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## **Trends in the Field of Mammalian Social Behavior and Health Over the Last 20 Years**

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In any scientific field there are thematic changes over time as new technologies and methods of investigation are developed and accumulated knowledge drives new research directions. The current study examines how themes in the investigation of social behavior and health have changed over the last 20 years. Literature searches were performed to identify articles published between 1993-2012 that investigate the intersection between social behavior and health in mammals. Results identify the top journals that publish articles in this field and describe trends in how sub-divisions in social behavior (e.g., aggression or dominance) and health (e.g., immunity or brain chemicals) have changed over the last 20 years. Our results suggest a dramatic increase in publications on the intersection between social behavior and health over this time span. Major categories of study include relationships between general social behavior or social stress and health outcomes relating to stress responses, endocrinology, and the brain.

The study of the relationship between social behavior and health is diverse and spans many fields and disciplines. Research in this area has ranged from understanding the effects of hormone replacement therapy and social stress on body fat distribution in cynomolgous macaques (Wallace, Shively, & Clarkson, 1999) to the interaction of the social environment and genetics on the risk for autism and schizophrenia in mice (Laviola, Ognibene, Romano, Adriani, & Keller, 2009) to the influence of social network role and structure on deleterious social aggression and trauma (Beisner, Jackson, Cameron, & McCowan, 2011; McCowan et al., 2011). In addition, the development of new technologies and new statistical and research methods has allowed long-studied fields to be examined in new ways. For example, modern genetic techniques have led to the discovery that early social experiences can result in epigenetic changes that have long lasting impacts on behavior and physiology (Szyf, McGowan, & Meaney, 2008).

The publishing environment has also changed over the last 20 years. One major change has been the growing popularity of online and open-access journals which began publishing in the 1980s (Suber, 2013a). The move toward open-access publishing was slow, in part due to concern over the impact work would have if published in this new venue. However, open access journals gained more traction in the late 1990s and became an increasingly common and trusted publication format in the 2000s (Eysenbach, 2006; Suber, 2013a). For example, the Public Library of Science (PLoS) began publishing in the 2000s, with PLoS Biology established in 2003, PLoS Medicine established in 2004, and PLoS ONE established in 2006 (Suber, 2013a). Following this trend, many traditional journals now offer some open access content in addition to subscription or fee-for-access content, but the market share and impact of journals with all content open access remains competitive with traditional journals (Eysenbach, 2006; Suber, 2013b).

In this review we examine historical trends in the publication of behavioral and health studies in order to uncover valuable information regarding areas of research that are of increasing importance, as well as identify areas of decreasing importance to the field. We also hope that understanding journal publication

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trends in social behavior and health may help researchers to identify journals where their work may be published to reach their target audience. To our knowledge, a review of publication trends of this scope has never been done for the area of social behavior and health. To better understand investigative trends in this diverse field of research, we present a descriptive analysis of how publications in the field of social behavior and health have changed over the last 20 years and the journals where this work is most commonly published.

## Method

### Search Engines and Keywords

We conducted literature searches in three of the most commonly used search engines in the social and behavioral sciences: Web of Science, PubMed, and PsychINFO to collect research and review articles. These search engines were chosen due to the large number and composition of journals that are searchable (>12,000, 5,080, 2,543 respectively), the required filters that allow for targeted searching (e.g., year, keyword, or species), the ability to export a large number of references at a time, options to select additional fields for export, and other database tools. Although Google Scholar was another potential search engine with a high volume of articles indexed and wide use among academics, we did not use it for several important reasons. Many non-academic sources were found in Google Scholar results, Google Scholar does not have options to filter article and journal types, and it has no mechanism for uploading multiple records at a time into reference manager software. Therefore, Google Scholar was not appropriate for the large-scale literature search conducted for this review. Search results were imported into Endnote reference managing software and duplicate records were removed after consolidating non-matching keywords.

To obtain a representative sample of the articles published on social behavior and health interactions in nonhuman mammals in the past 20 years (1993 – 2012), we developed a list of keywords for each of the three components of this topic: social behavior, health, and taxonomic group of nonhuman mammals. Because the Class Mammalia is quite large and encompasses approximately 20 different Orders, we focused on four Orders of mammals that appear most commonly in the behavioral research literature: Artiodactyla, Carnivora, Primates, and Rodentia. Initial searches using the taxonomic Order as the search term yielded very little, and so the scientific and common names of genera or species within the Order were also used as search terms (see Table 1).

