Zero-dimensional noise is not suitable for characterizing processing properties of detection mechanisms

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Baker and Meese (2012) have recently published an article entitled, "Zero-dimensional noise: The best mask you never saw." In this article, they describe 0D noise, which basically consists in randomly jittering the contrast of the target stimulus. In a series of experiments, they compared processing properties for a detection task in 0D with 2D noise (i.e., white pixel noise). They found that humans behave more like a noisy ideal observer under 0D than 2D noise.

They argued that 0D noise is more suitable for equivalent noise paradigms than pixel noise because 0D noise introduces activity only within the detection mechanisms, whereas 2D noise also affects detection through cross-channel interactions. They propose that "0D noise offers a cleaner method for assessing the factors limiting human performance" (Baker & Meese, 2012, p. 9) within equivalent noise paradigms. Unfortunately, 0D noise is not suitable for characterizing processing properties of detection mechanisms because (a) the processing strategy underlying contrast detection in 0D noise differs from the one in no noise, and (b) detection threshold in 0D noise does not depend on any properties of the detection process.

An underlying assumption of equivalent noise paradigms (Pelli, 1981) is that the same processing strategy operates in absence and presence of noise (i.e., the noise-invariant processing assumption, Allard & Cavanagh, 2011, 2012). Thus, if different processing strategies underlie contrast detection in no and 0D noise, then this compromises the application of the equivalent noise paradigms. A hint that the processing strategy differs in no noise and 0D noise is that the typical instructions given by the experimenter to the observer in detection tasks in no noise are not sufficient in 0D noise. For instance, for a contrast detection task in noiseless condition using a 2-interval forced choice paradigm (as used by Baker & Meese, 2012), the instructions can simply be: "Indicate whether the target was presented in the first or second interval." These simple instructions are not sufficient in 0D noise because the observer usually perceives two stimuli, one in each interval. Consequently, in 0D noise, observers are not performing a "detection" task per se since they are usually detecting the target in both intervals. They are rather discriminating two contrasts while considering a polarity opposite to the target as a negative contrast. An additional indication that a "detection" task in 0D noise is really a discrimination task is that a classical yes-no detection task would be confusing and impractical in 0D noise because the observer almost always perceives a target. Consequently, given that adding 0D noise makes a detection task shift to a discrimination task and that this violates the noise-invariant processing assumption underlying equivalent noise paradigms, we conclude that 0D noise is not suitable for equivalent noise paradigms.

Baker and Meese acknowledge that the processing strategy may differ between 0D and 2D noise because 2D noise contains "activity in the extraneous mechanisms" (Baker & Meese, 2012, p. 9), while 0D noise does not. However, they did not address the more relevant question of whether the processing strategy differs or not when the target is embedded in internal noise (i.e., no external noise) and in high (0D) noise. This question is crucial because equivalent noise paradigms implicitly assume that the processing strategy is the same in low and high noise. Given that internal noise is present in all mechanisms, if the processing strategy differs between 0D and 2D noise due to the activity in the extraneous mechanisms, it would also likely differ between no noise and 0D noise. In a recent study, Allard and Cavanagh (2011) have

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shown that the processing strategy can drastically change depending on the noise conditions. Specifically, a strategy shift was observed when the external noise was spatiotemporally localized on the target (as the 0D and 2D noise used by Baker and Meese), but not when the noise was spatiotemporally broad (i.e., continuously displayed and full screen). They concluded that to minimize the risk that the noise triggers a processing strategy shift, the external noise should be as similar as possible to the internal noise, i.e., be spatiotemporally and spectrally diffused. Since the use of localized noise has been found to cause a processing strategy shift for a detection task (Allard & Cavanagh, 2011) and that 0D noise is perfectly localized as a function of all dimensions, 0D noise does not appear to be suitable for equivalent noise paradigms evaluating contrast detection.

