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Meeting the challenge of the Psychonomic Society's 2012 *Guidelines on Statistical Issues*:

Some success and some room for improvement

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Abstract

The Psychonomic Society (PS) adopted *New Statistical Guidelines for Journals of the Psychonomic Society* in November 2012. To evaluate changes in statistical reporting within and outside PS journals, we examined all empirical papers published in PS journals and in the Experimental Psychology Society journal, *The Quarterly Journal of Experimental Psychology* (QJEP), in 2013 and 2015, to describe these populations before and after effects of the Guidelines. Comparisons of the 2013 and 2015 PS papers reveal differences associated with the Guidelines, and QJEP provides a baseline of papers to reflect changes in reporting that are not directly influenced by the Guidelines. A priori power analyses increased from 5% to 11% in PS papers, but not in QJEP papers (2%). The reporting of effect sizes in PS papers increased from 61% to 70%, similar to the increase for QJEP from 58% to 71%. Only 18% of papers reported confidence intervals (CIs) for means; only two PS papers in 2015 reported CIs for effect sizes. Although variability statistics are important to understanding data, and to further analysis, they were only reported as numbers in just over half of the PS journal papers. Almost all PS and QJEP papers relied exclusively on null hypothesis significance testing to guide interpretation of the data. Changes associated with the Guidelines are in the desired direction with respect to reporting effect sizes and power analyses, but are not yet reflected in researchers' practices in describing their data, addressing data assumptions, and thinking beyond the p value when interpreting their data.

Meeting the challenge of the Psychonomic Society's 2012 Guidelines on Statistical Issues: Some success and some room for improvement

The Psychonomic Society's Publications Committee, Ethics Committee, and the Editors-in-Chief of the Society's six journals published new guidelines on statistical issues for papers to appear in the Society's journals (*New Statistical Guidelines for Journals of the Psychonomic Society*, 2012) in November 2012. In recent years there has been growing concern about research practices, at least in part related to statistical usage. These include problems with reproducibility (e.g., Open Science Collaboration, 2015), undisclosed flexibility in data collection, selection and analysis (e.g. Simmons, Nelson, & Simonsohn, 2011), and reliance upon null hypothesis significance testing (NHST) combined with neglect of other properties of the data such as effect sizes (e.g. Cohen, 1994; Cumming, 2014; Cumming & Calin-Jageman, 2016; Fritz, Morris & Richler, 2012; Kline, 2013). We believe that evaluating the success of the Guidelines provides a good starting point for reviewing the current state of reporting of statistics in several leading experimental psychology journals and as the foundation for future improvements in making the best use of research data.

We monitored reporting changes following the introduction of the Guidelines by examining papers from the empirical journals of the Society: *Attention, Perception & Psychophysics* (*AP&P*), *Psychonomic Bulletin & Review* (*PB&R*), *Memory & Cognition* (*M&C*), *Cognitive, Affective, & Behavioral Neuroscience* (*CA&BN*), and *Learning & Behavior* (*L&B*). As a baseline, we examined how well the Guidelines were already met by authors and editors in Psychonomic Society (PS) journals from 2013 (Morris & Fritz, 2014); these were papers accepted before the 2012 Guidelines were published. We compared these data with similar coding from papers published in 2015: papers that had been accepted for publication after the Guidelines had been adopted.

To take into account general changes in the reporting practices of authors extending beyond the PS Journals, we also coded empirical papers published in *The Quarterly Journal of Experimental Psychology (QJEP)* in 2013 and in 2015 (Morris & Fritz, 2017). QJEP is published by the Experimental Psychology Society (EPS) and its papers are similar in topics and status with those in the PS journals, but the EPS have not issued guidelines similar to the 2012 Psychonomic Guidelines.

It was not possible to examine every topic addressed in the Guidelines, but we were able to explore many of the issues raised. These included the reporting of a priori power analyses (e.g. Faul, Erdfelder, Lang, & Buchner, 2007) to estimate the number of participants required to have a given probability (e.g. 80%) of obtaining a significant result for a particular size of effect, if the effect does exist. We also recorded whether there was any discussion of power in the papers. The Guidelines emphasize the benefits of going beyond NHST by routinely reporting effect sizes (e.g., Fritz, Morris & Richler, 2012; Morris & Fritz, 2013a, 2013b) and their confidence intervals (CIs) (e.g., Cumming, 2012, 2014; Masson & Loftus, 2003; Smith & Morris, 2015). We therefore coded the papers for these practices. The Guidelines state: "it is important to report appropriate measures of variability around means and around effects (e.g., confidence intervals around means and/or around standardized effect sizes)". We surveyed the reporting of measures of variability both of the sample data, such as standard deviations (*SD*s), and of the sample means, through standard errors (*SE*s) and confidence intervals (CIs). There are two principle ways in which variability is reported: in error bars in figures or in numerals within the text or tables. Error bars can visually convey the likely values of means in other data samples, but the figures are often too small to allow the error bars to be translated into numbers for further analysis (e.g. Morris & Fritz, 2013a). Therefore, we coded both the use of error bars and numbers in reporting variability within

each article. We also took the opportunity to survey the types of statistical tests being reported in the papers surveyed, and we catalogued the types of effect size measures reported.

Finally, we noted the types of figures used in presenting means and variability. Newman and Scholl (2012) demonstrated that the use of bar charts to present means leads to a "within-the-bar bias" such that values within the bar are perceived as more likely than values outside (e.g. above) the bar. (See also Fritz, Morris, Cherchar, Smith, & Roe, 2015, and Okan, Garcia-Retamero, Cokely, & Maldonado, under revision.)

Our purpose in this research was to document recent practices in the conduct and reporting of experimental research in both Psychonomic Society journals and another experimental psychology journal. Where practice falls short of the Guidelines, we hope to encourage improvement.

Method

Articles

Every empirical paper published in 2013 and in 2015 in *Attention, Perception & Psychophysics* (*AP&P*), *Psychonomic Bulletin & Review* (*PB&R*), *Memory & Cognition* (*M&C*), *Cognitive, Affective & Behavioral Neuroscience* (*CA&BN*), *Learning & Behavior* (*L&B*) and *The Quarterly Journal of Experimental Psychology* (*QJEP*) was coded. This comprised a total of 1272 articles. Table 1 reports the numbers of papers from the 2013 and 2015 issues of the PS journals and the QJEP that were coded.

Statistics coded

The following statistics were coded if they were reported at least once in each article: A priori power analyses and references to power; the inclusion of standardized effect sizes, the type of effect size; and any discussion of these effect sizes. Where papers reported eta squared and were using factorial designs, we checked by calculation whether the statistic reported was eta squared (η^2) or was actually partial eta squared (η_p^2), which could be

seriously misinterpreted (see Fritz, Morris & Richler, 2012; Morris & Fritz, 2013a). Papers giving η_p^2 values were counted as reporting η_p^2, despite having been mislabelled; this error occurred in 7% of both the QJEP and PS papers for 2015.

The reporting in the Results sections, graphically or numerically (including tables), of means, *SE*s, *SD*s, *MSE*s, and CIs was coded. We also identified papers where figures representing means appeared and the types of error bars provided, if any. The statistical tests reported were also coded.

Coding was carried out by searching each paper for a set of keywords or terms and supplementing these searches by reading through the method and results sections to check that no terms had been missed because of unusual names or spelling.