Table 1  
*Topics and search terms used*

Topic	Search Terms
Social behavior	affiliation, aggression, behavior, dominance, rank, social
Health	disease, health, immunity, injury, stress, trauma, welfare, well-being
Artiodactyla	antelope, artiodactyl, bovid, camel, cattle, deer, giraffe, pig, ungulate
Carnivora	bear, carnivore, canis, civet, dog, feline, hyena, raccoon, seal, skunk, walrus, weasel,
Primate	anthropoid, ape, ateline, baboon, bonobo, bushbaby, cebus, cercopithecus, chimp, colobus, gorilla, lemur, loris, macaque, marmoset, monkey, primate, tarsier
Rodentia	agouti, beaver, capybara, chipmunk, gerbil, gopher, hamster, mice, porcupine, rat, rodent, squirrel, vole

We performed a total of 123 searches using combinations of the search terms listed above, between August and September 2013. These searches yielded a total of 9,034 unique records on health and social behavior in nonhuman mammals. However, it is worth noting that that our searches initially yielded an additional ~5,000 records on either non-mammals or human subjects (despite selecting “animal,” “NOT humans,” or “nonhuman animals” during searches). Culling human and non-mammal research records from the Endnote database was accomplished by searching for terms that were more likely to be associated with non-mammals or humans, such as songbird, laying hen, reptile, American, childhood, economic, ethnic, religion, and women, and deleting those that involved only non-mammals or human subjects. Some abstracts, news articles, and book chapters were also found and deleted.

### Categorizing Keywords

In order to categorize these 9,034 records into broad subcategories of research within the field of behavior and health, we first identified all permutations of keywords that referred to the same category. For example, the terms dominance, hierarchy, social rank, and subordinate all refer to the category of Dominance. We re-coded all such permutations of keywords into a single category. Categories were not exclusive and some terms occur in the coding for more than one category and records may fit into multiple categories.

Re-coding was performed by exporting all 37,000 keywords, keyword phrases, and titles into SPSS (version 21.0.0.2, IBM Corp., 2012) to create new category variables indicating whether that paper covered a topic in the social or health categories of interest. The article title and keywords were combined into one variable because authors often use important keywords in the title that do not appear in the actual keyword list due to journal restrictions on keyword lists. For example, the SPSS syntax would search the keyword

field for the presence or absence of any permutations of the topic Dominance (such as dominance, hierarchy, social rank, or subordinate) and then create a new variable called “Dominance” with entries of “1” indicating presence of a dominance-related term in the keywords field, and entries of “0” indicating absence of a dominance-related term. This process was repeated for several possible categories and those comprising less than 5% of records across most years were combined with other larger categories. This process resulted in a final 22 categories in either a social or health topic (presented in the results section). Out of the 9,034 records, 5,516 have at least one category in each of the social and health topics. All subsequent summaries are limited to these 5,516 records. These 5,516 records contained a total of 34,101 category designations. All 5,516 records were used in the analysis of trends in subfields of behavior and health over time.

## Journals

The filtered 5,516 records are derived from 825 journals total; however, the overwhelming majority of these journals contribute less than 3% of the total records per year across most years. There are a total of 12 journals (presented in the results section) that contribute at least 3% of journals in at least two of the 20 years’ worth of records. These 12 journals produced 2,026 of the 5,516 records.

## Statistical Analyses

To determine whether changes in the percentage of representation of each journal and keyword category were significant, we conducted linear regression models on the percentage per year for the top 12 journals and for the 20 keyword categories using year as the predictor ( $N = 20$  years for each linear model). All models were run in the statistical programming environment R (version 2.15.3; R Core Team, 2013), and model coefficients, representing percent change per year, are reported below. Significance level was set to  $p = 0.05$ . All graphs, except the network graph, were produced in SPSS (version 21.0.0.2; IBM Corp., 2012).

To further examine publication patterns regarding the co-occurrence of keyword categories in our data set, we constructed a network graph in which links between keyword categories were drawn if the two topics were treated in the same publication. An edge list of paired keyword categories was constructed and graphed in UCINET (version 6.461; Borgatti, Everett, & Freeman, 2002). We also calculated weighted node degree, the sum of each category’s connections to other categories in the network, and dichotomized node degree, the total number of unique connections, to better quantify co-occurrence patterns of social behavior and health topics in our data set.

## Results and Discussion

Overall the field of social behavior and health has grown dramatically from 1993 to 2012. Our search yielded a total of 98 articles published in 1993 but that number grew to 564 in 2012, representing a 576% increase in the number of articles published per year. Over these 20 years and among the 12 journals publishing the majority of articles, the largest percentage of articles were published in the journal *Physiology and Behavior* (20.0%), followed by *Applied Animal Behaviour Science* (14.4%), *Behavioural Brain Research* (13.8%), and *Hormones and Behavior* (10.2%), with far fewer in the eight remaining journals (range 2.5-6.9%; see Table 2 and Figure 1). These top journals, with the exception of *Applied Animal Behaviour Science*, have an explicit stated focus on publishing studies on the intersection of biology and physiology and behavior (see Table 3 for journal descriptions).

