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DOES GENDER AFFECT A SCIENTIST'S RESEARCH OUTPUT IN EVOLUTIONARY ECOLOGY?

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To examine how an author's gender influences his or her research output, the authors analyzed (not simply scored) more than 900 published articles in nine leading scientific journals in the field of evolutionary ecology. Women were strongly underrepresented in all countries, but this bias is decreasing. Men and women differed significantly in their fields of research, with women preferentially conducting projects on behavior rather than evolution or ecology. Most aspects of the structure of published articles and the level of conceptual generality were unaffected by an author's gender. Because discriminatory practices by reviewers and editors can be manifested in attributes of the articles that survive the review process, the latter result suggests a lack of gender-based discrimination during the review process. Gender differences in research output presumably reflect a complex array of genetic and social influences; a clearer understanding of these causal factors may help identify (and thus reduce) gender-based discrimination.

INTRODUCTION

Many factors influence how scientists frame research projects and publish the results of their work. Some of these factors are imposed by external forces (such as granting agencies or employers), whereas others reflect intrinsic characteristics of scientist, such as their abilities and interests. Does a scientist's gender influence his or her work? An extensive literature examines differences between male and female researchers in total output: Men typically publish more than women, although the disparity is narrowing (Cole & Zuckerman 1984, 1987, 1991; Grant, Kennelly, & Ward, 2000; Xie & Shauman, 1998; note, however, that in a recent study among ecologists [Cassey & Blackburn, 2003], only 9 women [6%] were classified as "successful" with respect to their scientific careers against 142 men [94%]). Recent major reviews have provided extensive data on rates of participation and productivity by women in various scientific fields and attempted to identify factors that may be responsible for gender differentials in such variables (e.g., National Science Foundation, 2003). It is clear that women are significantly underrepresented at higher levels within the career structure, and hence, it is important to understand the processes that have led to this situation. One possibility, for example, is that manuscripts that are submitted to scientific journals for publication are scrutinized more critically if they are authored by women than if they are written by men. However, there have been few quantitative comparisons between men and women in terms of the roles they play in publications, their choices of study topics, how they frame the articles they write, and whether their articles are treated equally in the review process. We have conducted such an analysis on the basis of research articles

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published on the ecology, evolution, and behavior of vertebrates. We focused on four aspects, asking whether men and women differed in

1. their roles within research groups (the proportion of articles of which a scientist was the sole author, the senior author, or a junior author);
2. the research fields they chose (i.e., ecology, behavior, or evolution);
3. the degrees of conceptual generality with which their articles were framed. Because a more conceptually framed introductory section will develop ideas before mentioning particular taxa (Bonnet, Shine, & Lourdais, 2002), we analyzed the structure of each introductory section rather than simply scoring the gender and the number of authors; and
4. the taxonomic groups they studied (e.g., mammals, birds, reptiles, amphibians, fish).

Gender differences in any of these attributes might reflect differential social influences on men and women, differential access to grants, or the interplay between genetic and social processes (Hudson Keenihan, 2001; Kreeger, 2002; Shaywitz et al., 1995; Wenneras & Wold, 1997;Wilson, 1998).

METHODS

We selected 9 of the leading journals in the fields of evolutionary ecology and behavior (from a total of approximately 20 journals with ISI impact factors in 1997 greater than 1.8; the exact number depends on how one classifies some journals with respect to field). These journals were *Ecology*, the *American Naturalist*, *Evolution*, *Animal Behaviour*, *Behavioral Ecology*, the *Journal of Animal Ecology*, *Functional Ecology*, the *Journal of Evolutionary Biology*, and *Oikos*. The sample included both American and European journals and spanned a wide range from behavioral to evolutionary ecology. We analyzed all the issues of these journals that were published in 1992, 1996, and 2000. To facilitate and standardize comparison, we selected only articles that dealt with vertebrate organisms and had separate introductory sections. We scored the gender of the authors on the basis of their first names, which was possible for the first authors in 924 articles and for all the authors in 822 articles (of 1,180 total; the first names of authors were either ambiguous or not available for the other cases). Consequently, the sample size used in statistical tests varied between these two values. For each of these articles, we scored