The coding was carried out by the first author. However, as a check on reliability, a randomly selected 10% sample from each of the 2013 PS journals was independently coded by the second author, recording the results using the same spreadsheet columns recording the data. (Data are available at osf.io/589by.) There was a 99% correspondence, indicating a high degree of reliability. The small number of disagreements almost always involved unusual or ambiguous phrasing and all were satisfactorily resolved.

Results and Discussion

The summary results of our coding of the journal articles for 2013 and 2015 are reported as percentages in Figures 1-3 and Table 2. We restrict our comments here to the overall results for the PS journals and for QJEP, except where particular PS journals differ markedly in the pattern of the percentages. Details for the individual PS journals can be found in the online supplementary materials.

The types of statistical analyses carried out in the papers have implications for what other statistics can be expected; for example, statistics such as *SE* of the mean and *SD* are appropriate for a normal distribution and suggest a parametric analysis. We therefore begin

with a brief summary of the statistical analyses reported in the papers (see Figure 1), which

we found to be almost always parametric. ANOVA and related tests (MANOVA and

ANCOVA) were the most prevalent for all journals, followed by *t* tests. The *t* tests were often

follow-up tests after an ANOVA, or were used in the analysis of multiple regressions, but

they also appeared quite frequently as the main statistical test.

Pearson product moment correlations were reported in 20% to 33% of papers,

increasing across the two years, and slightly more frequently in QJEP. Linear or multiple

regressions were less frequently employed (11% - 23%) and appeared more often in QJEP

than PS journals. Other tests were even less frequently reported, as summarized in Figure 1.

Power

The Guidelines begin with a strong encouragement for researchers to conduct an a

priori power analysis before carrying out research. Such analysis ensures that adequate

numbers of participants are tested and requires a clear definition of the research design prior

to data collection which, in turn, easily enables pre-registration of the research (Cumming &

Calin-Jageman, 2016). However, power was infrequently addressed, as shown in the top

sections of Figure 2. For 2015, power was mentioned (a priori or otherwise) in only 16% of

PS and QJEP papers, usually merely as comments that a failure to find a significant effect

might be attributed to low power. A priori power analyses were very rare in the 2013 journals

but for PS journals increased from 5% to 11% in 2015. This improvement in reporting of the

a priori power analyses was most noticeable in M&C and CA&BN.

Effect size

The Guidelines emphasize the benefits of going beyond simple NHST by including

effect size estimates and their CIs. Effect size estimates add a great deal to any report (e.g.

Cumming, 2012; Cumming, & Calin-Jageman. 2016; Fritz et al., 2012; Smith & Morris,

2015). The reporting of standardized effect sizes was quite widely adopted in the journals that

we surveyed; some effect size estimates were included in three-fifths of the Psychonomic

Society papers in 2013, and this rose to nearly three-quarters by 2015. For the QJEP, half of

the papers were reporting standardized effect sizes in 2012, rising to three fifths in 2015.

Details are in the online supplementary materials.

Figure 3 plots the percentages of papers reporting particular effect size statistics for

PS journals and QJEP in both years. By far the most frequently reported statistic was η_p^2

which appeared in 41% of the PS papers in 2013, rising to 53% in 2015. Very similar

frequencies for η_p^2 occurred in QJEP. The dominance of η_p^2 has the appearance of some

authors addressing the need for reporting effect sizes in the easiest way – by copying η_p^2

from statistical software ANOVA output. Papers in which η_p^2 was reported for ANOVA

frequently provided no effect size estimates for the comparisons between pairs of conditions

when these were subsequently analysed by post hoc or t tests. So, for example, three fifths of

Psychonomics Journals papers in 2015 used t tests, which could have been accompanied by d

or r or other effect size statistics, but only a fifth of the papers reported d and a tiny handful

η_p^2 for those comparisons. Although effect sizes were quite frequently reported, they were

very rarely used when interpreting the findings.

Figure 3 shows that effect size statistics other than η_p^2 were far less frequently

reported. Cohen's d was the most common. Many regression analyses reported neither R^2,

nor any other standardized effect size measure. For example, in 2015 19% of PS papers used

regression analyses (see Figure 1) but only 9% reported R^2 or R_{adj}^2 (Figure 3). Standardized

regression weights (β) are another relevant effect size statistic for regression analyses, but, as

Figure 3 shows, they were reported in less than half of the regression analyses. Only 4% of

PS papers in 2015 reported β, despite 19% of them employing regression. Other effect size

statistics were very rarely reported. Omega squared and partial omega squared are highly

recommended measures of population effect size (e.g. Fritz et al., 2012; Grissom & Kim, 2011; Keppel & Wickens, 2004) but were almost never used.

Confidence intervals were provided for effect size estimates in just two of the PS 2015 journal papers, despite the recommendations of the Guidelines that they should be reported. The CIs for the effect size measures remind readers that the reported data are just one possible sample from those that might be obtained if the research was repeated; they suggest a range within which the vast majority of further sample means would probably lie. CIs in experimental psychological research are often wide because of small samples and a great deal of uncontrolled variability; this lack of precision has important implications for interpretation of the results in terms of theory, future research, and applications.

Variability

Turning to measures of variability, two types were coded: those indicating the precision of the estimate for the population mean (CIs and *SEs*) and those reporting the variability of the sample (*SDs*). Reports of variability are summarized in the middle parts of Figure 2. A distinction is made between reporting variability as numbers and reporting it graphically because, in practice, only papers reporting values numerically can be used accurately for further analysis by anyone interested in drawing more information from the reported data. Numerical values for the individual variability statistics (shaded areas in the bars) were reported for only a minority of papers except for *SD* reporting in QJEP.

Confidence intervals for means were provided in some form in very few papers (Figure 2), with PS journals showing a larger increase from 2013 than QJEP. The improvement in the Psychonomics papers mainly resulted from the increased reporting of CIs in M&C from 15% to 22% in 2015, and an even larger increase of 11% to 20% in PB&R. CIs were reported as numbers in roughly half as many papers as those providing CIs in any form. All but one of the CIs reported were for 95%CIs with the one exception of a 90%CI.

The majority of PS papers reported *SE*s (Figure 2). Reporting of *SEs* increased for both journals, moreso for QJEP. Almost two-thirds of PS and QJEP papers reported SEs in some form in 2015; in just under half of those papers *SE* was specified in numbers.

Although *SD*s in some form (Figure 2) were reported more frequently for QJEP than for PS journals, a substantial increase occurred for both. More papers reported *SD* in QJEP than in PS journals. *SD* in numbers was reported in roughly one-third of PS papers and just over half of QJEP papers.

The bottom part of Figure 2 gives the percentages of papers reporting *any* variability statistics; papers are included if at any point the results section provided CI, *SE* and/or *SD*. A small but nevertheless surprising number of papers failed to report any measure of variability. In 2013 this was true for 24% of PS journal articles; this percentage dropped to 19% in 2015. Some PS journals were more likely than others to omit all measures of variability: in 2015 30% of M&C papers and 25% of PB&R papers neglected to report the variability of the data. QJEP achieved a much better standard, with 95% of papers providing some measure of variability in 2015. The shaded part of each bar also shows how many papers had reports of variability in a numerical form that could be used in any further analysis. This was the case for just over half of the PS papers in 2013 and 2015. QJEP papers were more suitable to further analysis with 70% having numerical reports of variability in 2013, increasing to 85% in 2015.