Analysis of trends in these journals over the past 20 years indicate a decreasing representation in *Physiology and Behavior* (11.1% in 2012), with an increasing representation in *Behavioural Brain Research* (17.4% in 2012), *Hormones and Behavior* (12.1% in 2012), and *PLoS ONE* (10.6% in 2012; see Table 2 and Figure 1). The recent explosion of behavior and health research published in *PLoS ONE* as well as a sustained increase of research published in *Behavioural Brain Research* and *Hormones and Behavior* coincides with a decrease in the number of such publications in *Physiology and Behavior*, indicating a significant change in where authors are looking to publish these works. Most shifts over-time in percent of publications occurring in these journals are likely attributable to either a changing focus of research topics or a change in what authors want from the editorial style and management of the journals publishing their work. *PLoS ONE*, however, is unique among these journals as it is a nascent journal first appearing in 2006 as part of a new era of open-access publishing. All content in *PLoS ONE* is open-access and authors fund the costs of publication.

Table 2

The 12 most common journals publishing research on both social and health topics

Journal	Average Yearly Frequency	Average Yearly Percent	Percent change per year (model coefficient)
American Journal of Primatology	4.3	4.9%	-0.11*
Animal Welfare	5.5	6.6%	-0.11*
Applied Animal Behaviour Science	14.6	14.5%	-0.03
Behavioural Brain Research	14.0	11.2%	0.30**
Brain Research	6.4	6.8%	-0.09**
Hormones and Behavior	10.4	8.3%	0.22**
Neuroscience	5.4	4.7%	0.09*
Pharmacology Biochemistry and Behavior	5.5	6.3%	-0.13
Physiology and Behavior	20.3	22.4%	-0.38**
PLoS ONE	2.6	1.3%	0.12**
Psychoneuroendocrinology	5.7	6.0%	-0.09
Psychopharmacology	7.0	7.0%	-0.01

\* $p < 0.05$ . \*\* $p < 0.01$ .

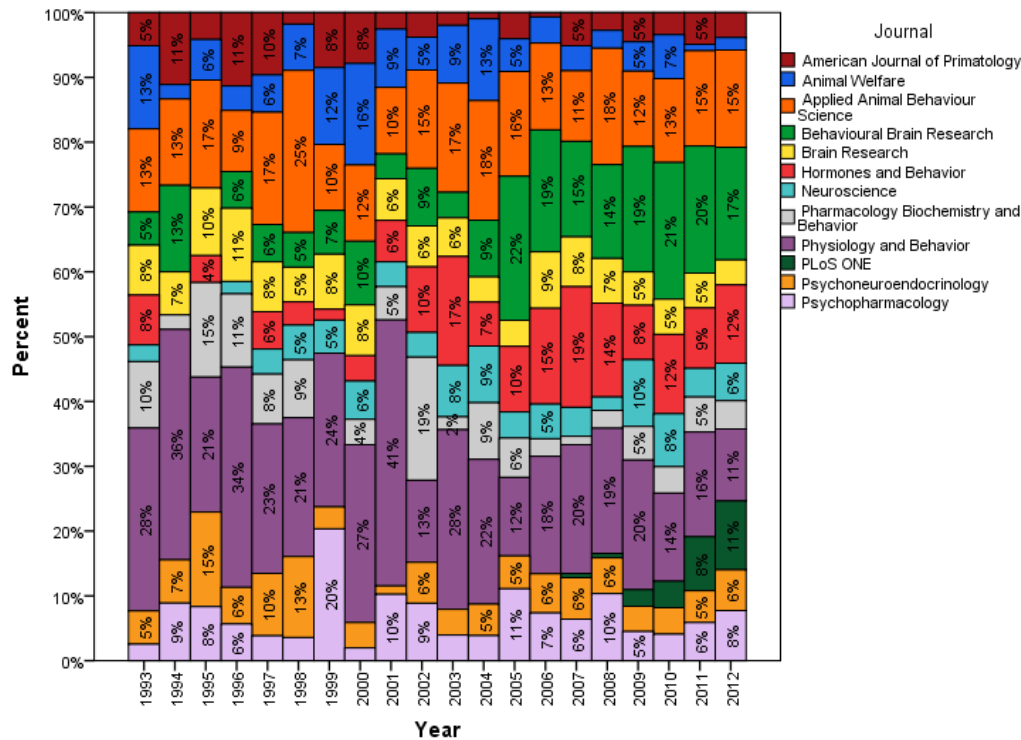


Figure 1. Percent of articles with both social and health topics published by journal and year (percentage markers omitted for values < 5%).

Additionally, it is uniquely broad in scope of both topics and type of work published, with articles reviewed primarily to discern rigorous methodology and it is left to the readership to discern the importance of the findings published in any one article. The large increase in articles published in PLoS ONE could be

associated with a decrease in publications to any or all of the other 11 journals due to the broad scope of PLoS ONE.

