

Psychophysical Functions as Models of Subjective Visibility

A fundamental issue for our understanding of consciousness is whether visual awareness is a graded continuum or all-or-none. These different hypotheses would require vastly different implementations in cortex: graded awareness implies a neural mechanism that scales, while an all-or-none threshold suggests a separate network might “turn on” during awareness. A number of experiments have found contradictory evidence for either the graded or threshold account of visual awareness. In a series of studies Overgaard and colleagues found graded awareness of stimuli based on gradual increases in performance with increasing stimulus strength accompanied by gradual increases in subjective reports of awareness (for an overview see Sandberg, Bibby, Timmermans, Cleeremans, & Overgaard, 2011). In contrast a number of phenomena show sudden transitions into awareness, for example in the perception of Mooney images, finding solutions to arithmetic problems, and the detection of gist in natural scenes. A biologically plausible explanation for these differences is that these stimuli are represented in different formats. The stimuli in experiments that report a graded increase in awareness are consistently basic visual features: e.g. contrast, color, and orientation whose underlying representations may be more related to their activation strength. In contrast Mooney images often use faces, which, along with numbers and natural scenes are processed and represented by higher stages in the visual hierarchy (Rees, Kreiman, & Koch, 2002). These higher representations may in turn be relatively invariant to strength of visual activation, but simply respond to the presence or absence of their preferred stimuli. Windey et al. (Windey, Gevers, & Cleeremans, 2013) propose that this distinction between earlier and later stages of the visual processing hierarchy is what differentiates continuous transitions into awareness from distinct thresholds. To test their hypothesis they modeled psychophysical data and looked for changes in the slope of their performance function. They show that the slope is steeper for hierarchically “higher” stimulus features. This hypothesis additionally suggests different underlying neural correlates of consciousness (NCC) at different stages of the visual hierarchy: a finding that should cause a shift in the focus of the search for NCCs. Although the hypothesis and modeling approach of Windey et al. are an exciting addition to the available toolkit for studying visual awareness their methodology does not warrant their conclusions. In this brief commentary I outline a methodological issue related to the cognitive model that they employ and steps that could be taken to improve our understanding of this interesting and exciting question.

Windey et al. set out to induce different processing in the visual hierarchy using identical visual stimuli. To produce this effect they asked subjects to perform either color discrimination or value judgment. Subjects were always presented with red or blue colored numbers from 1-9 for 10-80 ms, forward and backward masked. During two response periods participants reported the color (red or blue) or value ($>$ or $<$ 5) and then their subjective awareness on a 1-4 scale (the Perceptual Awareness

Scale, Overgaard et al. 2006). They make the simplifying assumption that performance and awareness are functions of the underlying neural responses according to the framework of signal detection theory. In line with that model they parameterize their performance and awareness data using a Weibull function, where two parameters indicate the upper and lower bounds of performance (floor and ceiling) and two parameters indicate the inflexion point (stimulus strength threshold for 75% performance) and the slope. They found that the slope parameter d differed between tasks. Their slope estimates for both performance and awareness were steeper in the “high-level” task involving numerical judgments; $d_{low} = 2.401$ (SE = 0.174), $d_{high} = 1.969$ (SE = 0.122), $t(19) = 2.033$, $p = 0$ for performance; $d_{low} = 1.797$ (SE = 0.164), $d_{high} = 1.451$ (SE = 0.106), $t(19) = 1.772$, $p = 0.046$ for awareness (Windey et al., 2013). They did not find significant differences in performance between tasks at any stimulus strength. The authors interpret their results to mean that taking into account level of processing is sufficient to integrate the conflicting psychophysical results reviewed earlier. These results are a potentially significant breakthrough showing that the linearity (or non-linearity) of changes in performance and awareness are caused by differences in processing. But their results rely on their comparison of the d parameter across subjects which is controversial given the history that surrounds estimates of the slope parameter.

