slopes: Evolution’s influence on neuroscience appears to be growing equally among both high- and low-impact journals.

Study 2

Method

Sample

Four of the ten neuroscience journals surveyed in Study 1 that specialize in human cognitive neuroscience were selected for Study 2 (Table 2). This sub-sample of journals remained fairly diverse, with 2005 impact factors ranging from 1.84 to 4.53 with a median of 2.74 ($M = 2.96$, $SD = 1.15$).

Procedure

As in Study 1, PsycINFO keyword searches were performed for evolution using the term “evol*” for articles published in each of the four journals from 1987 to 2006. In addition, other keyword searches were performed for four other areas of human science: anthropology (“anthropolog*”), economics (“econom*”), psychology (“psycholog*”), and sociology (“sociolog*”). As in Study 1, arcsine-transformed proportions were calculated.

Results

As in Study 1, a series of MRCMs were run using RML estimation. In contrast to Study 1, a three-level model was required that accounted for the dependency of years (level 1) nested within journals (level 2) nested within topic areas (level 3). The level-1 model,

$$\sin^{-1}(\text{proportion}^{1/2})_{tja} = \pi_{0jt} + \pi_{1ja}(\text{Year} - 1996.5)_{ja} + e_{tja},$$

was essentially the same as in Study 1, with the exception of an additional subscript, *a*, which represents the area of interest (e.g., evolution, psychology, etc.). The level-2 model,

$$\begin{aligned} \pi_{0ja} &= \beta_{00a} + r_{0ja}, \\ \pi_{1ja} &= \beta_{10a} + r_{1ja}, \end{aligned}$$

was also similar to Study 1, but with the additional subscript, *a*. The level-3 model,

$$\begin{aligned} \beta_{00a} &= \gamma_{000} + \gamma_{001}(\text{Evolution})_a + u_{00a}, \\ \beta_{10a} &= \gamma_{100} + \gamma_{101}(\text{Evolution})_a + u_{10a}, \end{aligned}$$

took the journal-level coefficients and modeled them as a function of different topic areas. In this model, the coefficient γ_{100} is of primary interest; it represents the simple change-over-time slope for articles that mention evolution averaged across the four cognitive neuroscience journals. Simple slopes for the other four topic areas were estimated in a similar manner by replacing $\gamma_{101}(\text{Evolution})_a$ with the area of interest, such as $\gamma_{101}(\text{Psychology})_a$. Each of these dummy-coded variables was created such that the area of interest was coded as 0 and the other four areas were coded as 1. As in Study 1, testing whether the arcsine-transformed proportion for a given area was different from zero in 2006 was done by re-centering the publication year variable by subtracting 2006 from each value and re-evaluating the model. The level-3 error terms, u_{00a} , and u_{10a} , represent the between-area residual variances for their respective intercepts (β_{00a} s) and slopes (β_{10a} s). As a final illustration, this three-level model is analogous to examining 20 change-over-time slopes (4 cognitive neuroscience journals x 5 topic areas), where sets of four journal slopes are averaged (“braided together,” i.e., “ropes of slopes”) within each of their five respective topic areas, yielding five “grand,” area-level slopes for comparison (Figure 2).

An initial, random effects test indicated there was a significant amount of variance among the five topic areas’ change-over-time slopes ($\chi^2_4 = 9.73, p = .04$), which suggested that examining differences in simple slopes could be informative. The 2006 estimated means and simple change-over-time slopes from the multilevel model described above are shown in Table 2. For the 2006 estimated means, only mentions of psychology differed significantly from zero ($t_3 = 4.50, p < .03$). Psychology was also the only area to show a trend of increased penetration over time, albeit not a significant one ($p < .07$). The simple change-over-time slopes are shown as raw percentages (back-transformed from the arcsine metric) in Figure 2. The top panel shows all five topic areas, whereas the bottom panel shows a magnified version of the top panel to highlight differences among anthropology, economics, and sociology.