Table 3  
Journal descriptions and impact factor for top 12 journals

Journal	Type of Articles and Research Published	2012 Impact Factor	2012 5-year impact factor
<i>American Journal of Primatology</i>	Basic, applied, field, captive, and lab research articles on all aspects of primate behavior and biology	2.459	2.419
<i>Animal Welfare</i>	Research articles, invited essays, technical reports, reviews, short communications on captive animals or wild animals impacted by human activities	1.433	1.668
<i>Applied Animal Behaviour Science</i>	Research articles, review articles, letters, book reviews on the application of the study of behavior to human management of animals	1.497	2.059
<i>Behavioural Brain Research</i>	Research, methods (novel or major advances), or critical review articles on the neural mechanisms of behavior	3.327	3.674
<i>Brain Research</i>	Research and invited review articles in brain science by section. Sections: cell biology, signaling and synaptic transmission; development, degeneration and regeneration, and aging; systems neuroscience and behavior; cognition and computation; neurobiology of disease	2.879	2.892
<i>Hormones and Behavior</i>	Research and review articles on hormone-brain-behavior research in invertebrates and vertebrates, including humans	3.735	4.006
<i>Neuroscience</i>	Research articles on the nervous system reporting "significant, new and carefully confirmed findings with full experimental details."	3.122	3.389
<i>Pharmacology Biochemistry and Behavior</i>	Clinical, preclinical, or basic research and review articles in studies of pharmacology and biochemistry within the primary context of behavior.	2.608	2.848
<i>Physiology and Behavior</i>	Research articles on studies of physiology within the primary context of behavior	3.160	3.339
<i>PLoS ONE</i>	Research articles from all science and medicine disciplines that are determined through peer review to be methodologically rigorous without judgment on the importance or impact of the topic and results	3.730	4.244
<i>Psychoneuroendocrinology</i>	Basic and applied research, review, commentary, short communication, and book review articles with a multidisciplinary approach to studying psychology, neurobiology, endocrinology, immunology, neurology, and psychiatry.	5.137	5.926
<i>Psychopharmacology</i>	Research, review, methods (in consultation with editor), and commentary articles on the effect of neurochemical mechanisms on behavior in both humans and other animals.	4.016	4.285

Note. Descriptions obtained from journal websites December 2013. Impact factor information obtained from Thompson Reuters (2013).

### Trends in Social Behavior

The most frequently used keywords relating to social behavior were mainly non-specific, including the terms social and instinctive behavior, social behavior, and social environment. The use of these generic social behavior keywords instead of specific social behavior keywords by thousands of papers limited the number of

records we could further explore. Thus, despite our best efforts to categorize social behavior, the category of Other Social remains quite high (46.2%; Table 4 and Figure 2a). This general Other Social behavior category was used by a growing number of studies (Figure 2a). Social Stress was by far the most commonly studied topic across the 20 year span with an average of 59.7% of articles citing this category. Although Social Stress was a commonly cited keyword category, the proportion of articles per year investigating this topic has decreased from 63.3% of all articles in 1993 to 53.0% of all articles in 2012 (Figure 2a). Also showing a declining proportion of articles per year were the categories of Dominance (16.3% to 9.0%), Groups and Herds (16.3% to 6.7%), and Aggression (21.4% to 12.4%; Figure 2b). These decreases in publication rates in Dominance, Groups and Herds, and Aggression likely reflect general trends in social behavior research overall; an early focus on aggressive behavior, dominance hierarchies, and the evolution of group-living has given way to more individual-level measures and greater emphasis on affiliative interactions. Supporting this idea, the categories of Mating (3.1% to 6.0%) and Social Bonds and Affiliation (varies widely prior to 1997, then increases relatively steadily from 7.9% to 16.1%) show a small but increasing representation across the study period (Figure 2c). Studies of Feeding and Lactation have stayed relatively steady at approximately 9.7% of publications each year, (Figure 2c; Table 4).

Table 4  
*Mean yearly usage of social categories in research articles on behavior and health*

Category	Average Yearly Frequency	Average Yearly Percent	Percent change per year (model coefficient)
Aggression	47.8	19.1%	-0.59**
Feeding and Lactation	27.6	9.7%	0.12
Dominance	33.0	13.4%	-0.50**
Groups and Herds	22.4	9.2%	-0.37**
Mating	16.5	5.5%	0.15*
Other Social	131.4	46.2%	0.44*
Social Bonds and Affiliation	44.3	15.1%	0.31*
Social Stress	157.6	59.7%	-0.79**

\* $p < 0.05$ . \*\* $p < 0.01$ .

