The unique criterion constraint: a false alarm?

TO THE EDITOR—In a recent paper in *Nature Neuroscience*, Gorea and Sagi[1] proposed a novel method for estimation of the separate signal and noise components of the contrast transducer in humans. Their experimental task requires detection, simultaneously, in two locations of contrast increments differing by either increment value (see their Fig. 3b) or baseline contrast (their Fig. 4a). In this mixed task, observers adopt a common false alarm rate (FA) for both locations[2] to provide separate estimates of the transducer exponents for the signal and the noise, which took the form of a compressive signal nonlinearity and an almost constant noise.

In the Gorea and Sagi task, however, the only independent quantities are FA and the discriminability (d') derived through signal detection theory. These quantities both depend on the signal-to-noise ratio governing performance rather than on the signal transducer alone. To overcome these basic limitations of psychophysics, Gorea and Sagi[1] introduce a “unique criterion constraint” for all attended stimuli that is critical for their subsequent analysis of mixed-stimulus situations. They show that the assumption of a single criterion is appropriate for same-baseline conditions and then generalize this assumption to mixed-pedestal situations where the properties of the noise sources are at issue.

Formally, the criterion c is linked to the false alarm rate through the expression

$$z(FA) = \Phi^{-1}\left(1 - p(FA)\right) = \frac{c}{\sigma} \qquad (1)$$

where z is the probability z-score, Φ^{-1} is the inverse Gaussian cumulative distribution function with unity standard deviation, and σ is the noise standard deviation. Gorea and Sagi[1] argue that the mixed task enforces the constraint that

$$c_1 = c_2$$

and hence

$$z(FA)_1 \cdot \sigma_1 = z(FA)_2 \cdot \sigma_2 \qquad (2)$$

However, the only property they established was that the false alarm rates were found experimentally to be equal:

$$p(FA)_1 = p(FA)_2 \qquad (3)$$

It therefore follows only that

$$c_1 \cdot \sigma_2 = c_2 \cdot \sigma_1 \qquad (4)$$

and nothing is independently known about the equality of either the criteria or the noise levels. All one can say is that, if the noise levels are equal, the criteria are equal. Previous studies[3–5] would suggest that these different baseline contrasts should evoke different noise levels σ_1 and σ_2. Consequently, the mixed-baseline stimuli could be judged by different criteria (eq. 4), while the false alarm rates could still conform to eq. 3. There is no evidence from Gorea and Sagi[1], therefore, that the different baseline stimuli were judged by a single criterion. Invoking the unique criterion constraint in this situation is just an arbitrary choice. Given that the observers were cued to which stimulus was to be presented on each trial, however, the simplest (most parsimonious) assumption is that the observers equated the false-alarm rates by adopting appropriate criteria for each stimulus condition. For example, if you are asked to detect a bird against a scene containing both a blue sky and choppy waves, you will respond to a faint motion against the sky, but require a much stronger stimulus before accepting a motion in front of the moving waves as a flying bird.

The lack of evidence for unique criterion constraint leaves the transition from their Eq. 4 to Eq. 5 unjustified, because the σ-ratio cannot be related to the $z(FA)$ ratio as asserted in their Eq. 3. In fact, their Eq. 5 can be expressed as a power function of the baseline contrast ratio

$$\frac{d'_2 \Delta C_1}{d'_1 \Delta C_2} = \left(\frac{C_1}{C_2}\right)^{1-\gamma+\gamma\beta} \qquad (5)$$

whose exponent is the slope of the threshold contrast (TvC) function (0.57 ± 0.02 for their two-alternative forced-choice task), and whose remainder is the empirical ratio from their Fig. 4

$$\frac{z(FA)_1}{z(FA)_2} \approx \left(\frac{C_1}{C_2}\right)^{-0.1\pm 0.08} \qquad (6)$$

Therefore, the full ratio in their Eq. 5 should be

$$\frac{d'_2 \Delta C_1 z(FA)_1}{d'_1 \Delta C_2 z(FA)_2} \approx \left(\frac{C_1}{C_2}\right)^{-0.47\pm 0.08} \qquad (7)$$

which is consistent with the Gorea and Sagi estimate of 0.42 ± 0.07 of the same ratio exponent. Their measurements thus confirm the already-known value of the slope of the TvC function and validate the applicability of signal detection theory to contrast discrimination data. Nevertheless, their data are inadequate for disentangling the separate signal and noise exponents.