In ANOVA reports, *MSE* combined with *F* ratio and degrees of freedom provide another way to express variability in the data and to reconstruct the analysis. In PS journals, *MSE*s were reported in only 20% of papers using ANOVA in both 2013 and 2015. *MSE*s were more frequently reported in QJEP, with 34% in 2013 and 33% in 2015.

Graphical display of means and variability

Most papers in both PS journals and QJEP included a figure when reporting means and the use of graphs increased slightly between 2013 and 2015. Bar charts were most often used; for PS journals they appeared in 44% of the papers in 2013, increasing to 53% in 2015. QJEP percentages were similar at 47% and 55%, respectively. Bar charts may lead to a "within-the-bar bias" so that values within the bar are perceived as more likely than values outside the bar, even though points equidistant above and below the top of the bar are equally likely to represent the population mean (Newman & Scholl, 2012). Alternatives to bar charts, typically representing the mean as a point, often with error bars and frequently connected by lines to other levels in the variable, were reported in around a quarter of papers. Line graphs appeared in 23% of PS journal papers in both years; for QJEP they appeared in 21% and 25% of papers, respectively. Graphs representing means as points (with or without error bars) not connected by lines were very rarely used.

The vast majority of figures included error bars (see Table 2), with little change in frequency between 2013 and 2015. PS papers were more likely to include error bars than were QJEP papers. Error bars were sometimes (12 – 21% of papers) present but not defined. There was considerable variation among PS journals. *SE* bars were the most common across all journals, appearing in more than half of the papers with means graphs, followed by CI error bars and a few papers with *SD* error bars. An occasional paper provided box plots marking the median, quartiles and range. Comparing 2013 to 2015, for PS journal papers there was a small shift from *SE* to CI error bars. Some papers depicted the error bars in only the upward direction, even though the margin of error extends in both directions from the mean. Both PS journals and QJEP had fewer of these cases in 2015 (13%) than in 2013 (19% and 17%, respectively).

Conclusions

Overall, the Guidelines appear to fill a need, as evidenced by the papers accepted for publication before the Guidelines' adoption. After the publication of the Guidelines there were changes to some practices in the direction recommended by the Guidelines, but those changes were limited to a small proportion of the papers and left big gaps between the practices suggested in the Guidelines and the actual practice in most papers. If the overall level of reporting of data in Psychonomics Journals (and the QJEP and other journals) is to be improved to reflect good practice and to make the most of the statistical techniques that are available for the analysis and interpretation of data, then more needs to change. We hope that our summary and analysis will encourage authors and editors to reflect on their practice and to embrace the Guidelines more fully, leading to further improvements in research planning, reporting and data interpretation.

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Table 1

The Numbers of Surveyed Empirical Articles from 2013 and 2015 in the Psychonomic Society Journals and the Quarterly Journal of Experimental Psychology.

| Year | QJEP | Psychonomic Society Journals | | | | | |
		AP&P	PB&R	M&C	CA&BN	L&B	PS Overall
2013	141	148	120	99	60	36	463
2015	127	208	152	91	60	30	541

Note: QJEP = *Quarterly Journal of Experimental Psychology*; AP&P = *Attention, Perception & Psychophysics*; PB&R = *Psychonomic Bulletin & Review*; M&C = *Memory & Cognition*; CA&BN = *Cognitive, Affective and Behavioural Neuroscience*; L&B = *Learning & Behavior*

Table 2

Error Bars Appearing in 2013 and 2015 Psychonomic Society Journals and the Quarterly Journal of Experimental Psychology; Data are Percentages of Papers with Graphs and the Difference in Percentages Between Years.

Error bar type	2013		2015		Change	
	QJEP	PS	QJEP	PS	QJEP	PS
CI error bars	10	11	12	16	+2	+5
SE error bars	51	67	61	62	+10	-5
SD error bars	2	2	1	3	-1	+1
Undefined bars	21	13	12	12	-9	-1
Any error bars	83	96	86	93	+3	-3

Note: CI = confidence intervals; *SE* = standard error; *SD* = standard deviation; PS = Psychonomic Society journals; QJEP = *Quarterly Journal of Experimental Psychology*

Figure 1.
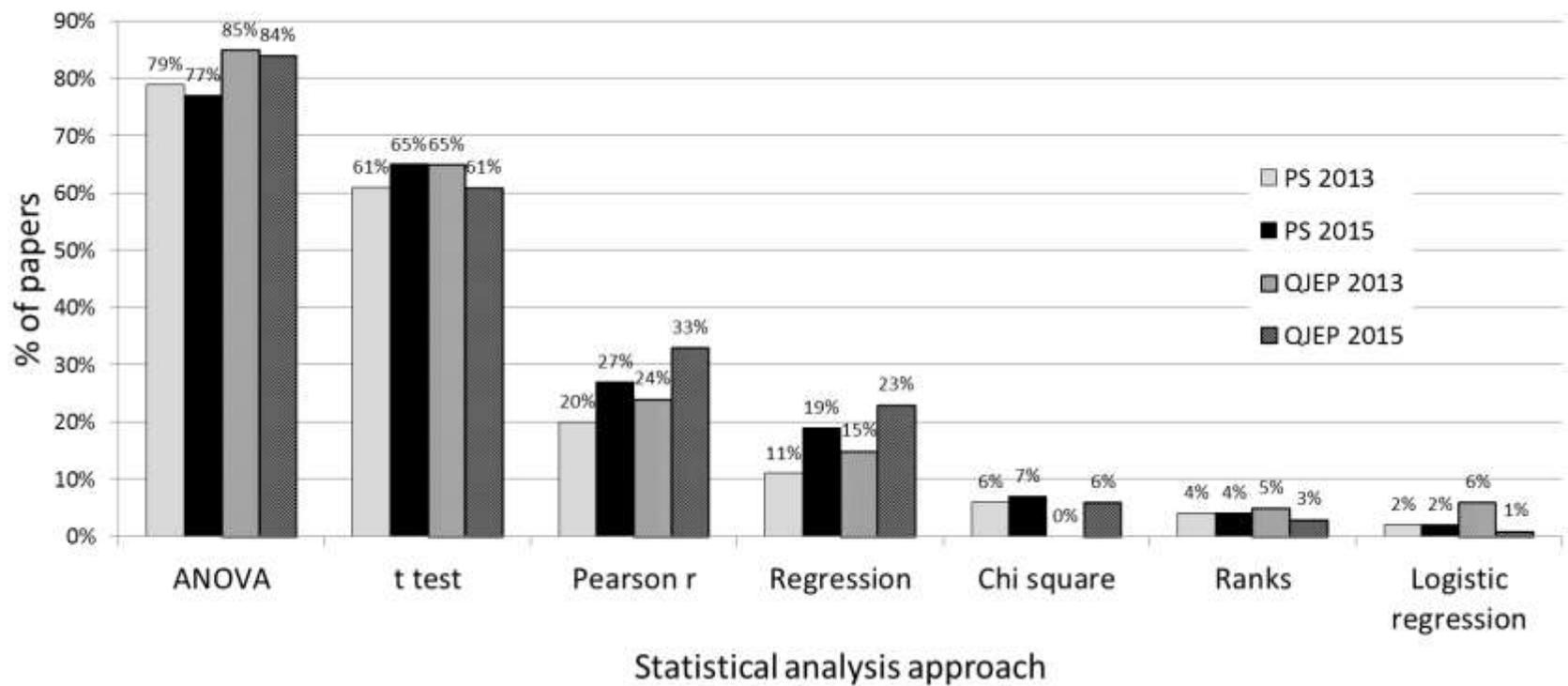
Figure 1. Statistical tests reported In Psychonomics Journals and QJEP in 2013 and 2015. Other tests appeared far less frequently.