As mentioned above, Baker and Meese propose that "0D noise offers a cleaner method for assessing the factors limiting human performance" (Baker & Meese, 2012, p. 9). However, removing all the dimensions in the noise (except the contrast) also abolishes the evaluation of various factors limiting contrast detection threshold such as the spatiotemporal and spectral tuning of the detection mechanisms. When the target is embedded in uncorrelated noise, performance will be maximized when the tuning of the detection process most closely matches the target. Integrating information over a range wider than the target (for any dimension) would integrate more noise, resulting in a performance decline. Integrating over a range smaller than the target would average out less uncorrelated noise, which would also result in a performance decline. But in 0D noise, varying the integration window should not affect performance. Integrating over a range wider than the target does not integrate more 0D noise, which contains no noise surrounding the target. Integrating over a smaller window would also have no impact since the target and 0D noise templates are perfectly correlated. So what processing factors of the detection process can be assessed by measuring "detection" threshold in 0D noise? It seems that it is not assessing any factor because the task of discriminating which interval contains the highest positive contrast (i.e., detecting a target in 0D noise) is generally trivial (i.e., the ideal response is obvious) and therefore does not assess any limit of the detection process (not its tuning nor any other processing properties). Indeed, in high contrast jitter noise, the two intervals will rarely contain two stimuli having similar contrasts. On most of the trials, the two contrasts will differ substantially (even when the contrast of the target is very low). Therefore, the task is trivial: Report the target that has the highest contrast (while considering the opposite polarity as a negative contrast). For the relatively rare trials in which the two contrasts are similar, the small contrast difference between the intervals provides little information on the interval in which the target is presented so both human and ideal observers would be near chance at identifying the interval containing the target. Even if the observer does not make the ideal choice (i.e., if he chooses the interval with the slightly lower contrast), his chance of having the correct answer (slightly below chance) is not much less than the one of an ideal observer (slightly above chance). Consequently, detection thresholds in 0D noise should be very close to the one of an ideal observer and is therefore not informative of the processing properties of the detection mechanisms.

Baker and Meese measured detection thresholds in high 0D noise but only reported thresholds relative to thresholds in absence of noise. Because they did not provide any absolute detection threshold, we were not able to compare their results with an ideal observer. Nonetheless, in a recent study, Allard and Cavanagh (2012) evaluated orientation discrimination thresholds in 0D noise (i.e., noise defined by orientation rather than contrast). They found that most observers (three out of four in one experiment and three out of three in another) had an orientation discrimination threshold very close to the ideal threshold. This shows that orientation discrimination in 0D noise did not assess processing properties of the orientation discrimination mechanism. This should also be the case for contrast detection. To confirm this, we compared

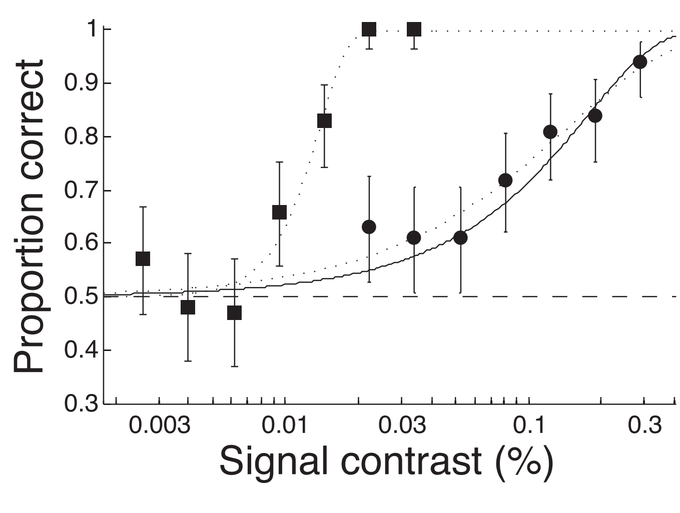

Figure 1. Proportion of correct trials as a function of the stimulus contrast in noiseless condition (squares) and in 0D noise (circles). Error bars show 95% confident interval. The two dotted lines represent the best fits (Weibull functions). Note that the two slopes substantially differ ($\beta = 3.6$ and 0.98, respectively), which is consistent with Baker and Meese's (2012) results. Solid line shows the ideal performance in 0D noise, which closely matches the empirical data.

the performance of an observer (RA, one of the authors) in 0D noise with the one of an ideal observer. We used a contrast detection task in which the target was a Gabor (spatial frequency of 0.5 c/° and standard deviation of the Gaussian window of 1°) with a 2IFC paradigm in which the presentation time was 200 ms and the ISI was 500 ms with the method of constant stimuli (100 trials per contrast level). In both intervals, 12.5% 0D noise was added, which was uncorrelated across intervals and trials. Results are shown in Figure 1: The performance in 0D noise was very close to the one of an ideal observer. Since detection thresholds in 0D noise can be nearly as low as the one of the ideal observer, this implies that measuring detection threshold in 0D noise does not depend on any properties of the detection process and therefore cannot be used to characterize its processing properties.

We conclude that 0D noise should not be used within equivalent noise paradigm because it violates its underlying noise-invariant processing assumption: Adding 0D noise makes a detection task shift to a discrimination task and the localized energy distribution of 0D noise differs from the diffused energy distribution of internal noise, which has been found to trigger a processing strategy shift between the absence and presence of the noise (Allard & Cavanagh, 2011). Furthermore, by using noise in which all the dimensions are removed, the task becomes trivial and therefore does not measure any limit of the detection mechanism. We therefore conclude that 0D noise is not relevant for characterizing the processing properties of detection mechanisms.

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