### Trends in Health and Disease

The health outcomes examined in relation to social behavior were greater in number and variety than the social behavior categories. While Social Stress was by far the most commonly studied category in social behavior, the brain and nervous system, physiological stress response, and the endocrine system were all commonly studied health outcomes including a yearly average of 44.2%, 42.1%, and 40.2% of articles, respectively (see Table 5 and Figure 3a). Of the 5,516 articles included in our analysis 4,065 included at least one of these topics with 2,164 records including more than one of these categories. The greatest overlap was between the Endocrinology and Stress Response categories, however, a large overlap between these categories is expected due to the fact that cortisol, a commonly studied hormone in stress research, is also part of the endocrine system. Specifically, there were 1,429 records that were included in both the Stress Response and Endocrinology categories, 40% of which were due to the shared use of “cortisol” for recoding purposes. Although studies examining the relationship between social behavior and stress response or endocrinology were a large proportion of studies published, studies of Stress Response comprise a smaller percentage of articles published each year while studies of Endocrinology have stayed relatively stable.

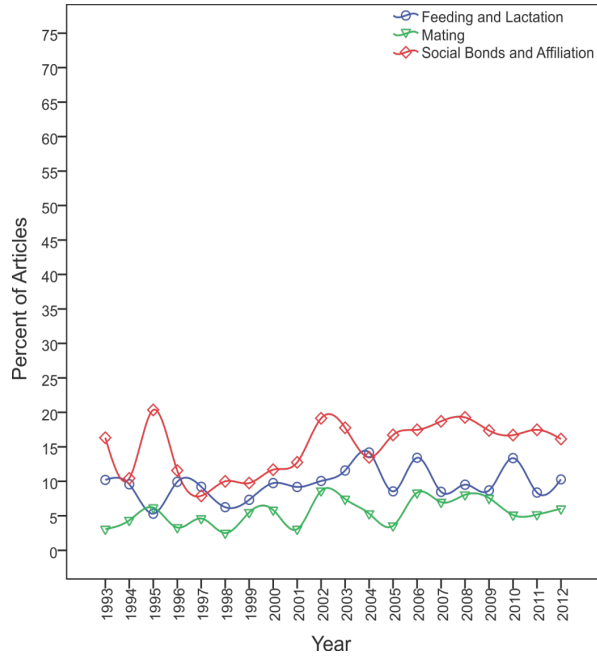
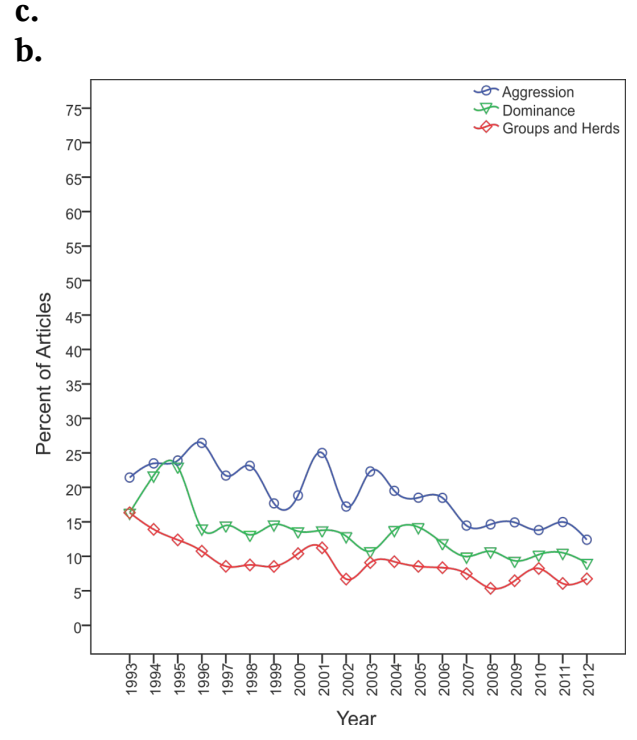
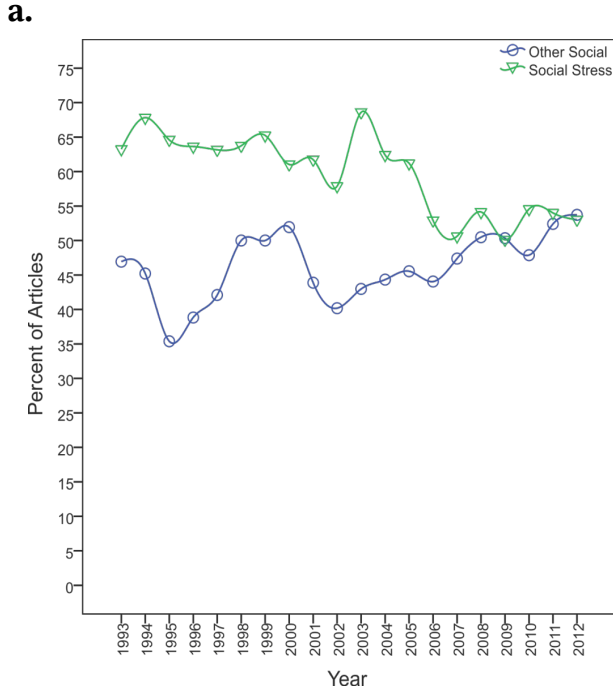


Figure 2. Percent of articles by year that have keywords in the social categories represented. **a.** Other Social or Social Stress, **b.** Aggression, Dominance, or Groups and Herds, **c.** Feeding and Lactation, Mating, or Social Bonds and Affiliation.