Figure 2.
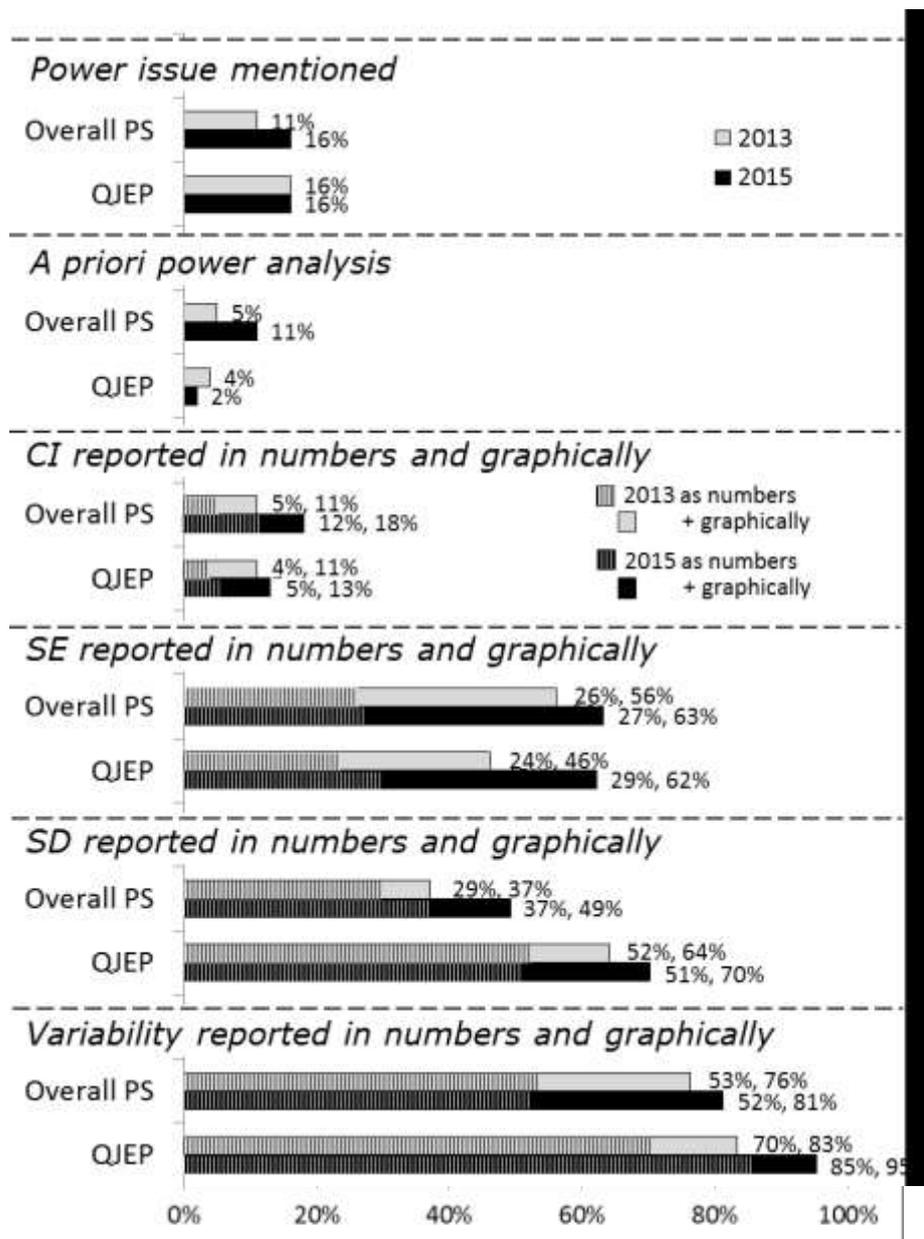
Figure 2. Percentage of papers reporting power considerations and variability information.

Figure 3
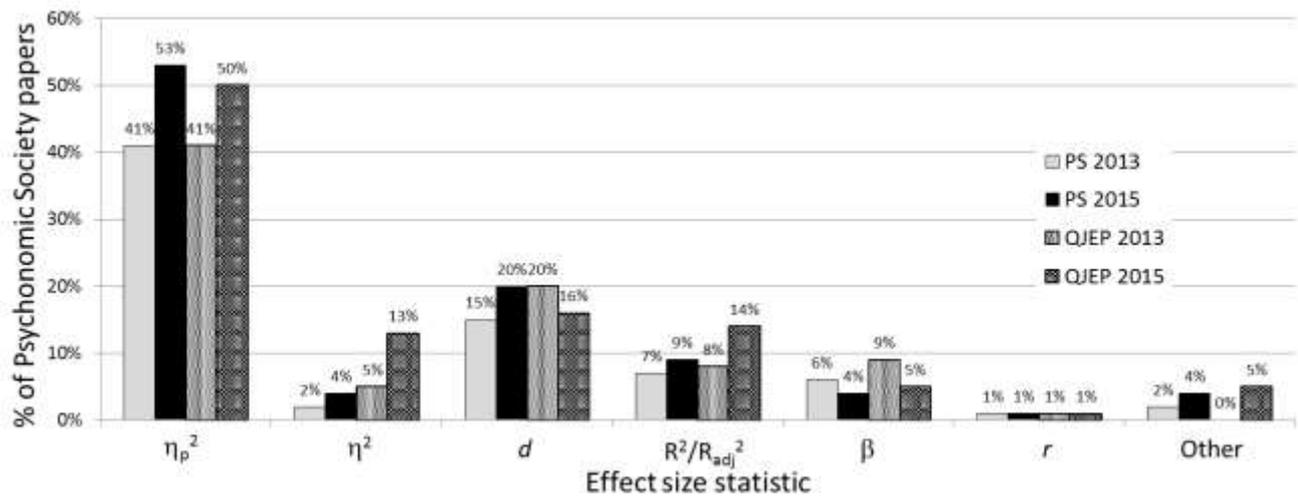
Figure 3. The reporting of standardized effect sizes in the 2013 and 2015 journals.