1. the length of the introductory section (the number of printed lines; one line typically contained 8 to 10 words in all the journals we examined);
2. the "line of first mention" of the study organism, as an index of generality. That is, how far into the introductory section (how many printed lines) did we need to read before the study species (or higher lineage) was mentioned for the first time? This was done at the taxonomic level of class (fish, reptiles, amphibians, birds, and mammals) or lower. Although the class system does not reflect vertebrate phylogeny, it is still the most commonly used classification (e.g., articles on birds do not appear in herpetological journals, even though cladistic analyses unite these groups);
3. the total number of times the study organism was mentioned in the introductory section, at the level of the family or lower (species or subspecies). For example,

canid, *canis*, and *dog* were treated as equivalent. This provided another index of the generality of the introductory section; and
4. a subjective evaluation of the narrowness of the introductory section. If a single phrase in the introductory section was devoted to general concepts (e.g., trade-offs, speciation), then we considered the introductory section as general (see Bonnet et al., 2002, for additional details on method).

RESULTS

Role of the Scientist

Women constituted a minority of the authors of the articles we examined. Overall, in 305 of 822 articles for which we could identify the gender of all the authors, at least one of the authors (some workers counted more than once) was a woman (37.1%); by contrast, in 754 articles (91.7%), at least one of the authors was a man (χ^2 = 494.4, df = 1, p < .00001). Women were senior authors of only 203 of 924 articles (22%; χ^2 = 157.58, df = 1, p < .00001, against a null hypothesis of equal numbers of male and female authors). However, women were senior authors as often as expected under their overall numerical frequency among all authors (χ^2 = 1.59, df = 1, p = .21). Women were sole authors on 47 articles compared with 161 articles for men (χ^2 = 33.78, df = 1, p < .00001).

Do the genders assort randomly as authors, or do members of each gender tend to collaborate with each other (rather than with the other gender) in writing articles? Our analyses revealed the second pattern. The probability for a woman to be a junior author on an article was higher when the senior author of that article was also a woman (52 of 135 [27.8%] compared with 114 of 517 [18.1%] when the senior was male; χ^2 = 8.46, df = 1, p < .004). The same effect occurred with men, but less strongly; the probability for a man to be a junior author was higher when the senior author was also a man (193 of 476 [71.2%] compared with 69 of 114 [62.3%], χ^2 = 5.29, df = 1, p = .02). Thus, same-gender coauthorship was more common than expected by chance.

The degree of male dominance in publication output changed rapidly over the period of our survey (Figure 1). Women were senior authors of 39 of 250 articles (15.6%) in 1992, 71 of 321 articles (22.1%) in 1996, and 93 of 353 articles (26.4% in 2000 (comparing numbers through time, χ^2 = 9.86, df = 2, p < .01). Thus, the proportion of senior-authored articles by women increased faster than the proportion of women with junior authorships of articles (which were 13.5%, 11.4%, and 15.6%, respectively; comparing the two sets of numbers, χ^2 = 81.05, df = 2, p < .00001; Figure 1). In combination, these patterns mean that the proportion of articles with at least one woman as an author increased from 31% in 1992 to 45% in 2000.

On average, articles with women as the senior authors included the same number of junior authors (2.32 ± 0.08, n = 203) as articles senior-authored by men (2.42 ± 0.04, n = 721), one-factor analysis of variance (ANOVA) with senior author gender as the factor and number of authors as the dependent variable, $F(1, 922)$ = 1.07, p = .30. Similarly, the proportion of articles with women as senior authors was virtually identical in different regions of the world (North America and South America, 22.5%; Australia, 24.3%; Europe, 20.8%; Africa, 21.0%; χ^2 = 0.46, df = 3, p = .94), indicating that women are underrepresented in all countries.

