Justify Your Alpha

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10

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Abstract: In response to recommendations to redefine statistical significance to $p \leq .005$, we

propose that researchers should transparently report and justify all choices they make when

designing a study, including the alpha level.

1   **Justify Your Alpha**

2

3   Benjamin et al.[1] proposed changing the conventional "statistical significance" threshold (i.e.,

4   the alpha level) from $p \leq .05$ to $p \leq .005$ for all novel claims with relatively low prior odds.

5   They provided two arguments for why lowering the significance threshold would

6   "immediately improve the reproducibility of scientific research." First, a p-value near .05

7   provides weak evidence for the alternative hypothesis. Second, under certain assumptions,

8   an alpha of .05 leads to high false positive report probabilities (FPRP[2]; the probability that a

9   significant finding is a false positive).

10

11   We share their concerns regarding the apparent non-replicability of many scientific studies,

12   and agree that a universal alpha of .05 is undesirable. However, redefining "statistical

13   significance" to a lower, but equally arbitrary threshold, is inadvisable for three reasons: (1)

14   there is insufficient evidence that the current standard is a "leading cause of non-

15   reproducibility"[1]; (2) the arguments in favor of a blanket default of $p \leq .005$ do not warrant the

16   immediate and widespread implementation of such a policy; and (3) a lower significance

17   threshold will likely have negative consequences not discussed by Benjamin and colleagues.

18   We conclude that the term "statistically significant" should no longer be used and suggest

19   that researchers employing null hypothesis significance testing justify their choice for an

20   alpha level before collecting the data, instead of adopting a new uniform standard.

21

22   **Lack of evidence that $p \leq .005$ improves replicability**

23

24   Benjamin et al.[1] claimed that the expected proportion of replicable studies should be

25   considerably higher for studies observing $p \leq .005$ than for studies observing $.005 < p \leq .05$,

26   due to a lower FPRP. *Theoretically*, replicability is related to the FPRP, and lower alpha

27   levels will reduce false positive results in the literature. However, *in practice,* the impact of

28   lowering alpha levels depends on several unknowns, such as the prior odds that the

11

1   examined hypotheses are true, the statistical power of studies, and the (change in) behavior

2   of researchers in response to any modified standards.

3

4   An analysis of the results of the Reproducibility Project: Psychology[3] showed that 49%

5   (23/47) of the original findings with p-values below .005 yielded $p \leq .05$ in the replication

6   study, whereas only 24% (11/45) of the original studies with $.005 < p \leq .05$ yielded $p \leq .05$

7   ($\chi^2(1) = 5.92$, $p = .015$, $BF_{10} = 6.84$). Benjamin and colleagues presented this as evidence of

8   "potential gains in reproducibility that would accrue from the new threshold." According to

9   their own proposal, however, this evidence is only "suggestive" of such a conclusion, and

10 there is considerable variation in replication rates across p-values (see Figure 1).

11 Importantly, lower replication rates for p-values just below .05 are likely confounded by p-

12 hacking (the practice of flexibly analyzing data until the p-value passes the "significance"

13 threshold). Thus, the differences in replication rates between studies with $.005 < p \leq .05$

14 compared to those with $p \leq .005$ may not be entirely due to the level of evidence. Further

15 analyses are needed to explain the low (49%) replication rate of studies with $p \leq .005$, before

16 this alpha level is recommended as a new significance threshold for novel discoveries

17 across scientific disciplines.

18

19 ***Weak justifications for the α = .005 threshold***

20

21 We agree with Benjamin et al. that single p-values close to .05 never provide strong

22 "evidence" against the null hypothesis. Nonetheless, the argument that p-values provide

23 weak evidence based on Bayes factors has been questioned[4]. Given that the marginal

24 likelihood is sensitive to different choices for the models being compared, redefining alpha

25 levels as a function of the Bayes factor is undesirable. For instance, Benjamin and

26 colleagues stated that p-values of .005 imply Bayes factors between 14 and 26. However,

27 these upper bounds only hold for a Bayes factor based on a point null model and when the

28 p-value is calculated for a two-sided test, whereas one-sided tests or Bayes factors for non-

1   point null models would imply different alpha thresholds. When a test yields BF = 25 the data

2   are interpreted as strong relative evidence for a specific alternative (e.g., μ = 2.81), while a *p*

3   ≤ .005 only warrants the more modest rejection of a null effect without allowing one to reject

4   even small positive effects with a reasonable error rate[5]. Benjamin et al. provided no

5   rationale for why the new *p*-value threshold *should* align with equally arbitrary Bayes factor

6   thresholds. We question the idea that the alpha level at which an error rate is controlled

7   should be based on the amount of relative evidence indicated by Bayes factors.