The field of neuroscience has been growing over the past 20 years and a number of brain imaging technologies (e.g., two-photon imaging and fMRI) have become more widely available and more commonly used. Therefore it is not surprising that our analysis indicates that topics relating to the Brain and Nervous System (e.g., brain structure or brain activity) in general as well as Brain Chemistry, and Brain Damage and



Disease (e.g., Alzheimer’s, Parkinson’s disease, stroke) all increased over the years studied, with Brain and Nervous System exhibiting the greatest increase (31.6% in 1993 and 50.4% in 2012) relative to all other health categories (Table 5 and Figure 3a). The study of social behavior in relation to mental health outcomes like Anxiety and Depression also increased from 8.2% to 17.6% and 5.1% to 14.2%, respectively, over the last 20 years (Figure 3b and Table 5). Although there are few, the number of articles investigating social behavior in relation to Physical Injury (from 1.0% in 1993 to 5.9% in 2012) and Other Health (from 0.0% in 1993 to 4.3% in 2012) outcomes also increased (Table 5 and Figure 3b). The field of animal Welfare represented, on average, 23.1% of publications and decreased somewhat between 1993 and 2012 (Table 5 and Figure 3b). Similarly, studies of Alcohol and Drug Addiction and Metabolic outcomes comprised less than 10% each of articles published each year and showed no change and a slight decrease, respectively, from 1993 to 2012 (Table 5 and Figure 3c). Finally, declining in relation to other areas of study were the study of the associations between social behavior and Immunology or Cardiac Health (Table 5 and Figure 3c).

Table 5  
*Mean yearly usage of health categories in research articles*

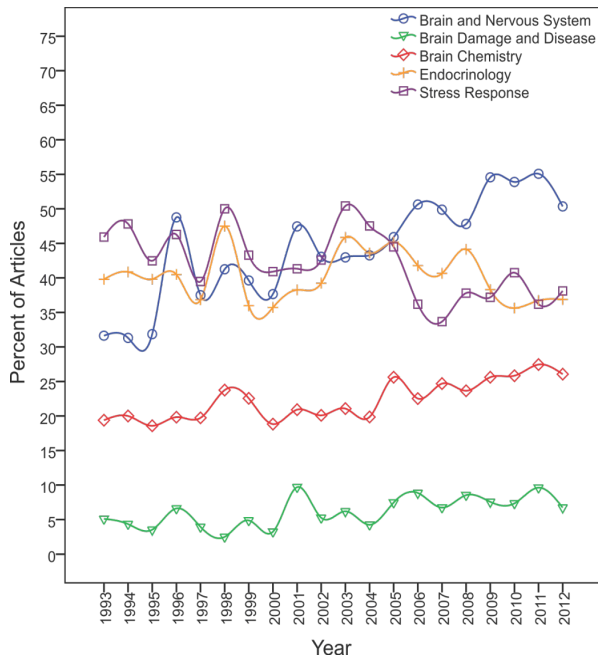
Categories	Average Yearly Frequency	Average Yearly Percent	Percent change per year (model coefficient)
Alcohol and Drug Addiction	25.2	9.1%	0.04
Anxiety	42.2	14.0%	0.45**
Brain and Nervous System	131.1	44.2%	1.1**
Brain Chemistry	65.0	22.3%	0.39**
Brain Damage and Disease	18.9	6.1%	0.24**
Cardiac Health	17.5	7.6%	-0.46**
Depression	28.8	9.1%	0.44**
Endocrinology	110.0	40.2%	-0.07
Immunology	33.1	12.7%	-0.21**
Metabolism	18.0	6.7%	-0.04**
Other Health	8.3	2.8%	0.09
Stress Response	111.5	42.1%	-0.50**
Physical Injury and Trauma	13.3	4.2%	0.20**
Welfare	61.6	23.1%	-0.23*

\* $p < 0.05$ . \*\* $p < 0.01$ .