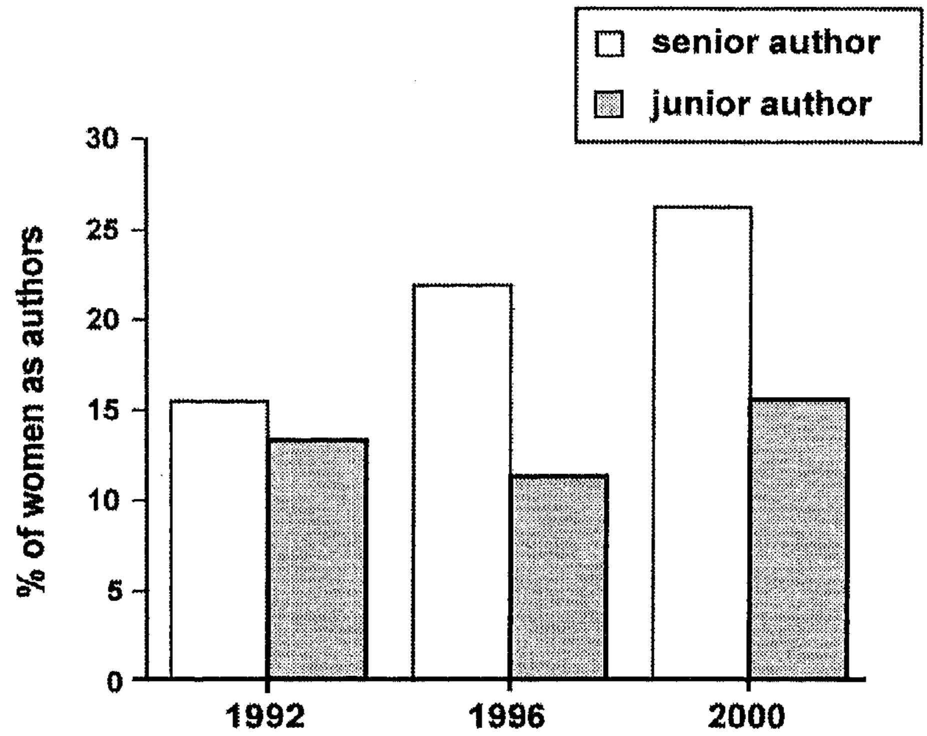

Figure 1. Changes through time in the proportions of articles in nine evolutionary ecological journals in which women were senior authors (open histograms) or junior authors (shaded histograms).

Choice of Research Field

Because each journal has a distinctive theme, we used the journal in which an article was published to classify that article with respect to research field. Analysis revealed strong gender biases: Women published much more frequently in behavioral journals than in those devoted to evolution or ecology (see Figure 2; for senior authors, $\chi^2 = 28.88$, $df = 8, p < .0005$; for junior authors, $\chi^2 = 33.51$, $df = 8, p < .00005$).

Structure of Published Articles

Our analyses of indices of the conceptual generality with which an article was framed (Bonnet et al., 2002) revealed no significant differences between male and female scientists. The length of the introductory section (the number of lines) averaged 99.8 ± 2.77 lines for 203 articles authored by women and 95.4 ± 1.47 lines for 720 articles authored by men, ANOVA $F(1, 921) = 2.04, p = .15$. The first line of mention of the study organism was also very similar for articles written by women (19.75 ± 1.69) and men (22.14 ± 0.90), ANOVA $F(1, 922) = 1.55, p = .21$. We then repeated this analysis after including another factor that has been shown to strongly affect the line of first mention: whether the study organism was an ectothermic or endothermic vertebrate (see Bonnet et al., 2002). The two-factor ANOVA revealed no significant main effect of gender, $F(1, 920) = 2.15$, $p = .14$, or interaction between gender and metabolic mode, $F(1, 920) = 0.54, p = .46$.