8

9   The second argument for α = .005 is that the FPRP can be high with α = .05. Calculating the

10   FPRP requires a definition of the alpha level, the power of the tests examining true effects,

11   and the ratio of true to false hypotheses tested (the prior odds). Figure 2 in Benjamin et al.

12   displays FPRPs for scenarios where most hypotheses are false, with prior odds of 1:5, 1:10,

13   and 1:40. The recommended *p* ≤ .005 threshold reduces the *minimum* FPRP to less than

14   5%, assuming 1:10 prior odds (the true FPRP might still be substantially higher in studies

15   with very low power). This prior odds estimate is based on data from the Reproducibility

16   Project: Psychology[3] using an analysis modelling publication bias for 73 studies[6]. Without

17   stating the reference class for the "base-rate of true nulls" (e.g., does this refer to all

18   hypotheses in science, in a discipline, or by a single researcher?), the concept of "prior odds

19   that H1 is true" has little meaning. Furthermore, there is insufficient representative data to

20   accurately estimate the prior odds that researchers examine a true hypothesis, and thus,

21   there is currently no strong argument based on FPRP to redefine statistical significance.

22

23   ***How a threshold of p ≤ .005 might harm scientific practice***

24

25   Benjamin et al. acknowledged that their proposal has strengths as well as weaknesses, but

26   believe that its "efficacy gains would far outweigh losses." We are not convinced and see at

27   least three likely negative consequences of adopting a lowered threshold.

28

1   *Risk of fewer replication studies*. All else being equal, lowering the alpha level requires larger

2   sample sizes and creates an even greater strain on already limited resources. Achieving

3   80% power with α = .005, compared to α = .05, requires a 70% larger sample size for

4   between-subjects designs with two-sided tests (88% for one-sided tests). While Benjamin et

5   al. propose α = .005 exclusively for "new effects" (and not replications), designing larger

6   original studies would leave fewer resources (i.e., time, money, participants) for replication

7   studies, assuming fixed resources overall. At a time when replications are already relatively

8   rare and unrewarded, lowering alpha to .005 might therefore reduce resources spent on

9   replicating the work of others. More generally, recommendations for evidence thresholds

10   need to carefully balance statistical and non-statistical considerations (e.g., the value of

11   evidence for a novel claim vs. the value of independent replications).

12

13   *Risk of reduced generalisability and breadth.* Requiring larger sample sizes across scientific

14   disciplines may exacerbate over-reliance on convenience samples (e.g., undergraduate

15   students, online samples). Specifically, without (1) increased funding, (2) a reward system

16   that values large-scale collaboration, and (3) clear recommendations for how to evaluate

17   research with sample size constraints, lowering the significance threshold could adversely

18   affect the breadth of research questions examined. Compared to studies that use

19   convenience samples, studies with unique populations (e.g., people with rare genetic

20   variants, patients with post-traumatic stress disorder) or with time- or resource-intensive data

21   collection (e.g., longitudinal studies) require considerably more research funds and effort to

22   increase the sample size. Thus, researchers may become less motivated to study unique

23   populations or collect difficult-to-obtain data, reducing the generalisability and breadth of

24   findings.

25

26   *Risk of exaggerating the focus on single p-values.* Benjamin et al.'s proposal risks (1)

27   reinforcing the idea that relying on *p*-values is a sufficient, if imperfect, way to evaluate

28   findings, and (2) discouraging opportunities for more fruitful changes in scientific practice

1 and education. Even though Benjamin et al. do not propose $p \leq .005$ as a publication

2 threshold, some bias in favor of significant results will remain, in which case redefining $p \leq$

3 .005 as "statistically significant" would result in greater upward bias in effect size estimates.