Discrimination tasks like the one used by Windey et al. are a variant of signal detection tasks (Swets, Tanner Jr, & Birdsall, 1961). Instead of asking participants to report a “yes-no” response for detection they are asked to report about two alternatives of a stimulus feature. This forces subjects to guess when no information is available, effectively removing their response criterion and replacing it with a criterion related to the dimension of interest. According to Swets et al. we can imagine the two-alternative discrimination task to be a choice between Gaussian distributions along a stimulus feature dimension or as two dimensions each with a signal and noise distribution. An observation then is categorized according to some criterion as coming from one of the two signal distributions where the criterion maximizes the rate of success on the task. Another popular modeling approach is to consider two-alternative choices as part of a drift diffusion model in which competing options “drift” towards a response threshold as evidence accumulates (see e.g. Ratcliff, 1978). One issue that continues to plague signal detection and psychophysics in general is the question of how to compare task performance, which requires estimating the underlying distributions and their parameters or the drift/diffusion rates. One approach, and that used by Windey et al, has been to parameterize the performance function and compare the parameters across tasks. This approach is problematic: parameter distributions are known to be skewed and comparisons are therefore best done via bootstrapping (Maloney, 1990; Wichmann & Hill, 2001). In addition, estimating a slope requires significantly more trials than estimating other parameters, for example the psychophysical threshold (the stimulus strength corresponding to a specific % performance) (King-Smith, Ewen P. & Rose, David, 1997). King-Smith & Rose report that with 50 trials the variance of their slope parameter remained large, more than an order of magnitude larger than the threshold, which stabilizes within 50 trials. Kontsevich & Tyler report similar results, that within 30 trials the threshold is precise to 2 dB (23%) but it takes 300 trials to achieve similar precision for the slope (Kontsevich & Tyler, 1999). Accordingly they outline an adaptive procedure to efficiently collect information about the slope (their adaptive staircase chooses its next test value on each trial so as to obtain the maximum amount of information about the slope). Note that Windey et al. recorded 32 trials per task for each participant, corresponding to four trials at each of 8 stimulus strengths. Their choice was undoubtedly motivated by cost and convenience, but according to the brief review of slope

estimation outlined above it significantly undermines the reliability of their estimates. One could argue that by averaging across subjects they avoid the need to accurately estimate the slope within each individual, but this leads to a second major issue. The assumption behind their hypothesis is that in a given brain processing that leads to consciousness of low-level features is graded, while processing for high-level features is some threshold function of lower-level activation. But this difference is likely to be inconsistent and variable across a small sampling of brains. Windey et al. do not report any information about the variability of their slope parameter within subject, but they do report that across subjects their measured confidence intervals are on the order of 25% of their slope measurement.

If our goal in parameterizing the psychometric function is to make a basic model of how different stimulus processing might lead to awareness then we should be primarily focused on whether individual subjects show different awareness functions for each task. This suggests a different task design in which a smaller number of individuals perform a large number of trials. In this way we ensure that slope estimates for each task are precise and that they are comparable. Specifically, they need to be comparable for each subject so that we can ensure that the slope differences are consistent across subjects. For example, if the sign of the slope change differs across subjects then this would be a signal that the model is more nuanced than just a question of hierarchical processing. Crucially, it's the precise magnitude of the difference within each subject that is the estimate of the effect of hierarchical processing differences.

Understanding the nature of conscious experience is a difficult and contentious goal and small steps like those outlined by Windey et al. are of the utmost importance. By parameterizing the psychometric function of performance for two tasks which rely on different processing they show that a single parameter (hierarchy "height") may be sufficient to explain diverging evidence in the literature on visual awareness. In addition their hypothesis makes many predictions about the directionality of measurements of perception for other hierarchically organized features, including that features at equal hierarchical levels in different brain regions should show similar gradation in perceptual awareness. Pursuing these questions with experimental designs that allow increased precision on parameter estimates will undoubtedly yield interesting results. Windey et al.'s methodology is a step in the right direction and opens the door to re-examining a number of cognitive modeling approaches by adding hierarchical processing level as a parameter of interest.

References

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