The study organism was cited an average of 6.34 ± 0.56 times for articles authored by women compared with 6.30 ± 0.30 times for men, $F(1, 797) = 0.002$, $p = .96$. Again,

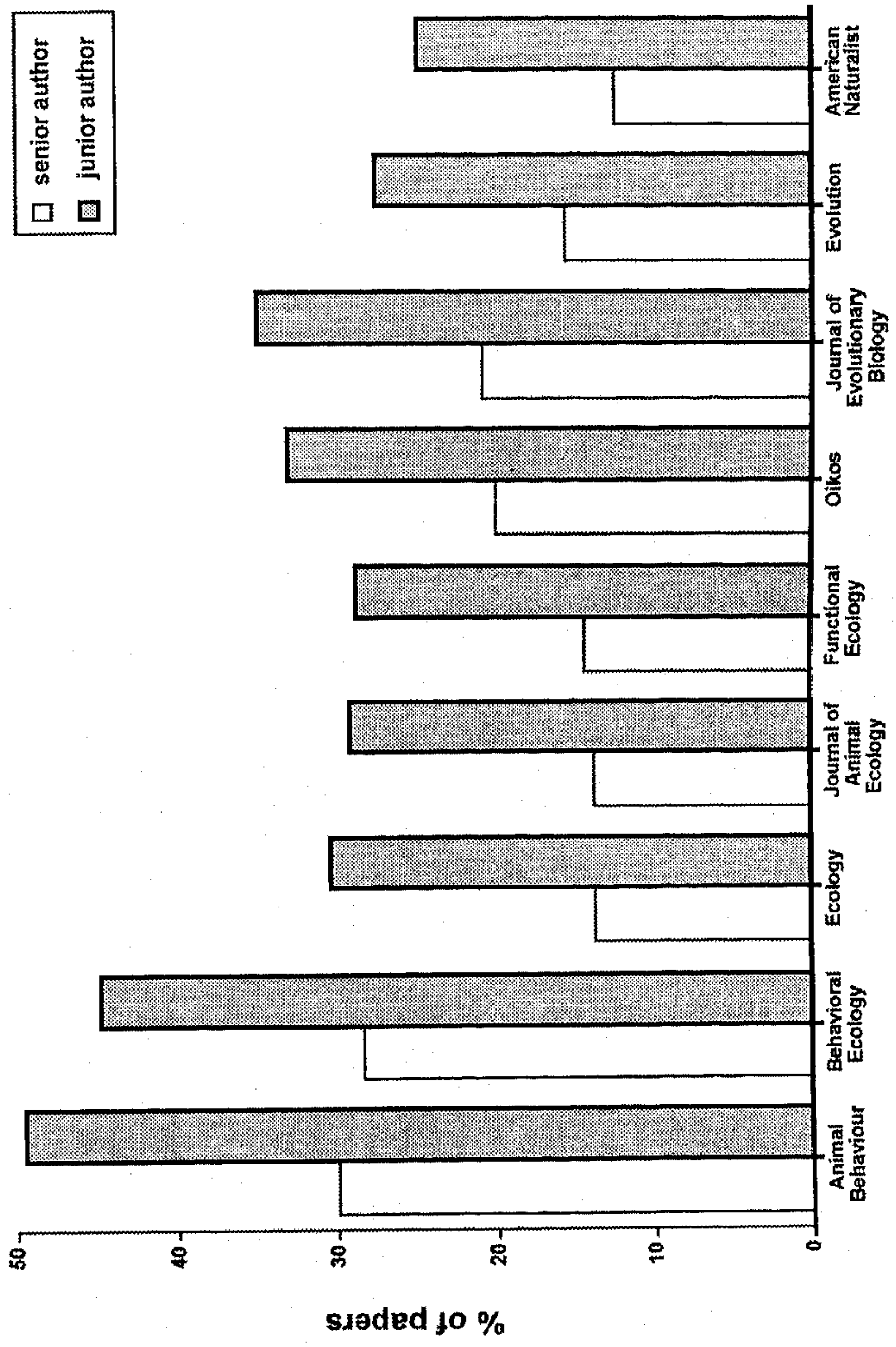

Figure 2. The proportions of articles in nine evolutionary ecology journals that were authored by women compared with men. Data are shown separately for senior authorship (open histograms) and junior authorship (shaded histograms).

including ectothermy and endothermy as an additional factor did not alter this conclusion, main effect of gender $F(1, 797) = 0.14$, $p = .71$; interaction $F(1, 757) = 0.64$, $p = .42$. We scored 18.6% of introductory sections to "male" articles as conceptually narrow, compared with 19.7% of "female" articles ($\chi^2 = 0.12$, $df = 1$, $p = .73$).