Indeed, the Gorea and Sagi results are consistent with any combination of signal and noise nonlinearities that predicts the correct TvC slope. In particular, they are consistent with our recent estimates[6] of the accelerating signal transducer $\gamma = 2.3$ and almost multiplicative noise $\beta = 0.83$. These values predict a TvC slope of $1 - \gamma + \gamma\beta = 0.61$, which is indistinguishable from the experimental value of 0.57 measured by Gorea and Sagi.

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REPLY—In our view, the criticism of our work[1] from Kontsevich *et al.* bears on the following two points. First, the observed equality of the false alarm z-scores (zFA) across paired conditions (i,j) does not guarantee our claim of a unique criterion constraint expressed by the equality $c_i = c_j$, with $c_k = zFA_k\sigma_k$ (with c the criterion and σ the standard deviation of the noise). Rather, it necessarily implies

$\sigma_i = \sigma_j$, that is, noise constancy across any conditions i,j. Second, verification of the zFA (rather than c) scores equality for equal baseline conditions (our Fig. 3) does not allow its generalization to unequal baseline conditions; hence zFA scores cannot be compared across baseline levels without an assumption regarding the relative noise values, whose assessment was the purpose of our study.

Kontsevich and colleagues' logic seems to be the following: posing the unique criterion constraint (their eq. 2) and given the equality of the zFAs (or, equivalently, of p(FA)-s; their eq. 3), the equality of the corresponding noises (from their eq. 4) is inescapably true. The major point here is that although we do indeed assume the unique criterion constraint (see below), equality of the FA rates is definitely not a trivial finding; it is the main empirical result presented in our Fig. 4 (ref. 1).

Our original[2] and subsequent[1,7] analyses rest on one important statement: in multiple detection tasks, observers form a unique internal representation of the stimuli, precluding their access to the statistical properties of the internal responses evoked by each stimulus. Based on this average representation, observers presumably set their response criteria according to the standard signal detection theory decision rule (maximizing correct responses). The unique internal representation, together with this decision rule, accounts well for the zFA shifts observed for paired stimuli whose contrasts are sufficiently close for us to assume equal variance (that is, noise) of their internal representation[2]. Given this noise constancy across paired stimuli, zFA and *c* scores are indeed strictly equivalent. Conceptually, however, the unique internal representation model bears on how observers set their response criterion, with the corresponding zFA score being a consequence of it rather than the reverse. Posing the zFA equality as the starting point for their reasoning provides Kontsevich *et al.* with no constraints (on the information available to the observer) to account for why this should be so (whether the observer has to detect a "bird against…a blue sky (or some) choppy waves"). Contrary to the implications of Kontsevich *et al.*, our original account of the data[1] does not draw on the observed equality of the zFA scores. This equality (and thus its criterion equality counterpart) fails—as predicted by the unique internal representation—for unequal probability paired stimuli. Hence, not only is our theoretical starting point not the one given by eq. 3 in Kontsevich *et al.*, but, more importantly, even when verified, this equation has no theoretical basis other than the unique internal representation. In short, although we definitely agree that ultimately we have measured FA rates, predictions of these rates can be made solely based on the unique internal representation or, equivalently, given the equality of the stimulus occurrence probabilities, on the unique criterion constraint.

It clearly follows from the definition of $c_k = zFA_k\sigma_k$ that the unique criterion constraint (and thus the unique internal representation) can be verified directly only for stimulus pairs for which one has good reasons to assume the equality of the related internal noises (in our case for detection and for discrimination with equal strength baselines). We thus agree with Kontsevich *et al.* that posing the unique criterion constraint for unequal baseline paired stimuli is a leap that we prefer to call generalization. However, we do not agree with them that this is an "arbitrary choice". In view of our validation of the unique internal representation over a large number of (equal noise) detection[2,7] and discrimination[1] conditions, we see no *a-priori* reason to reject it for potentially unequal noise paired stimuli (especially in view of our discussion on how the noise within a neural response, if pooled over a large neural population, may override the response-dependent noise of each neuron in the pool[1]). The empirical zFA equality under such conditions is not just a random finding, and Kontsevich *et al.* have not offered an account for it. In sum, the debate here does not bear on whether or not we have generalized the unique criterion constraint from equal to unequal noise stimuli; we have indeed. The debate bears on the reasons for such a generalization. We believe they are good. Kontsevich *et al.* believe they are bad.

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