Figure S1. Percentage of papers reporting a priori power analysis. The guidelines call for reporting of a priori power analysis, but these are rarely reported. In most cases, no reason is provided for the sample size.
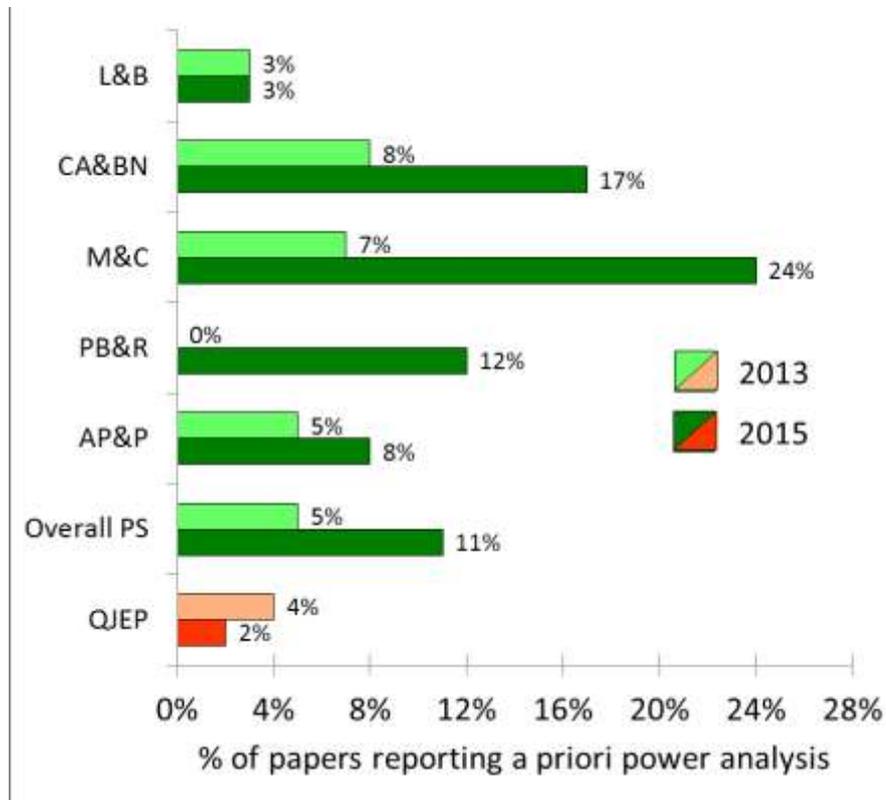
Figure S2. Percentage of papers mentioning power. Power was rarely mentioned in most journals, except as a possible reason for non-significant results.
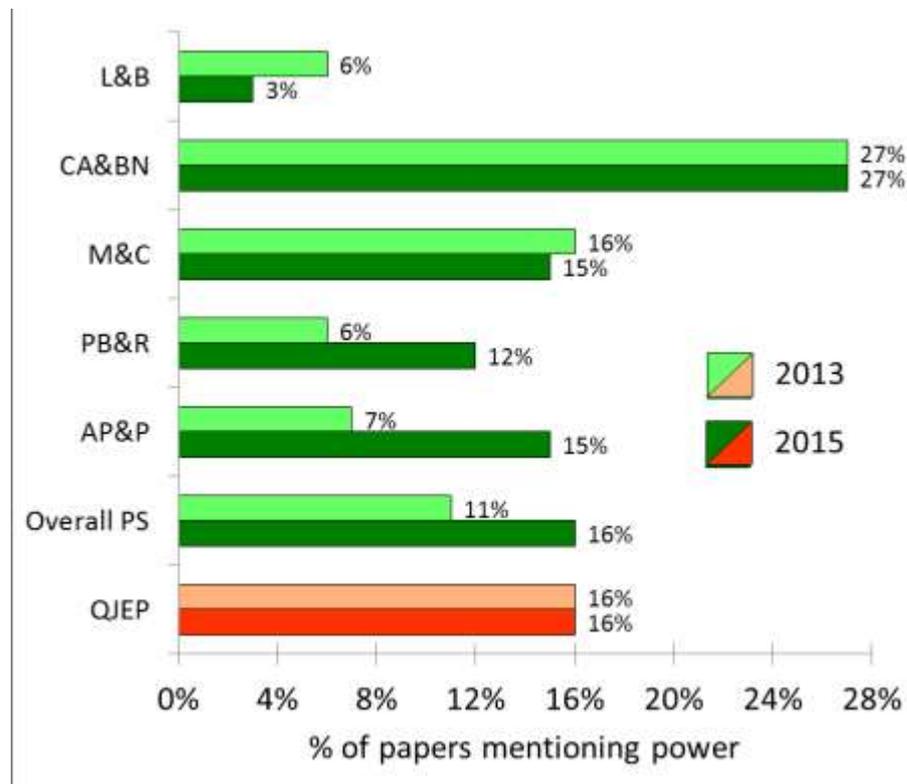
Figure S3. Percentage of papers reporting a standardized effect size statistic (e.g., partial eta squared, Cohen's *d, r, r^2*). Effect size statistics were usually, but not always reported. They were not accompanied by confidence intervals or standard errors except in two papers, which reported 95% CIs.
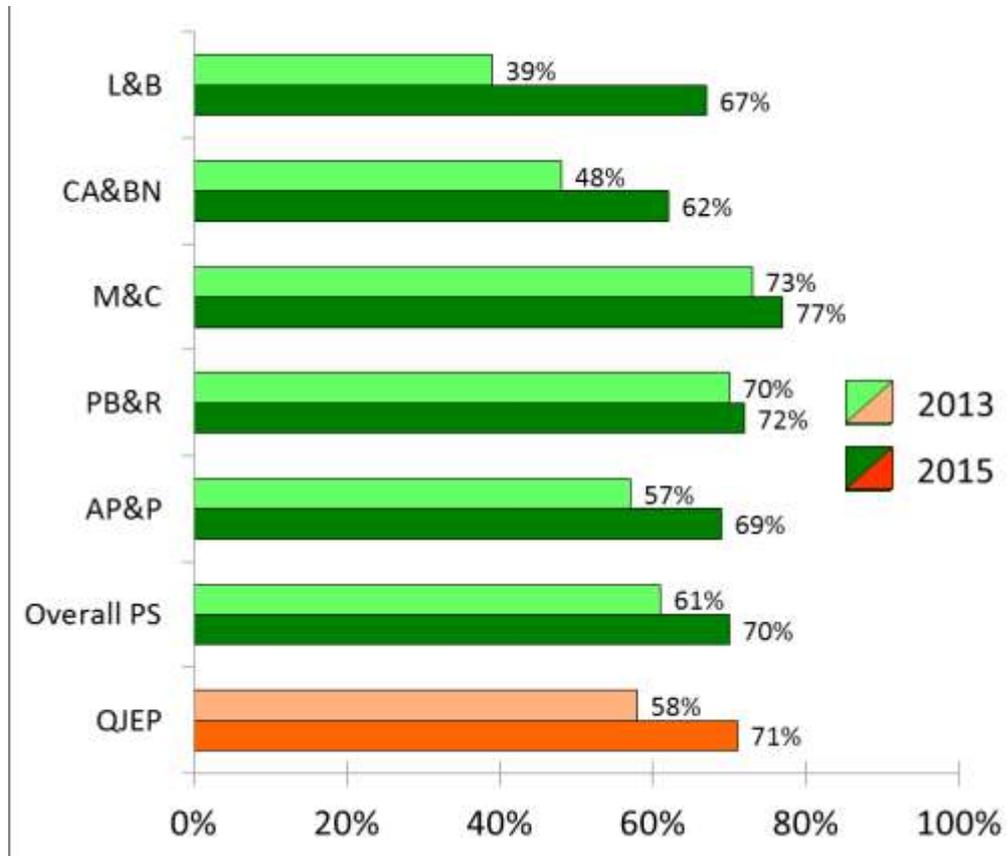
Variability: The following figures and tables describe the variability reported, graphically and in numbers, in each of the journals.