Choice of Taxonomic Group

Different taxonomic groups attracted different amounts of study, with strong overall similarity between men and women (correlating numbers of articles by men and women on each of the major vertebrate groups, $n = 5$, $r = .97$, $p < .005$). However, more detailed inspection revealed one outlier in this group (Figure 3). The proportion of women as senior authors was only half as great (13%) for reptiles as it was for all other groups (20% to 26%; Figure 3; $\chi^2 = 18.5$, $df = 7$, $p < .01$). Closer inspection suggested that snakes (11%), lizards (13.5%), and turtles (14.3%) were equally unpopular with female researchers. The taxonomic bias was much weaker for junior authorship (Figure 3; $\chi^2 = 8.70$, $df = 4$, $p = .07$).

DISCUSSION

We found strong gender-based differences in some aspects of research output but important similarities as well. Such comparisons are not only interesting in their own right but may

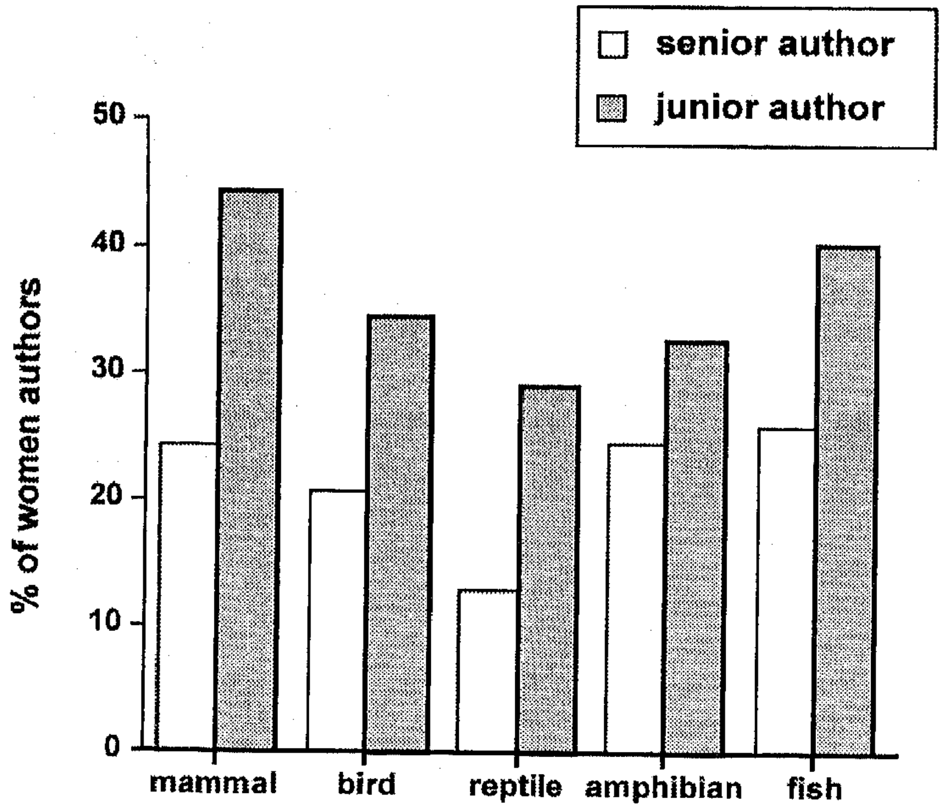

Figure 3. The proportions of articles on different taxonomic groups of vertebrates of which women were authors. Data are shown separately for senior authorship (open histograms) and junior authorship (shaded histograms).

also shed light on the relative importance of intrinsic versus socially forced influences that contribute to gender-based differences in research output. For example, gender differences that have declined markedly over the past decade are likely to reflect social rather than genetic factors. Because the measures of conceptual generality we have used are sensitive to bias during the reviewing process (Bonnet et al., 2002), we can also evaluate the importance of gender-based discrimination in peer review. If the gender of its author influences the way an article is handled during review, such a bias may be evident in these attributes (Bonnet et al., 2002).