4 Furthermore, it diverts attention from the cumulative evaluation of findings, such as

5 converging results of multiple (replication) studies.

6

7 ***No one alpha to rule them all***

8

9 We have two key recommendations. First, we recommend that the label "statistically

10 significant" should no longer be used. Instead, researchers should provide more meaningful

11 interpretations of the theoretical or practical relevance of their results. Second, authors

12 should transparently specify—and justify—their design choices. Depending on their choice of

13 statistical approach, these may include the alpha level, the null and alternative models,

14 assumed prior odds, statistical power for a specified effect size of interest, the sample size,

15 and/or the desired accuracy of estimation. We do not endorse a single value for any design

16 parameter, but instead propose that authors justify their choices before data are collected.

17 Fellow researchers can then evaluate these decisions, ideally also prior to data collection,

18 for example, by reviewing a Registered Report submission[7]. Providing researchers (and

19 reviewers) with accessible information about ways to justify (and evaluate) design choices,

20 tailored to specific research areas, will improve current research practices.

21

22 Benjamin et al. noted that some fields, such as genomics and physics, have lowered the

23 "default" alpha level. However, in genomics the overall false positive rate is still controlled at

24 5%; the lower alpha level is only used to correct for multiple comparisons. In physics,

25 researchers have argued against a blanket rule, and for an alpha level based on factors

26 such as the surprisingness of the predicted result and its practical or theoretical impact[8]. In

27 non-human animal research, minimizing the number of animals used needs to be directly

28 balanced against the probability and cost of false positives. Depending on these and other

1   considerations, the optimal alpha level for a given research question could be higher or

2   lower than the current convention of .05[9,10,11].

3

4   Benjamin et al. stated that a "critical mass of researchers" endorse the standard of a $p \le$

5   .005 threshold for "statistical significance." However, the presence of a critical mass can only

6   be identified *after* a norm has been widely adopted, not *before*. Even if a $p \le$ .005 threshold

7   were widely accepted, this would only reinforce the misconception that a single alpha level is

8   universally applicable. Ideally, the alpha level is determined by comparing costs and benefits

9   against a utility function using decision theory[12]. This cost-benefit analysis (and thus the

10   alpha level)[13] differs when analyzing large existing datasets compared to collecting data from

11   hard-to-obtain samples.

12

13   **Conclusion**

14

15   Science is diverse, and it is up to scientists to justify the alpha level they decide to use. As

16   Fisher noted[14]: "...no scientific worker has a fixed level of significance at which, from year to

17   year, and in all circumstances, he rejects hypotheses; he rather gives his mind to each

18   particular case in the light of his evidence and his ideas." Research should be guided by

19   principles of *rigorous science*[15], not by heuristics and arbitrary blanket thresholds. These

20   principles include not only sound statistical analyses, but also experimental redundancy

21   (e.g., replication, validation, and generalisation), avoidance of logical traps, intellectual

22   honesty, research workflow transparency, and accounting for potential sources of error.

23   Single studies, regardless of their *p*-value, are never enough to conclude that there is strong

24   evidence for a substantive claim. We need to train researchers to assess cumulative

25   evidence and work towards an unbiased scientific literature. We call for a broader mandate

26   beyond *p*-value thresholds whereby all *justifications* of key choices in research design and

27   statistical practice are transparently evaluated, fully accessible, and pre-registered whenever

28   feasible.

References

1. Benjamin, D. J., et al. Nature Human Behaviour 2, 6-10 https://doi.org/10.1038/s41562-017-0189-z (2017).

2. Wacholder, S., Chanock, S., Garcia-Closas, M., El Ghormli, L., & Rothman, N. Journal of the National Cancer Institute 96, 434-442 https://doi.org/10.1093/jnci/djh075 (2004).

3. Open Science Collaboration. (2015). Science 349 (6251), 1-8 https://doi.org/10.1126/science.aac4716 (2015).

4. Senn, S. Statistical issues in drug development (2nd ed). (John Wiley & Sons, 2007).

5. Mayo, D. Statistical inference as severe testing: How to get beyond the statistics wars. (Cambridge University Press, 2018).

