variance differs between groups (SDR = 2) but sample sizes are equal ($n_1 = n_2 = 50$). **Figure 3c** shows Student's *p*-values plotted against Welch's *p*-values of Scenario 3, where both sample sizes and variances are unequal between groups and the larger variance is associated with the larger sample size (SDR = 2). And, finally, **figure 3d** plots Student's *p*-values against Welch's *p*-values of Scenario 4, where the greater variance is associated with the smaller sample size (SDR = 0.5).

Dots are marked on the black diagonal line when both tests return the same *p*-value. The top left quadrant contains all *p*-values less than 0.05 according to a Student's *t*-test, but greater than 0.05 according to Welch's *t*-test. The bottom right quadrant reports all *p*-values less than 0.05 according to Welch's *t*-test, but greater than 0.05 according to Student's *t*-test. The larger the standard deviations ratio and the greater the sample sizes ratio, the larger the difference between *p*-values from Welch's *t*-test and Student's *t*-test.

Conclusion

When the assumption of equal variances is not met, Student's *t*-test yields unreliable results, while Welch's *t*-test controls Type 1 error rates as expected. The widely recommended two-step approach, where the assumption of equal variances is tested using Levene's test and, based on the outcome of this test, a choice of Student's *t*-test or Welch's *t*-test is made, should not be used. Because the statistical power for this test is often low, researchers will inappropriately choose Student's *t*-test instead of more robust alternatives. Furthermore, as we have argued, it is reasonable to assume that variances are unequal in many studies in psychology, either because measured variables are used (e.g., age, culture, gender) or because, after random assignment to conditions, variance is increased in the experimental condition compared to the control condition due to the experimental manipulation. As it is explained in the additional file, Yuen's *t*-test is not a better test than Welch's *t*-test, since it often suffers high departure from the alpha risk of 5 percent. Therefore, we argue that Welch's *t*-test should always be used instead of Student's *t*-test.

When using Welch's *t*-test, a very small loss in statistical power can occur, depending on the shape of the distributions. However, the Type 1 error rate is more stable when using Welch's *t*-test compared to Student's *t*-test, and Welch's *t*-test is less dependent on assumptions that cannot be easily tested. Welch's *t*-test is available in practically all statistical software packages (and already the default in R and Minitab) and is easy to use and report. We recommend that researchers make clear which test they use by specifying the analysis approach in the result section.

Convention is a weak justification for the current practice of using Student's *t*-test by default. Psychologists should pay more attention to the assumptions underlying the tests they perform. The default use of Welch's *t*-test is a straightforward way to improve statistical practice.

Notes

[1] There is a Type 1 error rate inflation in a few cases where sample sizes are extremely small and SDR is big (e.g., when $n_1 = n_2 = 3$ are sampled from uniform distributions and SDR = 2, the Type 1 error rate = 0.083; or when $n_1 = 3$ is sampled from a uniform distribution and $n_2 = 3$ is sampled from a double exponential distribution). However, with extremely small sample sizes ($N \leq 5$), the estimate of means and standard deviations is extremely inaccurate anyway. As we mentioned in table A2 (see the additional file), the smaller the sample size, the further the average standard deviation is from the population standard deviation, and the larger the dispersion around this average.

[2] This is called the Behren-Fisher problem (Hayes & Cai, 2007).

[3] In a simulation that explored Type 1 error rates, we varied the size of the first sample from 10 to 40 in steps of 10 and the sample sizes ratio and the standard deviation ratio from 0.5 to 2 in steps of 0.5, resulting in 64 simulations designs. Each design was tested 1,000,000 times. Considering these parameter values, we found that the alpha level can be inflated up to 0.11 or deflated down to 0.02 (see the additional file).

[4] Other variants have been proposed, such as the percent trimmed mean (Lim & Loh, 1996).

[5] Because sample sizes are equal for each pair of samples, which sample has the bigger standard deviation is not applicable. In this way, SDR = X will return the same answer in terms of percent power of Levene's test as SDR = 1/X. For example, SDR = 2 will return the same answer as SDR = ½ = 0.5.

[6] For example, many statistical users believe that the Mann-Whitney non-parametric test can cope with both normality and homosedasticity issues (Ruxton, 2006). This assumption is false, since the Mann-Whitney test remains sensitive to heterosedasticity (Grissom, 2000; Nachar, 2008; Neuhäuser & Ruxton, 2009).

[7] Like Bryk and Raudenbush (1988), we note that unequal variances between groups does not systematically mean that population variances are different: standard deviation ratios are more or less biased estimates of population variance (see table A2 in the additional file). Differences can be a consequence of bias in measurement, such as response styles (Baumgartner & Steenkamp, 2001). However, there is no way to determine what part of the variability is due to error rather than the true population value.

[8] Also known as the Satterwaite's test, the Smith/Welch/Satterwaite test, the Aspin-Welch test, or the unequal variances *t*-test.

Competing Interests

The authors have no competing interests to declare.

Additional File

The additional file for this article can be found as follows:

- DOI: https://doi.org/10.5334/irsp.82.s1

Author's Note

All code needed to recreate the simulations resulting in the figures and appendices is available at https://osf.io/bver8/files/, as are as the .txt files containing the results of all simulations.