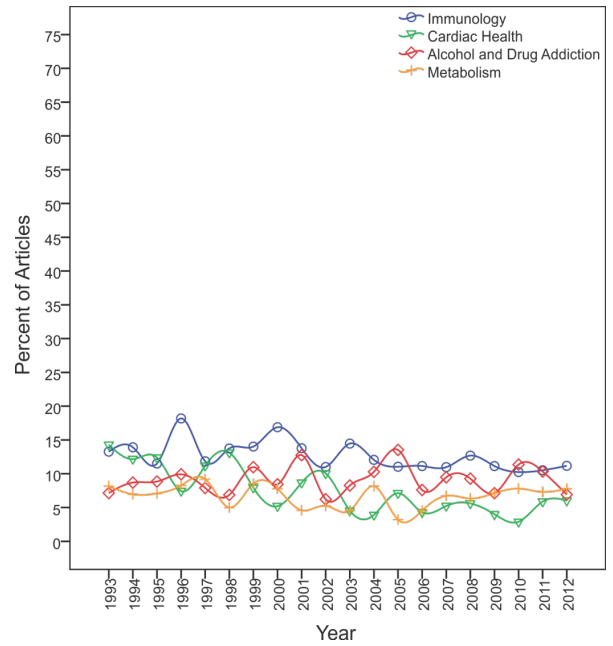
### Patterns in the Study of Social Behavior and Health

We constructed a social network of the co-occurrence of keyword categories across the 5,516 publications analyzed to gain a better understanding of which topics are published together most frequently (i.e. cluster together in the network; Figure 4). The core of this network comprised six keyword categories, 2 social behavior terms (Other Social, Social Stress) and 4 health terms (Brain & Nervous System, Brain Chemistry, Stress Response, and Endocrinology). These terms all showed connection to each other in at least 900 publications (i.e. each red link in the network represents co-occurrence in at least 900 publications). What is most interesting about the core of this network is the fact that only generalized social behavior keywords reach the level of connectedness exhibited by many of the health terms, indicating (as noted above) that most publications do not specifically define the nature of the social behavior studied in relationship to health, at least

a.



b.



c.

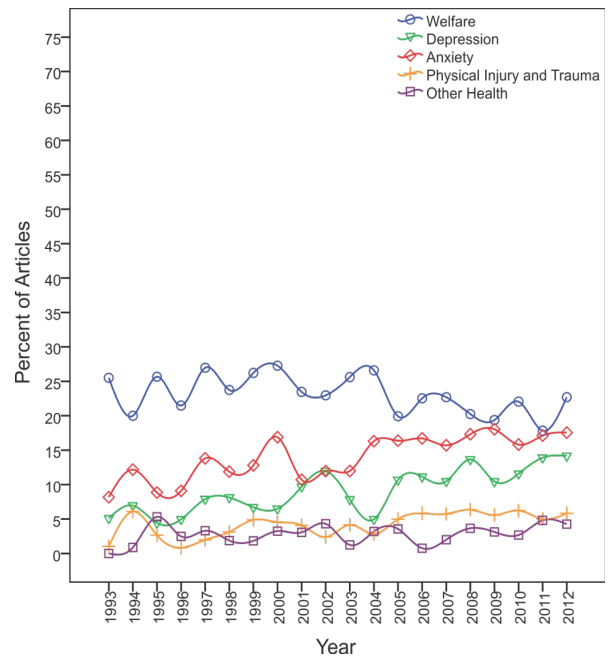


Figure 3. Percent of articles by year that have keywords in the health categories represented. **a.** Brain and Nervous System, Brain Damage and Disease, Brain Chemicals, Endocrinology, or Stress Responses, **b.** Welfare, Depression, Anxiety, Physical Injury and Trauma, or Other Health Outcomes, **c.** Immunology, Cardiac Health, Alcohol and Drug Addiction, or Metabolism.

not in their keywords or titles. The comparison between weighted and dichotomized node degree in this network (i.e. sum of all links per node vs. total unique links per node) indicate that all keyword categories in the core network other than Other Social are connected to all other categories; Other Social is connected to

only 75% of the other keyword categories. Furthermore, the category Welfare is connected to all other categories, but its frequency of connectedness does not reach the same level as those in the core of the network, indicating that the topic of welfare is studied with regard to all other topics, but not so frequently with any single topic that it is part of the network core.

