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## Justify your alpha

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1 **Justify Your Alpha**

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7

8 **Abstract:** In response to recommendations to redefine statistical significance to  $p \leq .005$ , we  
9 propose that researchers should transparently report and justify all choices they make when  
10 designing a study, including the alpha level.

11

## Justify Your Alpha

Benjamin et al.<sup>1</sup> proposed changing the conventional “statistical significance” threshold (i.e., the alpha level) from  $p \leq .05$  to  $p \leq .005$  for all novel claims with relatively low prior odds. They provided two arguments for why lowering the significance threshold would “immediately improve the reproducibility of scientific research.” First, a  $p$ -value near .05 provides weak evidence for the alternative hypothesis. Second, under certain assumptions, an alpha of .05 leads to high false positive report probabilities (FPRP<sup>2</sup>; the probability that a significant finding is a false positive).

We share their concerns regarding the apparent non-replicability of many scientific studies, and agree that a universal alpha of .05 is undesirable. However, redefining “statistical significance” to a lower, but equally arbitrary threshold, is inadvisable for three reasons: (1) there is insufficient evidence that the current standard is a “leading cause of non-reproducibility”<sup>1</sup>; (2) the arguments in favor of a blanket default of  $p \leq .005$  do not warrant the immediate and widespread implementation of such a policy; and (3) a lower significance threshold will likely have negative consequences not discussed by Benjamin and colleagues. We conclude that the term “statistically significant” should no longer be used and suggest that researchers employing null hypothesis significance testing justify their choice for an alpha level before collecting the data, instead of adopting a new uniform standard.

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

Benjamin et al.<sup>1</sup> claimed that the expected proportion of replicable studies should be considerably higher for studies observing  $p \leq .005$  than for studies observing  $.005 < p \leq .05$ , due to a lower FPRP. *Theoretically*, replicability is related to the FPRP, and lower alpha levels will reduce false positive results in the literature. However, *in practice*, the impact of lowering alpha levels depends on several unknowns, such as the prior odds that the

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<sup>3</sup> 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 $\alpha = .005$ 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<sup>4</sup>. 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.,  $\mu = 2.81$ ), while a  $p$   
3  $\leq .005$  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<sup>5</sup>. 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  $\alpha = .005$  is that the FPRP can be high with  $\alpha = .05$ . 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  $p \leq .005$  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<sup>3</sup> using an analysis modelling publication bias for 73 studies<sup>6</sup>. 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  $H_1$  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 $p \leq .005$ 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  $\alpha = .005$ , compared to  $\alpha = .05$ , 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  $\alpha = .005$  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<sup>7</sup>. 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<sup>8</sup>. 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<sup>9,10,11</sup>.

3  
4 Benjamin et al. stated that a “critical mass of researchers” endorse the standard of a  $p \leq$   
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  $p \leq .005$  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<sup>12</sup>. This cost-benefit analysis (and thus the  
10 alpha level)<sup>13</sup> 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<sup>14</sup>: “...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*<sup>15</sup>, 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.

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1 **Figure Caption**

2

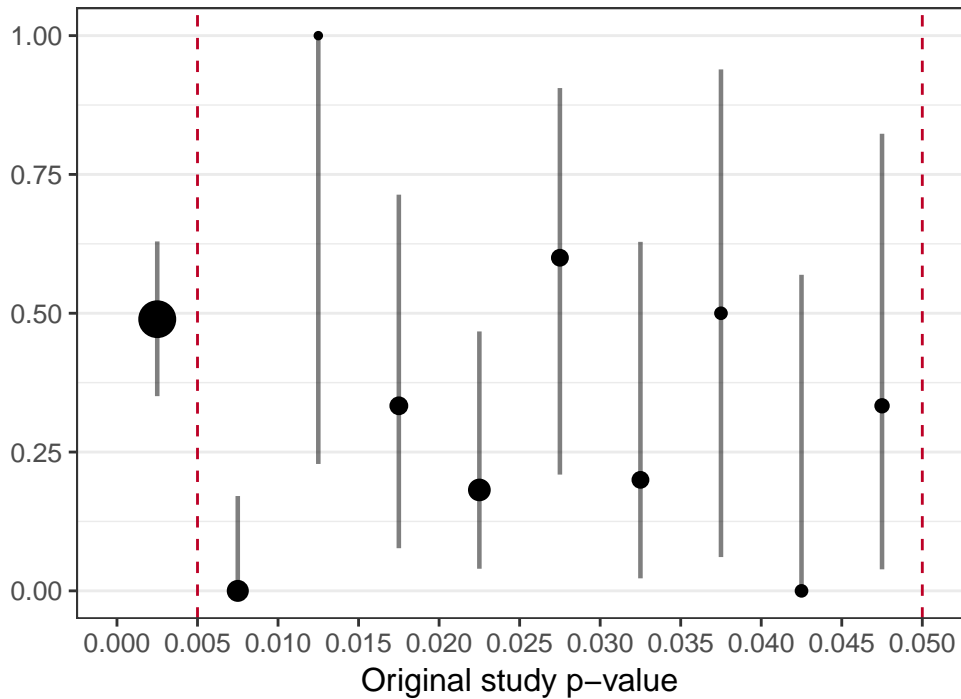
3 *Figure 1.* The proportion of studies<sup>3</sup> replicated at  $\alpha = .05$  (with a bin width of .005). Window

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/>.

Proportion of studies replicated



number of studies

