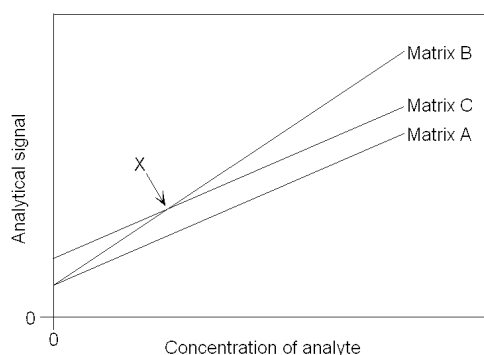


## Standard additions: myth and reality

**‘Standard additions’ is a generally applicable calibration technique, devised to overcome a particular type of matrix effect that would otherwise give rise to a biased result. This ‘rotational effect’ is manifested as a change in the slope of the calibration function. But the standard additions paradigm found in many textbooks does not tell the whole story. We must recognise that the method cannot overcome other types of matrix effect, which must be eliminated by additional measures before standard additions can be effective. Properly implemented, however, standard additions eliminates rotational effects with a negligible effect on precision.**

### Rotational and translational matrix effects

Matrix effects come in two main styles (Figure 1). Matrix A is the matrix of the analyte for calibration purposes. A rotational effect (Matrix B) arises when the size of the signal derived from the analyte is affected by non-analyte constituents of the test solution. The size of the effect for a given matrix is usually proportional to the signal and is therefore sometimes called a ‘proportional’ effect. It changes the slope of the calibration function, but not in its intercept. A ‘translational effect’ (Matrix C) arises from a signal produced by concomitant substances present in the test solution but not by the analyte. It is therefore independent of the concentration of the analyte. It is often referred to as a ‘background’ or ‘baseline’ interference. It affects the intercept of a calibration function, but not its slope. Notice that both styles of interference could have the same effect on the observed signal (point X); it takes observations at more than one concentration to distinguish between the two styles. It is not unusual for both effects to be present simultaneously, but the method of standard additions can correct rotational effects only. Translational effects (if present) have to be separately eliminated or corrected, or the results could be seriously misleading

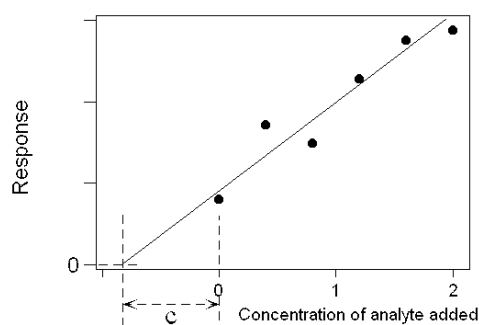


**Figure 1.** Different types of matrix effect on the analytical signal. Matrix A is the calibration matrix. With Matrix B a rotational effect changes the size of the signal derived from the analyte, but not the intercept. With Matrix C the intercept has been shifted by a translational effect, but the slope is unaffected. At point X the two matrix effects fortuitously have the same outcome.

### The method of standard additions

The method is usually presented as the separate addition of several different equally-spaced amounts of analyte to separate

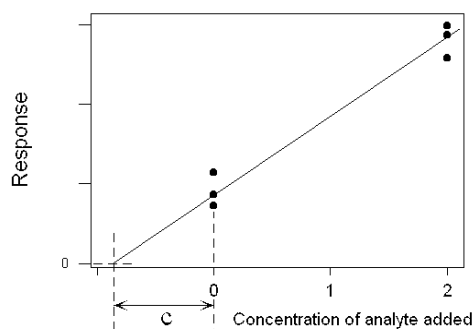
aliquots of test solution (Figure 2). Measurement is followed by extrapolation of the calibration line to zero response.



**Figure 2.** The usual presentation of standard additions. The estimated calibration function (solid line) is extrapolated to zero response, and the magnitude of the corresponding negative reading ( $c$ ) is the concentration estimate.

The use of several spiking concentrations is justified in the standard paradigm by the idea that it helps to check that the calibration is truly linear. However, this rationale is not compelling in a routine, quality-assured laboratory, because:

- you should not attempt standard additions unless you are quite convinced at the validation stage that the analytical calibration is truly linear over the whole relevant concentration range (non-linear extrapolation being an unwise enterprise);
- tests for non-linearity require a large number of measurements to have a useful degree of statistical power. That would require far more work for the analyst than is reasonable for obtaining a single measurement result.



**Figure 3.** Standard additions with the spike added at only one level. This design provides a concentration estimate ( $c$ ) with a precision slightly better than the equally spaced design.

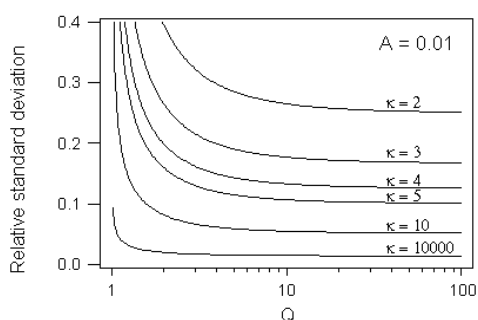
You obtain somewhat better precision in the estimation of the calibration slope if the measurements are confined to the ends of the range (Figure 3). The improvement approaches a factor of  $\sqrt{3}$  under favourable circumstances. With several measurements of response, on the test solution and on a single spiked solution, the best estimate of the calibration function is simply the line joining the two mean results. This procedure gives exactly the same response function as regression, either simple or weighted. Equally importantly, the strategy also requires a smaller number of operations per measurement result.