Figure S4. Percentage of papers reporting confidence intervals in some form – as numbers or graphically. Confidence intervals were not frequently reported in any form. See also Table S1 for details of the percentage of papers reporting the CIs in numbers rather than graphically.
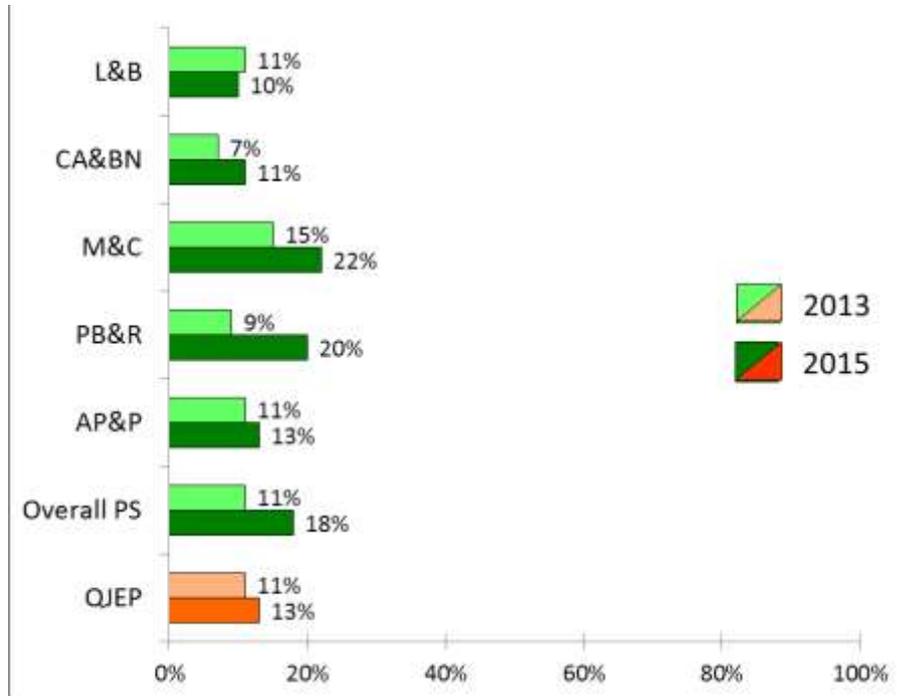

Figure S5. Percentage of papers reporting standard errors in some form – as numbers or graphically. See also Table S1 for details of the percentage of papers reporting the SEs in numbers rather than graphically.
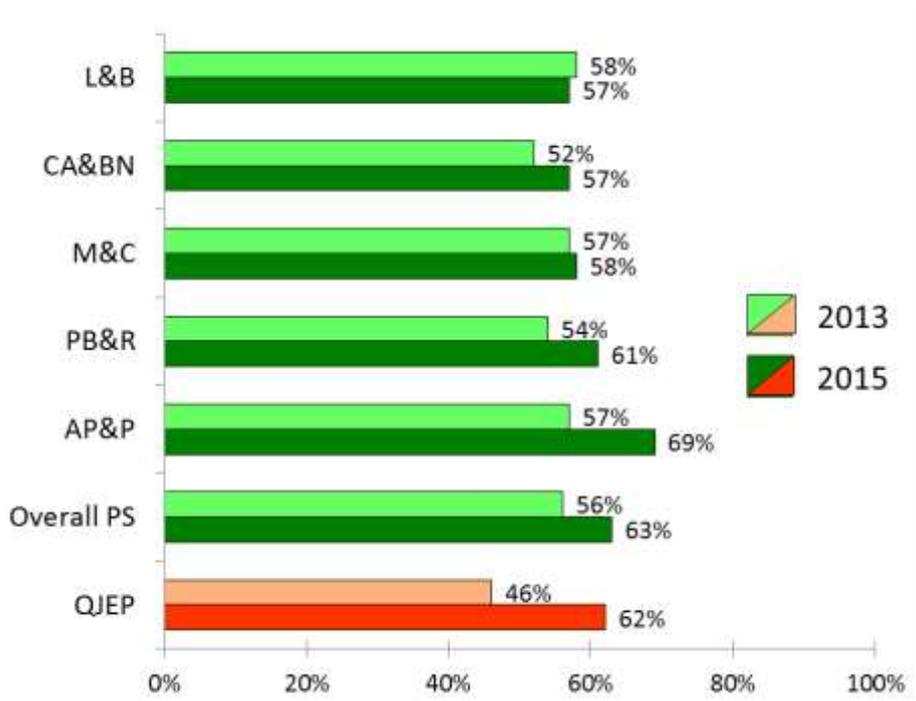
Figure S6. Percentage of papers reporting standard deviations in some form – as numbers or graphically. See also Table S1 for details of the percentage of papers reporting the SDs in numbers rather than graphically.
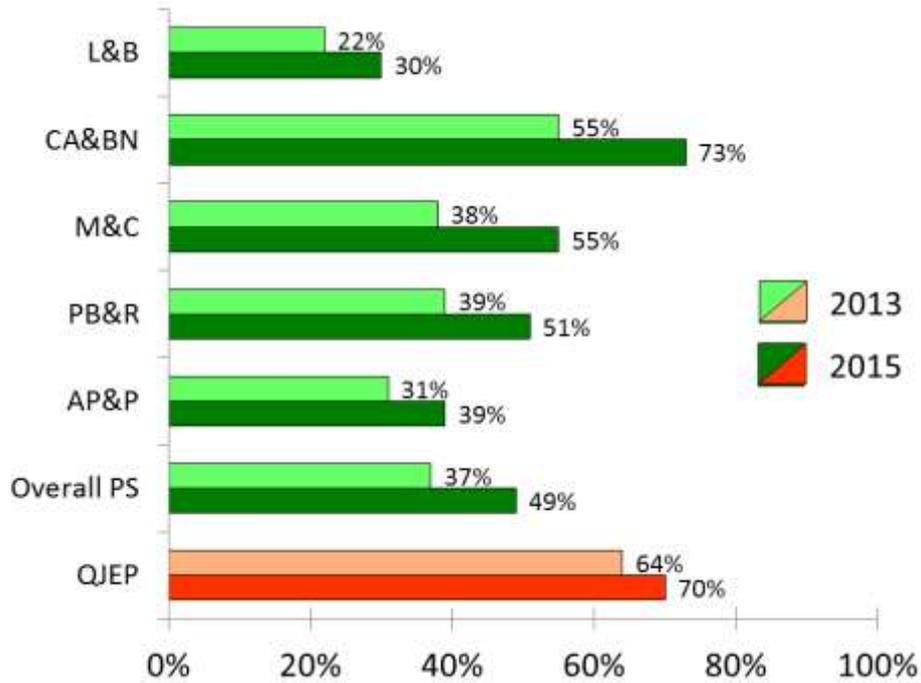

Table S1
Percentages of Articles from 2013 and 2015 in the Psychonomic Society Journals and the Quarterly Journal of Experimental Psychology Reporting CIs, SEs, SDs and MSEs in Numerals. The MSEs are as a Percentage of Papers Using ANOVA.

| Statistic | QJEP | Psychonomic Society Journals | | | | | |
		AP&P	PB&R	M&C	CA&BN	L&B	PS Overall
			2013				
CI	4	3	3	9	3	6	5
SE	24	15	33	36	28	19	26
SD	52	20	32	35	43	17	29
MSE	34	11	22	37	9	24	20
			2015				
CI	5	13	14	5	7	20	12
SE	29	22	31	33	32	7	27
SD	51	28	43	51	45	17	37
MSE	33	14	16	41	2	20	20