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The significance tests shown in Table 2, however, were based on only 3 degrees of freedom because the sample consisted of only five topic areas; thus, effect sizes might be more informative. Change-over-time effect sizes for psychology ($r = .88$) and evolution ($r = .49$) indicated that both were large in magnitude. Evolution's penetration into four cognitive neuroscience journals ($r = .49$) was comparable to the effect size obtained across ten neuroscience journals from Study 1 ($r = .65$). In contrast, change-over-time effect sizes were comparatively small for anthropology ($r = -.04$), economics ($r = .14$), and sociology ($r = .00$). Note that sociology was mentioned in none of the articles surveyed in this study, which explains its slope of zero.

Table 2. Change over time in arcsine-transformed proportions of cognitive neuroscience articles from four journals that mention one of five topic areas.

Area	Predicted 2006 mean	Slope	t_3
Anthropology	0.00021	-0.00017	-0.07
Economics	0.01411	0.00058	0.25
Evolution	0.09335	0.00231	0.98
Psychology	0.16001	0.00524	3.18†
Sociology	0.00000	0.00000	0.00

† $p < .07$.

Discussion

Recall that the two main questions for Study 2 were (a) whether the proportion of articles that mention evolution in journals that specialize in human cognitive neuroscience was different from zero by 2006 and (b) how the growth in evolution's penetration into cognitive neuroscience compared to that of other human sciences. Results indicated that, although mentions of evolution were indistinguishable from zero in cognitive neuroscience journals in 2006, the change over time in mentions of evolution was more positive than that of other disciplines such as anthropology, economics, and sociology, but evolution still lagged far behind the growth of psychology. In fact, according to the model, the proportion of mentions of evolution increased by more than 2.5 times between 1987 and 2006. In sum, Study 2 offers a mixed bag of findings: Evolution's influence is cognitive neuroscience continues to be small; however, it is growing at a respectable rate that outstrips at least three other relevant human sciences.

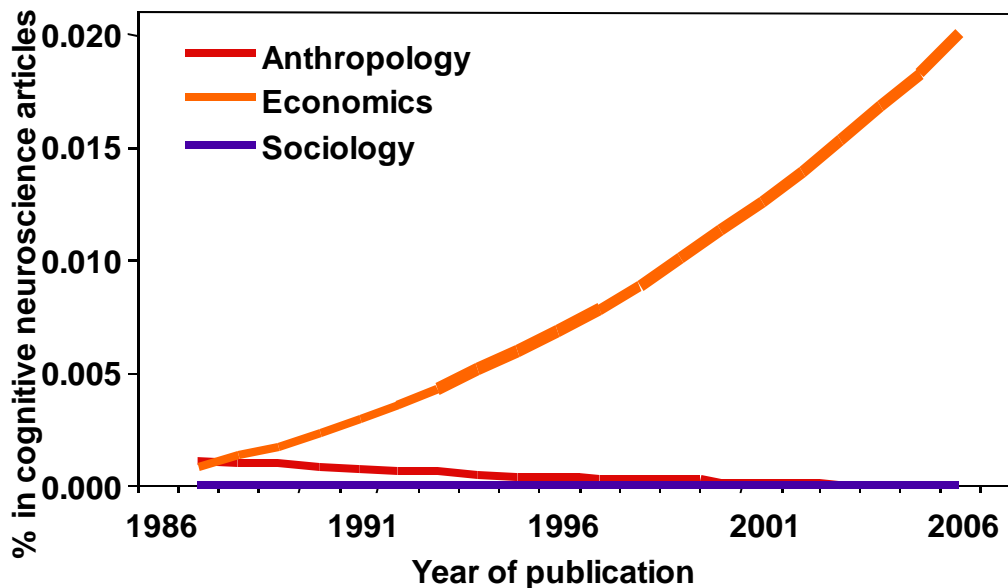
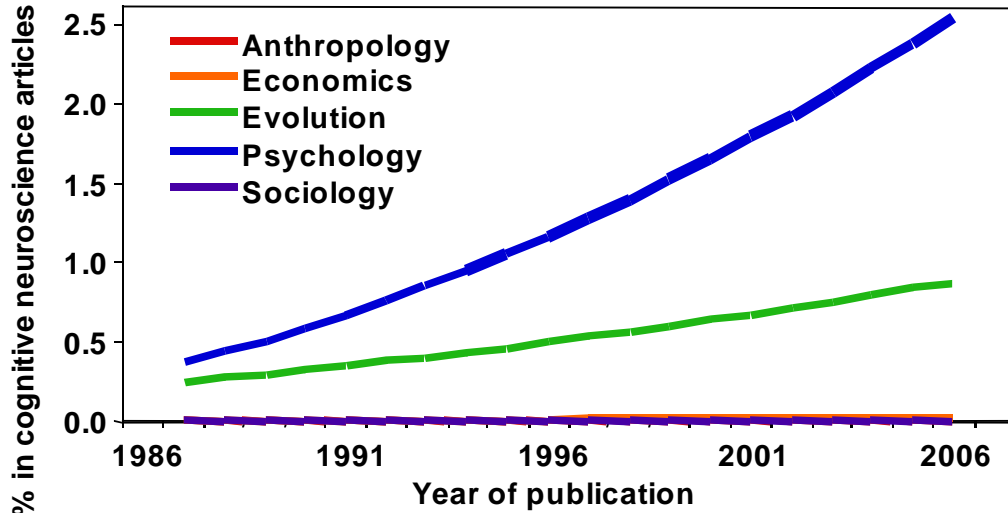
Conclusion