### Does standard additions degrade precision?

It is often assumed that the extrapolation involved in standard additions causes the precision of the result to be degraded in comparison with 'normal' external calibration. This assumption has been recently challenged [1] for the following reasons.

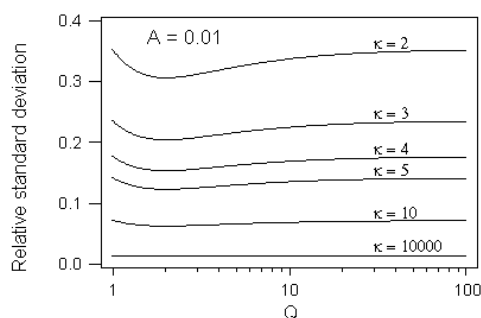
- The precision of the result using either calibration method depends on  $\kappa = T/c_L$ , the original concentration  $T$  of the analyte expressed in units of detection limit  $c_L$ .
- It depends also on  $Q = C/T$ , the relative concentrations of added analyte or top calibrator ( $C$ ) and the original analyte  $T$ .
- It is by no means obvious how to define for comparison purposes an external calibration design that is the exact equivalent of a particular standard additions set-up.

By using a plausible model of an analytical system that takes account of parameters  $Q$  and  $\kappa$ , it has been found possible to derive formulae for the relative standard deviation (RSD) of an analytical result based on either standard additions or external calibration [1]. The outcome of using this model for standard additions is given in Figure 4.



**Figure 4.** Relative standard deviation as a function of  $Q$  and  $\kappa$  with  $A = 0.01$ , of results obtained by standard additions using the one-point addition method shown in Figure 3. (The parameter  $A$  describes the asymptotic precision.)

Figure 4 shows that, when using standard additions, poor results will be obtained unless the concentration of analyte is greater than about 4 times the detection limit ( $\kappa = 4$ ). Generally we see the relative standard deviation of the result getting smaller with increasing  $Q$ . It would pay off always to make the standard addition more than five times the analyte concentration (so long as that is consistent with the linear range of the analytical method, of course). However, there is little improvement in RSD for  $Q > 10$ .

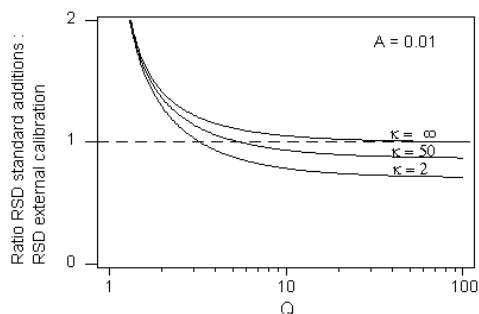


**Figure 5.** Relative standard deviation as a function of  $Q$  and  $\kappa$  with  $A = 0.01$ , of results obtained by external calibration. Here we use a two-point bracketing, with calibrators at zero and at  $Q = (C+T)/T$

Figure 5 shows results obtained by a roughly equivalent (two-point) external calibration strategy. Here we see less dependence on the value of  $Q$

When the two sets of RSDs are compared at equivalent values of  $Q$  and  $\kappa$ , for  $Q > 5$  we see that the ratio is everywhere close to unity, and standard additions gives a slightly better precision

(ratio less than unity) over much of the parameter space illustrated (Figure 6).



**Figure 6.** Ratio RSD by standard additions: RSD by external calibration as a function of  $Q$  and  $\kappa$  for  $A = 0.01$ .

### Recommendations for standard additions

1. Make sure that the analytical method is effectively linear over the whole of the required working range.
2. Make sure that any translational interference is eliminated separately.
3. Only one level of added analyte is necessary, with repeated measurements if better precision is required.
4. Let the concentration of the added analyte be as high as is consistent with linearity, and ideally at least five times the original concentration of analyte.

### A final word on quality control and uncertainty

Some analytical chemists may be concerned about the use of one-point standard additions because there is no built-in way of checking that the addition has been made correctly. With several different levels of addition, a mistake in one might be apparent as an obvious outlier. However, practice has shown that the reliable identification of such outliers is difficult [2]. Moreover, mistakes in procedure should be readily detectable in a quality-controlled analytical run.

When considering the possible use of standard additions, we must always remember that the RSDs referred to above comprise only one term in the uncertainty budget. Even if there is no rotational effect, minor deterioration in precision due to standard additions (if any) will probably make an inconsequential contribution to uncertainty. More importantly, if the procedure cures an otherwise severe (but unrecognised) rotational effect, the true combined uncertainty (as opposed to the incorrect estimated value) of the result will be considerably reduced.

### References

1. S L R Ellison and M Thompson, *Analyst*, 2008, **133**, 992-997.
2. M J Gardner and A M Gunn, *Fresenius J Anal Chem*, 1988, **330**, 103-106.

*This Technical Brief was prepared for the Analytical Methods Committee by the Statistical Subcommittee (Chairman M Thompson.)*

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