Figure S7. Percentage of papers reporting variability in any form – as numbers or graphically - for some statistics. Often papers reported variability for some but not all means. Papers excluded from these tallies failed to report any variability information for their data.
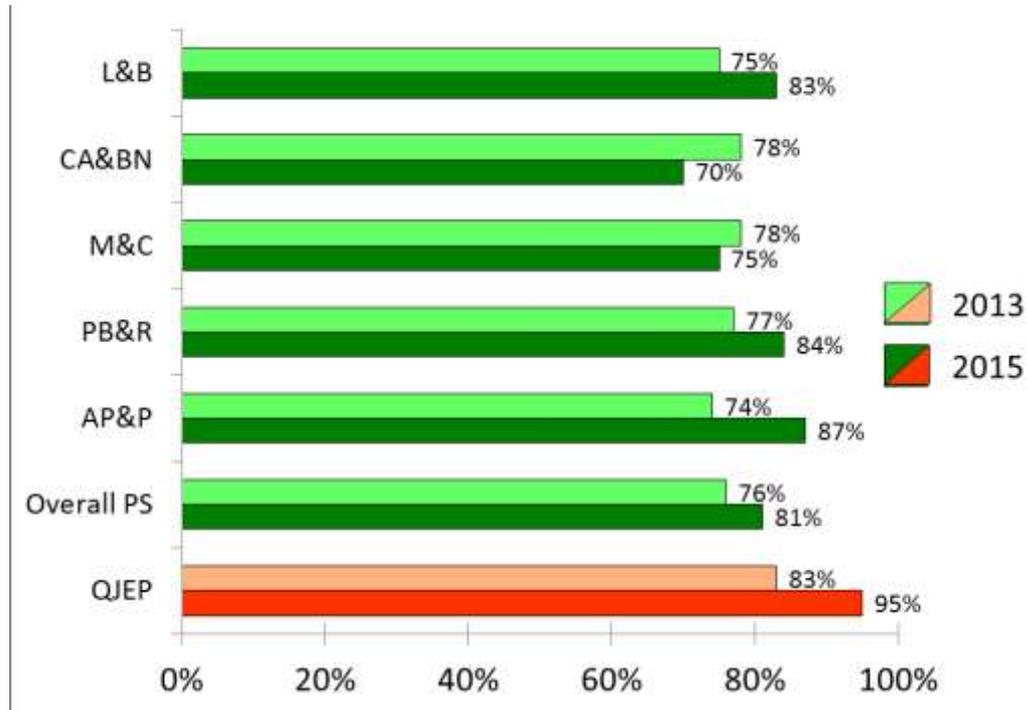

Figure S8. Percentage of papers reporting variability as numbers for some statistics. Often papers reported variability for some but not all means.
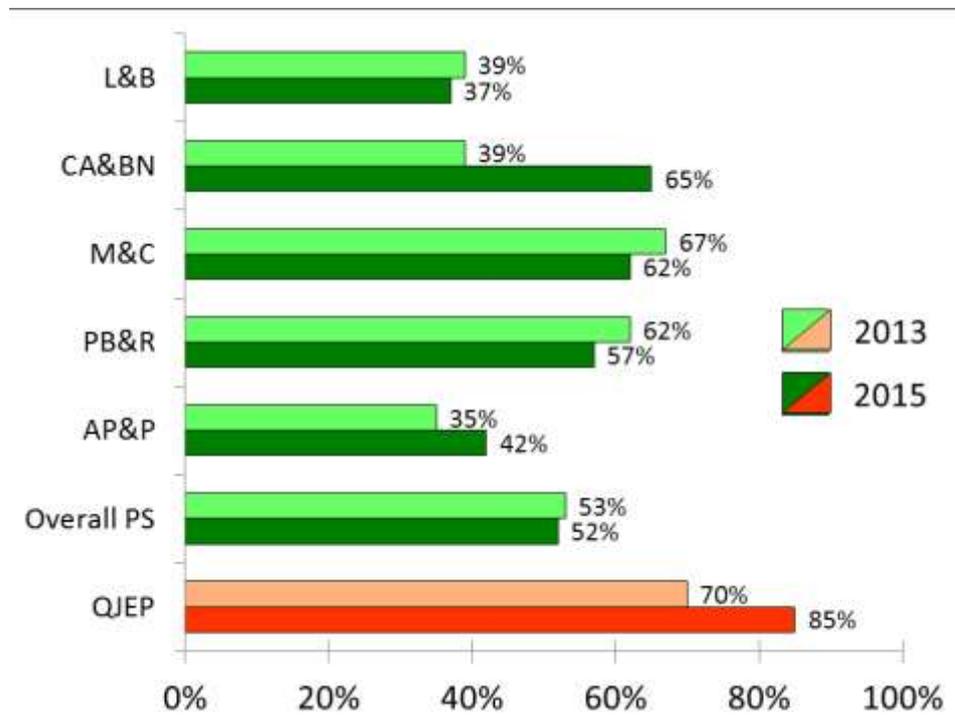
Graphs: The following figures describe the use of graphs in each of the journals.

Figure S9. Percentage of papers including at least one bar graph displaying means. Bar graphs are widely used, despite evidence that they may be perceived in a biased way (Newman & Scholl, 2012).
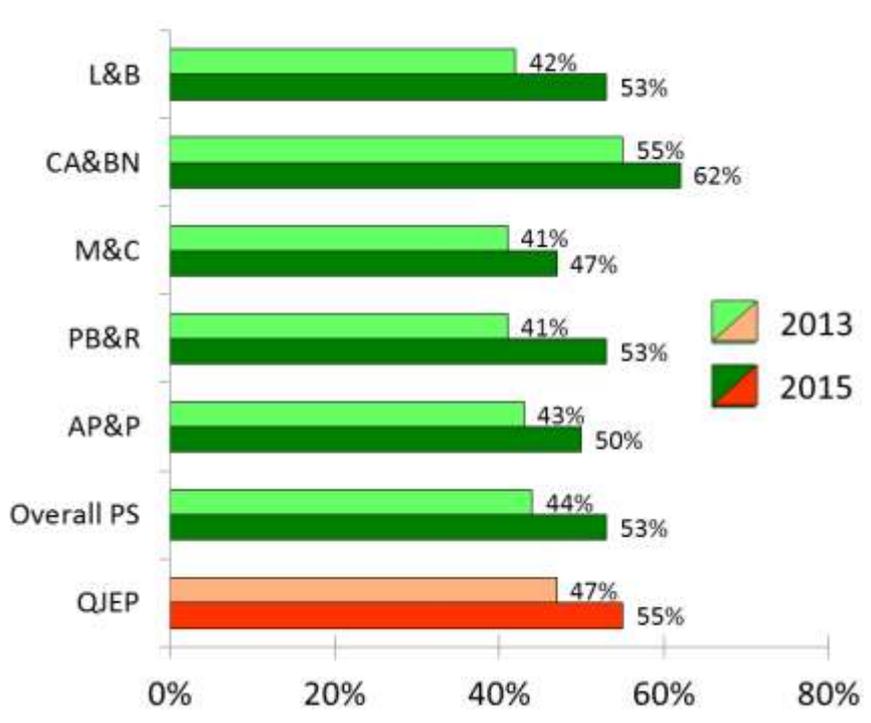