In concert, these quantitative findings imply that the outlook for evolutionary psychology's influence on neuroscience in general, and cognitive neuroscience in particular, is generally positive. Although mentions of evolution permeated only about 1% of neuroscience and cognitive neuroscience articles in 2006, its growth over time is certainly encouraging. Perhaps even more encouraging is the fact that mentions of evolution are growing faster than mentions of other human sciences such as anthropology,

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economics, and sociology, although mentions of psychology still outpace all of these areas. Given these promising trends, the emergence of evolutionary cognitive neuroscience as a viable interdisciplinary field is becoming less of a possibility and more of an inevitability.

Figure 2. Predicted mean percent of mentions by area in cognitive neuroscience articles. Top panel shows all five areas; bottom panel shows magnified version of top panel to highlight differences among three areas.



How does evolution's penetration into neuroscience and cognitive neuroscience compare to its penetration into other disciplines of psychological science such as social psychology? One way is to compare the change-over-time slopes and effect sizes for evolution among neuroscience (slope = 0.0039, $r = .65$), cognitive neuroscience (slope = 0.0023, $r = .49$), and social psychology journals (slope = 0.0019; $r = .47$; i.e., *Journal of Personality and Social Psychology*, 1985-2004; cf. Webster, 2007b). This comparison suggests that evolution's penetration into evolutionary cognitive neuroscience has increased at a rate that is roughly equivalent to its penetration into personality and social psychology over the last two decades; however, its penetration into neuroscience in general appears to have happened at an even faster rate.

Despite these interesting trends, the present research is not without its limitations. Chief among these are the fact that keyword searches are an imperfect measure of the extent to which a given topic such as evolution truly influences a given journal article. Not only are such keyword searches indiscriminant with regard to where the keyword occurs (e.g., title, abstract, keyword listing), but also with regard to the frequency with which the keyword occurs throughout the article. Thus, an article that mentioned evolution at least once was given the same weight as an article that may have mentioned evolution several times. The potential measurement limitation of the keyword search method, however, was partially mitigated by the fact that it allowed for an uncommonly large sample of articles to be surveyed efficiently (i.e., 18,051 in Study 1 and 4,859 in Study 2). Although the present findings suggest that evolution is having an increasing influence on cognitive neuroscience, assessing the exact depth of that influence will require more detailed analyses in the future.

The present findings add to a growing literature that suggests that evolutionary psychology is gaining in stature and influence. In addition to making inroads into social psychology and cognitive neuroscience, evolutionary psychology is also becoming a more empirical science, as evidenced by a recent survey of publication trends over the first 25 years of its flagship journal, *Evolution and Human Behavior* (Webster, 2007c). With its increased empirical focus, evolutionary psychology stands to gain further acceptance, both as a viable sub-discipline in psychology and neuroscience, and as an interdisciplinary field that helps foster and promote evolutionary perspectives in several sciences. It is hoped that the present study will not only inform readers on the current state of evolution's influence in neuroscience and cognitive neuroscience, but also inspire readers to pursue research in the emerging field of evolutionary cognitive neuroscience.

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