The authorship (and thus, presumably, leadership) role of women in science has changed rapidly, although there is still a long way to go before one could claim equality of contributions. It is important that women constitute not only an increasing proportion of all authors but a rapidly increasing proportion of senior authors (Figure 1). The historically low profile of female authors reflects both a lower number of women among the ranks of research scientists and a lower average productivity per worker (Cole & Zuckerman, 1984). Both of these factors are changing (Xie & Shauman, 1998; Wilson, 1998), presumably in response to changing social systems. Similar shifts in women's participation were reported in a recent major review of the contribution of women to scientific research (NSF 2003). The strong trend for same-gender coauthorship from our analysis is an interesting phenomenon and has remained stable through time.

The choice of research field also differed between the genders, with behavioral topics attracting more study from women (Figure 2). Similarly, female herpetologists are overrepresented proportionally in the fields of ecology and evolution (including behavior) and underrepresented in systematics research (Wilson, 1998). Similar biases are evident at even broader levels, among major fields of science (National Science Foundation, 2003). Unlike the case with taxonomic biases, there is no sign that this gender bias is diminishing through time from either Wilson's (1998) review or our own (49% of female-authored articles in the two behavioral journals in 1992 compared with 62% in 2000). Why have some kinds of topics and approaches to science consistently proved more appealing to one gender than the other? The temporal stability of this pattern suggests that it is not simply due to the kinds of conventional "gender roles" overt in earlier years.

Are some or all of these gender differences in research focus due to active discrimination during the process of peer review? We can evaluate this idea with information on the structure of published articles because discriminatory practices by reviewers and editors can be manifested in attributes of the articles that survive the review process. For example, articles on "unpopular" kinds of organisms need to be framed in very general conceptual terms to be judged acceptable for publication, whereas articles on "popular" organisms are accepted even if they are framed more narrowly (Bonnet et al., 2002). Thus, discrimination against female authors should similarly be manifested in the conceptual generality with which their articles are framed. No such gender differences were apparent, suggesting that such gender-based impediments to research productivity are minor or negligible (although the same cannot be said for other facets of a woman's professional career, Wenneras & Wold, 1997). A recent study concluded that the overall refereeing process, notably the acceptance rates of articles according to gender, is not sexist for the ecological scientific literature, although some disparities exist among journals (Tregenza, 2002); this result reinforces our conclusions.

Our analysis also revealed clear gender differences in the choice of study animal, with reptiles especially avoided by female researchers (Figure 3). A detailed analysis of publication rates in North American herpetological journals reported a similar pattern, with women tending to write articles on amphibians rather than reptiles (Wilson, 1998). However, this bias has declined through time; the percentage of female-authored articles that dealt with reptiles increased from 3% in 1992 to 6% in 2000 (see also Wilson, 1998). As with the shift to senior authorship (above), this changing pattern suggests that social factors influence taxon choice. It would be interesting to examine the ontogeny of scientific development in this respect; that is, at what point in his or her career does a young scientist decide on the taxa and approaches on which she or he will focus? Anecdotal reports suggest that many herpetologists are besotted with reptiles from a very early age, suggesting that structures in professional science may be less important determinants of taxon choice than factors (either social or genetic) acting earlier in life.

In summary, the articles written by male and female ecologists differ significantly in several ways. Many of these differences have become smaller over recent years but (on the basis of current rates of change) will take a long time to disappear entirely. Other gender-based differences (such as in the choice of research field) show no evidence of decline. The causal bases for gender differences are undoubtedly complex, and social attitudes (perhaps acting relatively early in life, before we begin our professional careers) may be important influences on subsequent research output.

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