6. Johnson, V. E., Payne, R. D., Wang, T., Asher, A., & Mandal, S. Journal of the American Statistical Association 112(517), 1–10 https://doi.org/10.1080/01621459.2016.1240079 (2017).

7. Chambers, C.D., Dienes, Z., McIntosh, R.D., Rotshtein, P., & Willmes, K. Cortex 66, A1-2 https://doi.org/10.1016/j.cortex.2015.03.022 (2015).

8. Lyons, L. Discovering the Significance of 5 sigma. Preprint at http://arxiv.org/abs/1310.1284 (2013).

9. Field, S. A., Tyre, A. J., Jonzen, N., Rhodes, J. R., & Possingham, H. P. Ecology Letters 7(8), 669-675 https://doi.org/10.1111/j.1461-0248.2004.00625.x (2004).

10. Grieve, A. P. Pharmaceutical Statistics 14(2), 139–150 https://doi.org/10.1002/pst.1667 (2015).

11. Mudge, J. F., Baker, L. F., Edge, C. B., & Houlahan, J. E. PLOS ONE 7(2), e32734 https://doi.org/10.1371/journal.pone.0032734 (2012).

12. Skipper, J. K., Guenther, A. L., & Nass, G. The American Sociologist 2(1), 16–18 (1967).

13. Neyman, J., & Pearson, E. S. Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences 231 694–706 https://doi.org/10.1098/rsta.1933.0009 (1933).

1   14. Fisher R. A. Statistical methods and scientific inferences. (Hafner, 1956).

2   15. Casadevall, A., & Fang, F. C. mBio 7(6), e01902-16. https://doi.org/10.1128/mbio.01902-

3   16 (2016).

4

1   **Figure Caption**

2
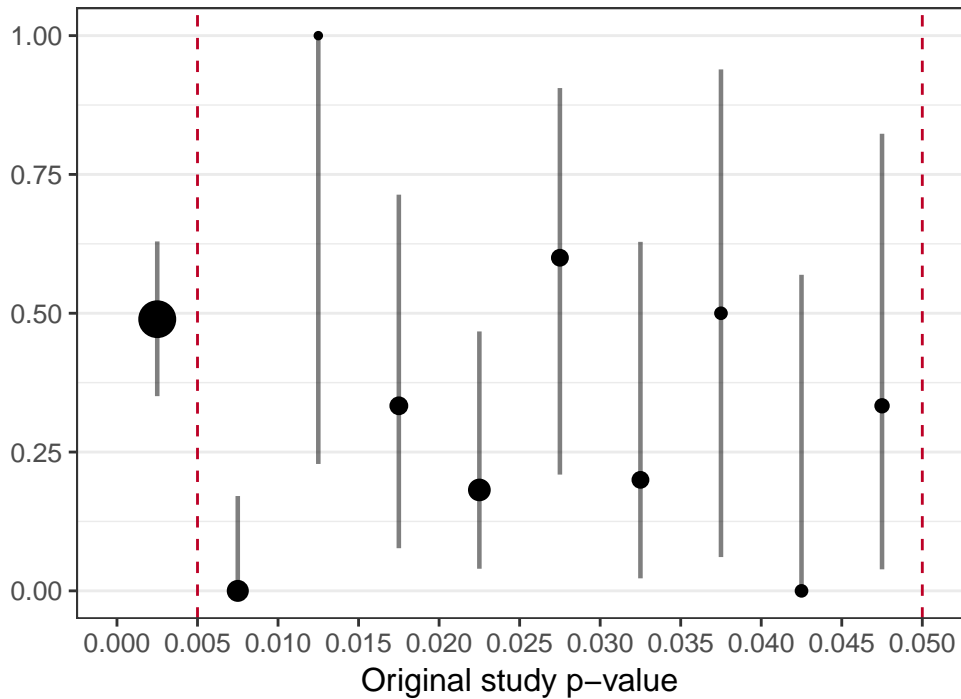
3   *Figure 1.* The proportion of studies[3] replicated at α = .05 (with a bin width of .005). Window

4   start and end positions are plotted on the horizontal axis. The error bars denote 95%

5   Jeffreys confidence intervals. R code to reproduce Figure 1 is available from

6   https://osf.io/by2kc/.