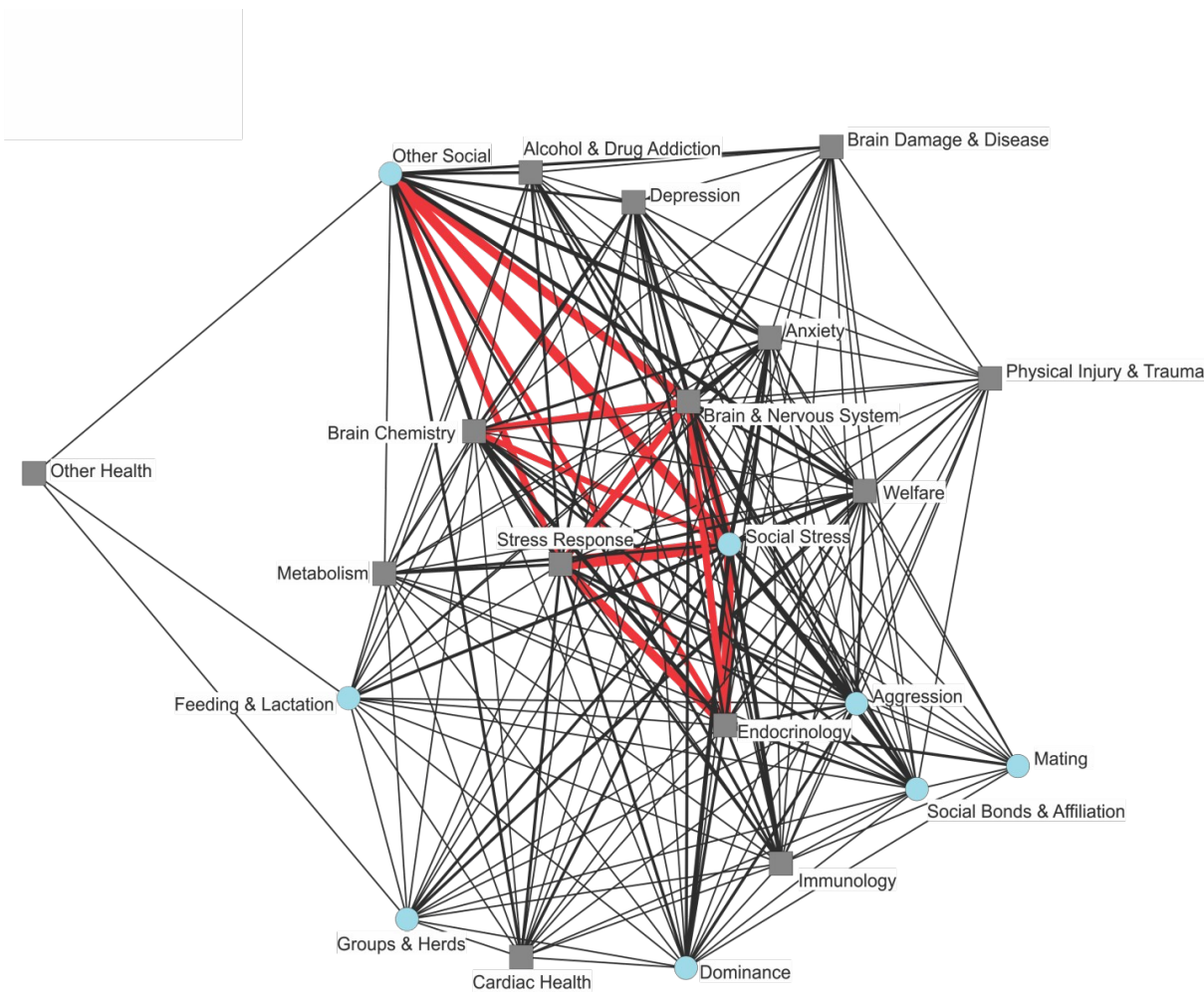


Figure 4. Weighted category network in which an edge is drawn if at least 20 articles include both categories. Thicker lines indicate more articles that use both categories. Red lines indicate category pairings that were used by 900+ articles. Blue circles represent social behavior categories. Grey squares represent health categories.

### Conclusion

In sum, the study of social behavior and health interconnections has grown substantially over the past 20 years, showing a five-fold increase in the frequency of publications on the subject. Much of this increase appears to have been facilitated by technological advances in health-related fields, thereby allowing a greater diversity of inquiry and measurement of animal health. This is evidenced by increased publication frequencies on that topics relating to the Brain and Nervous System (e.g., brain structure or brain activity) in general as well as Brain Chemistry, and Brain Disease and Damage (e.g., Alzheimer’s, Parkinson’s disease, and stroke). In addition, the primary journals in which to publish research on the intersection between social behavior and health have remained: Physiology and Behavior, Behavioral Brain Research, Applied Animal Behaviour

Science, and Hormones and Behavior. Notably, the open access journal PLoS ONE has seen a large increase in publications in this area since it started in 2006. Major topics of study in the field include Social Stress and Other Social behavior. Although there is a large increase in Other Social behavior, a lack of specificity in keywords and titles makes it difficult to determine patterns relating to the study of sub-types of social behavior limiting our understanding of exactly where the field of social behavior and health is headed. Trends in social behavior point to a movement away from the study of group behavior and towards the study of individuals and affiliative relationships. Current trends in research in general suggest a greater emphasis on interdisciplinary and systems research and we expect that in the future we may not see a drastic change in the types of behaviors or health outcomes studies but may instead see a change in how these topics are studied with a greater focus on multi-level approaches (e.g., studies that examine the interaction of group-level and individual-level behavior on health) to the study of social behavior and health.

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