VIEWPOINT

Editors should allow only significant digits

Arjan Polderman
Retired managing editor and copy editor, Woerden, The Netherlands; polderman.arjan@gmail.com

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"Out of 80 experiments, 45 (56.3%) had a favourable outcome." If you read this sentence in a manuscript, would you want to edit the figures?

I certainly would. There are too many digits in '56.3%'. The decimal 3 is meaningless; 56% is precise enough. If the number of favourable outcomes is 44, the percentage score is 55%; with 46 successes it is 58%. There is no uncertainty here.

But what should we do when we are dealing with 237 out of 623? Both 237 and 238 result in a score of 38%. Wouldn't it be wise to distinguish these outcomes by writing 38.0% and 38.2% respectively? Well, if such precision is important, we can simply present the absolute values. Absolute values are always accurate; percentages and fractions are only approximations.

What might be the purpose of accurate percentages? I appreciate that percentage scores and fractions are better for comparisons than absolute values. With percentages I can see at a glance that 237/623 is more than 165/465 (38% and 35% respectively). Percentages are quick – and inaccurate, even with additional decimals.

Conventions for rounding numbers

Many handbooks present conventions for accuracy in presenting values,[1-3] but these conventions are often neglected. Percentages for samples of fewer than 100 should usually be reported as whole numbers, and those of fewer than about 25 are generally not reported at all unless two or more samples are being compared.

In general, calculations should be performed with one or two digits more than will be reported to prevent cumulation of rounding errors. The resulting value, however, should be rounded to present only significant digits.

Statisticians generally report calculated summary statistics (such as means and standard deviations) to one more decimal place than the numbers from which they are calculated.

The fallacy of false precision

Think again: would 38.0% favourable outcomes in my data set of 623 shed a different light on my scientific experiments than 38.2%?

Some scientists seem to think that such differences are important. The following quotation is an arbitrary (though not random) example: "*Outcomes A and C* were found to be 176.8% and 227% respectively. The 90% CI of *outcomes A and C* were found to be 129.8%–239.8% and 151.4%–341.4% respectively."[4] (Italicized parts are simplified representations.) The confidence interval (CI) of 90% is a measure of the uncertainty of the outcomes. Apparently it is considered important that we know this uncertainty with a precision of four 'significant' digits. Taking value A as an example, the reader should not be misled to suppose that the lower limit of its CI is 129.7% or 129.9%; no, this limit is definitely 129.8%. The value 129.7% is 'out' – but out of what? It is still an outcome with a certain probability.

Let us not be foolish. If the real population average is somewhere between 129.8% and 239.8%, it is accurate enough to write '177% (90% CI 130%–240%)'. If the results are presented as fractions, I would be tempted to trim the figures even more, to '1.8 (90% CI 1.3–2.4)'. The digits that remain in this last option are really significant: omitting them would misrepresent the data set.

What digits are significant?

How many digits are significant in a scientific experiment? Suppose I conduct an experiment with an intervention group and a control group; the outcome may be favourable or not. You may think of votes, patients, mineral concentrations, or whatever you like. I threw a die. A total of 161 throws resulted in the outcomes presented in Table 1.

Table 1. Favourable outcomes (≥ 4) from throwing a die with right hand (control) and left hand (intervention)

Group	Outcome			Favourable outcomes (%)	90% CI (sd = 1.653)
	≤ 3	≥ 4	Total		
Control	40	41	81	50.62	35.51–65.72
Intervention	35	45	80	56.25	41.05–71.45

Now suppose I could include one more experiment. (Who would not welcome such an opportunity?) How would that affect the results? It depends on the place in the matrix:

- control group, outcomes ≤ 3 (n = 41): favourable outcomes 50.00% (34.99%–65.01%);
- control group, outcomes ≥ 4 (n = 42): favourable outcomes 51.22% (36.21%–66.23%);
- intervention group, outcomes ≤ 3 (n = 36): favourable outcomes 55.56% (40.45%–70.66%);
- intervention group, outcomes ≥ 4 (n = 46): favourable outcomes 56.79% (41.69%–71.89%).

Considering these variations, is there really a significant difference between the point estimates 50.00% and 51.22%, or between 55.56% and 56.79%? No, neither in this example nor in many similar study designs.

In the point estimates of the percentages of favourable outcomes, the second digit appears to be unreliable if only 1 in 160 outcomes changes. Not one of the decimal digits is reliable, so none of these is significant. Therefore, I plead for their omission and prefer to present the results as shown in Table 2. Be aware that even these shortened values may change if one additional experiment is included.

Table 2. Favourable outcomes (≥ 4) from throwing a die with right hand (control) and left hand (intervention): percentages expressed in whole numbers instead of up to 2 decimal places

Group	Outcomes			Favourable outcomes (%)	90% CI (sd = 1.65)
	≤3	≥4	Total		
Control	40	41	81	51	36–66
Intervention	35	45	80	56	41–71

This is not a new plea.[1-3,5-8] Already in 1977, referring to even earlier sources, Ehrenberg gave the same guidance in a publication on numerical presentations: "The general rule is to round to two significant or effective digits […]", and went on to offer another important reason "[…] we can see, manipulate, and communicate two-digit numbers much better" than more-digit numbers.[5]

Depending on the position of the decimal point, I encourage writing 0.51 and 0.56, 5.1 and 5.6, 510 and 560, 5100 and 5600, etc, rather than 5062 and 5625 (in the latter case).

Science demands consistency

Did you notice that in the example sentences I quoted above, one value has no decimals? I suspect that the value '227' is short for '227.0' – which is unacceptable in science: '227' indicates a value between 226.5 and 227.5; '227.0' indicates a value between 226.95 and 227.05. This is an essential difference in precision. If decimals are important (which I doubt in the quoted example), they must be presented consistently. If '38.2' is significant, then so is '38.0'. If I have sound reasons for writing '50.62', the same reasons should drive me to write '50.00' as well.

Categories and boundaries

I would also like to make a remark on a loosely related matter: the use of the symbols ≤ and ≥ (as I used in the tables). These symbols are fine for discrete variables, such as policemen, planets, or roulette chances (discrete multiples of 1/37), but not for continuous variables such as distances, stock market indexes, or blood pressure readings. The reason lies in the "equal to" part, which is inappropriate.[9]

Suppose I must sort mail in two classes: up to 20 g and over 20 g. There is no sense in designating these classes as <20 g and ≥20 g (or ≤20 g and >20 g). I do not believe that any letter has a weight of precisely 20.000,000,000,… g – and even then, affixing a postage stamp will increase the weight. There is nothing wrong with categorizing mail in two groups, namely <20 g and >20 g.

I should admit that I am unsure about referring to a crowd of 'under 10,000' or 'over 10,000' people, because people are discrete individuals and there is a chance that exactly 10,000 individuals are present. But even in such a case I would use '<10,000 people' or '>10,000 people', not ≤ or ≥.

But beware: $P > .999$ should not be presented as 1.000 nor $P < .001$ as 0.000.[7]

Conclusion

When presenting values, consider what is essential to the message. All values should be reported with appropriate degree of precision; unnecessary elements should be omitted. Editors have a responsibility here.

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