Figure S10. Percentage of papers including at least one line graph displaying means as points, connected by lines. Very few papers included graphs displaying means as points that were not connected by lines.
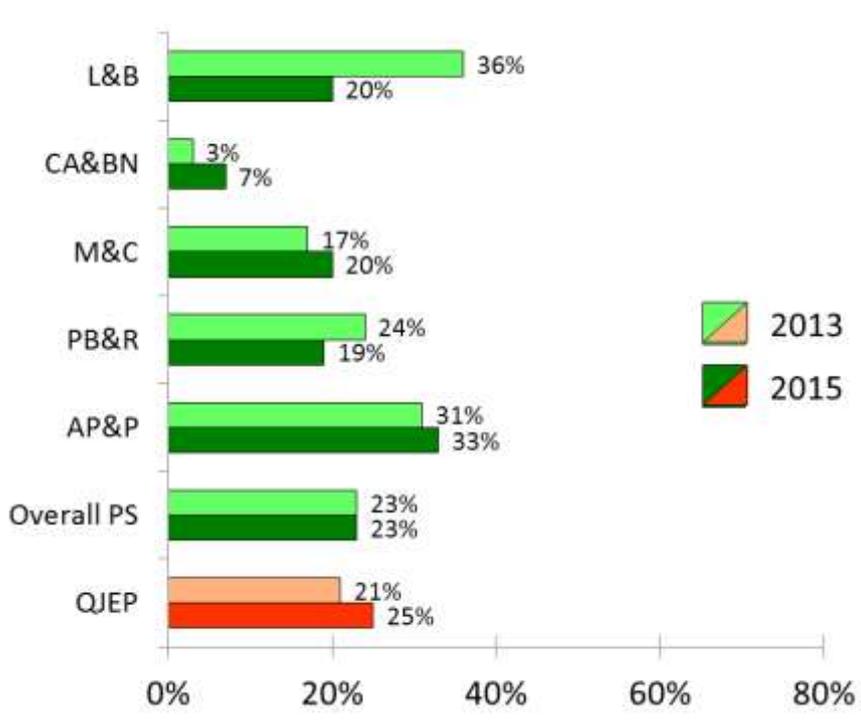
Figure S11. Percentage of the papers with means graphs (bars, lines, or points) that also include error bars of some sort.
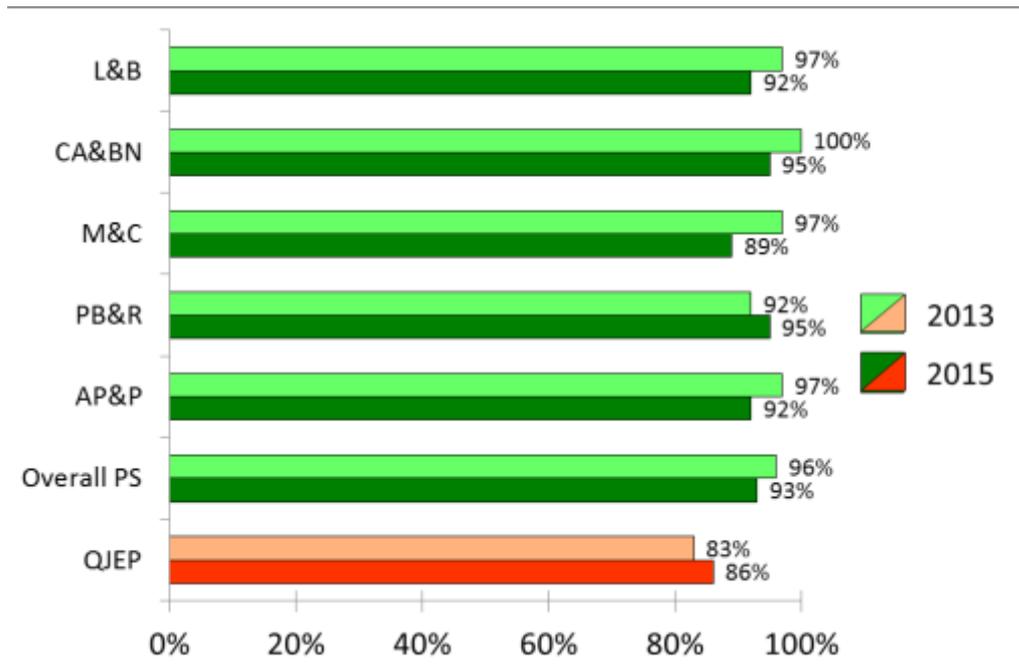

Table S2.
Types of Error Bars Used in Figures. Values Are Percentages of Papers with Figures.

Statistical analysis	QJEP	Psychonomic Society Journals					
		AP&P	PB&R	M&C	CA&BN	L&B	PS Overall
		2013					
SE error bars	51	64	68	66	72	72	67
CI error bars	10	14	10	16	11	10	11
SD error bars	2	2	0	3	8	3	2
Undefined bars	21	18	13	10	6	7	13
		2015					
SE error bars	61	66	60	56	61	62	62
CI error bars	12	17	19	17	10	8	16
SD error bars	1	3	2	2	2	8	3
Undefined bars	12	8	14	14	20	12	12

Figure S12. The frequency of problematic error bars in figures. Figure S12a shows the percentage of the papers with graphs that have undefined error bars. Figure S12b shows the percentage of the papers with graphs that have error bars only in an upward direction.

S12a. Percentage of the papers with graphs that have undefined error bars
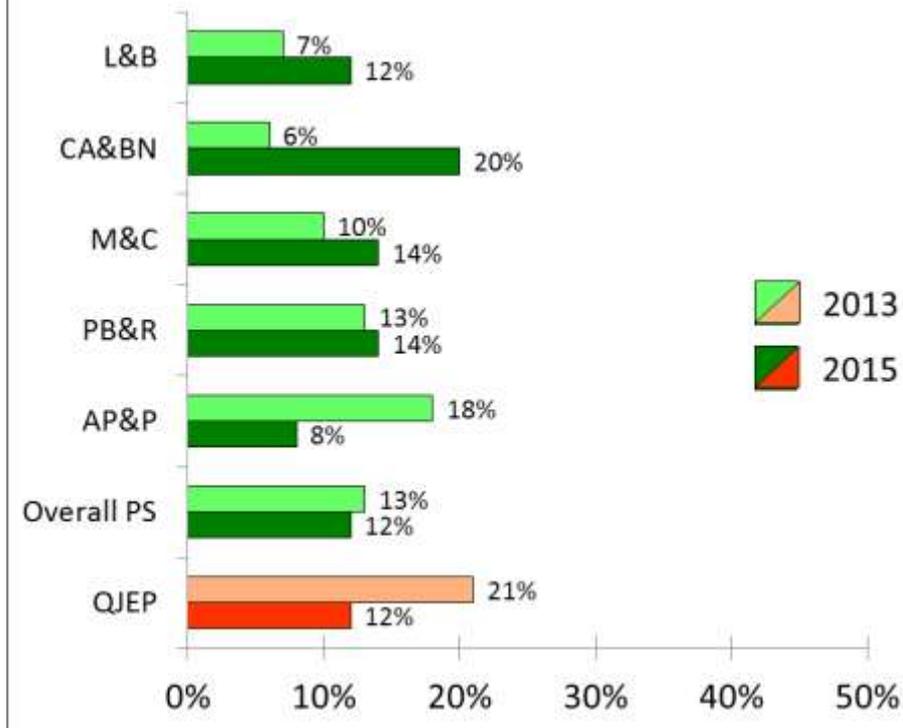
S12b. Percentage of the papers with graphs that have error bars in the upward but not downward direction.