

THEORETICAL NOTE

The Nature of Psychological Thresholds

Jeffrey N. Rouder
University of Missouri

Richard D. Morey
University of Groningen

Following G. T. Fechner (1966), thresholds have been conceptualized as the amount of intensity needed to transition between mental states, such as between a states of unconsciousness and consciousness. With the advent of the theory of signal detection, however, discrete-state theory and the corresponding notion of threshold have been discounted. Consequently, phenomena such as subliminal priming and perception have a reduced theoretical basis. The authors propose a process-neutral definition of threshold that allows for graded perception and activation throughout the system. Thresholds correspond to maximum stimulus intensities such that the distribution of mental states does not differ from that when an appropriate baseline stimulus is presented. In practice, thresholds are maximum intensities such that the probability distribution on behavioral events does not differ from that from baseline. These thresholds, which the authors call *task thresholds*, may be estimated with modified item response psychometric measurement models.

Keywords: psychophysics, consciousness, subliminal perception, item response models, thresholds of consciousness

The duality of consciousness and unconsciousness has been influential in shaping psychological theory at least since Leibniz's unpublished 1704 essay (see Boring, 1950, pp. 166–168). It has often been claimed that stimuli too faint to be detected or identified nonetheless arouse unconscious activation that may influence subsequent behavior (e.g., *subliminal perception* and *subliminal priming*; Dehaene et al., 1998; Greenwald, Draine, & Abrams, 1996; Van Opstal, Reynvoet, & Verguts, 2005). These findings of subliminal phenomena not only are surprising in their own right but have influenced theories of human information processing (e.g., Greenwald, Abrams, Naccache, & Dehaene, 2003), emotional processing (e.g., Li, Zinbarg, Boehm, & Paller, 2008), and mental pathology (e.g., Dehaene et al., 2003).

The phenomena of subliminal priming and subliminal perception imply that there exists a perceptual threshold or limen. Yet modern perceptual theories, such as signal detection theory (Green & Swets, 1966; Tanner & Birdsall, 1958), posit a continuum of mental states rather than discrete mental states. On the basis of the success of the theory of signal detection, Swets (1961) declared that thresholds do not exist. Since then, the concept of a threshold has been discounted. In modern psychophysics, the threshold is nothing more than shorthand for an arbitrary level

of performance, say, .707 or .75, which has little theoretical meaning or justification.

The success of modern perceptual models that posit a continuum of mental states without recourse to thresholds poses a challenge for researchers of subliminal phenomenon. Consider the following from Greenwald, Klinger, and Schuh (1995):

The term *subliminal* implies a theory of the perceptual threshold, or limen, that has been largely abandoned as a consequence of the influence of signal detection theory (Green & Swets, 1966). A more theoretically neutral designation of the class of stimuli which this article is concerned is *marginally perceptible*. This article uses *subliminal* and *marginally perceptible* as interchangeable designations. (p. 22)

Greenwald et al.'s solution to this problem is semantic—they consider subliminal perception as marginal perception. In our view, the problem is not mitigated by simple redefinitions. In this article, we propose a revised conceptualization of threshold that has two benefits: First, these thresholds are compatible with continuous-state models, and second, they are useful in assessing the existence of subliminal phenomena.

In the next section, we briefly review the Fechnerian view of the psychophysical threshold. This view posits a latent threshold that separates mental states of consciousness from unconsciousness. Though this view is convenient, it is not as competitive as continuum-state models that have no recourse to perceptual thresholds. Following this review, we propose a different view of the threshold. We assume that without stimulation, there is a distribution on the possible mental states that govern performance on a particular task. If and only if a stimulus is above threshold in intensity, then the distribution across these mental states is different than that from the no-stimulation baseline. We term this threshold the *task threshold* and show how it provides a natural theoretical framework for investigating subliminal perception. Though task thresholds are theoretically appealing, they entail substantial statistical difficulties in measuring threshold inten-

Jeffrey N. Rouder, Department of Psychological Sciences, University of Missouri; Richard D. Morey, Heymans Institute, University of Groningen, Groningen, The Netherlands.

We thank Micahel Pratte, Steven Hackley, James Townsend, Duncan Luce, and Geoffrey Loftus for helpful comments. This research is supported by National Science Foundation Grant SES-0351523 and National Institute of Mental Health Grant R01-MH071418.

Correspondence concerning this article should be addressed to Jeffrey N. Rouder, Department of Psychological Sciences, 210 McAlester Hall, University of Missouri, Columbia, MO 65211. E-mail: rouderj@missouri.edu

sities. To overcome these difficulties, we recommend a class of hierarchical item response models.

Historical Definitions of the Threshold

The modern concept of a psychological threshold was formulated by 19th century German philosopher–scientists Herbart, Weber, and Fechner to separate consciousness from unconsciousness. These scholars were occupied with Leibniz’s problem of consciousness (Boring, 1950). Leibniz noted that one may be conscious of the sound of a wave at a beach but that the sound of each drop of water crashing remains unnoticed. Given that the wave is nothing more than the sum of droplets, how could the sum of unnoticed elements reach consciousness? To Leibniz, each droplet left a *petite perception* that was more intense than the absence of a droplet but not sufficient in itself for consciousness. Because these petite perceptions have finite intensity, they may sum past a threshold level, that is, their sum may be consciously perceived.

Leibniz’s petite perceptions serve as a precursor for Fechner’s psychophysics. Fechner conceptualized thresholds as the amount of stimulation needed to transition between the mental states of unconsciousness and consciousness. Fechner (1966) wrote,

The following phenomenon is inherent in the nature of the threshold. The farther the stimulus or stimulus difference falls below the threshold, the less chance there is for the stimulus or stimulus difference to be perceived and the greater must be the amount added before sensation can be felt. As long as the stimulus or stimulus difference remains below threshold, its perception is, as one says, unconscious. (pp. 205–206)

Fechner’s prose is remarkably contemporary. According to Fechner, stimuli give rise to latent sensations. These sensations are graded and may even vary across repeated presentations of the same stimulus. If they are sufficiently strong, then there is a transition from the mental state of unconsciousness to the mental state of consciousness. We refer to these Fechnerian thresholds as *mental-state thresholds* because they govern the transition from one mental state to another.

Fechner’s threshold for the transition between states is similar to formal discrete-process theories of detection and discrimination. Examples of these formal models include the high-threshold model (Blackwell, 1953), the double-high-threshold model (Egan, 1975), the Bekésy–Stevens quantum model (Stevens, 1972), and the low-threshold model (Luce, 1963). In general, these models incorporate one state for detection and another for the lack thereof. Although these models rely on discrete mental states, they do not preclude graded perception per se. They do stipulate, however, that there is a mapping of graded perception into discrete mental states, and it is the probabilities on these discrete mental states that determine the response probabilities. These discrete-state models may be contrasted with more modern continuous-state models such as the theory of signal detection.

One of the properties of the Leibniz–Fechner view is that even faint stimuli are transduced into some sensation. Though these sensations are not sufficiently strong to be conscious, they nonetheless exist and can be added to other faint sensations. A contrasting view is that faint stimuli are not transduced at all. In this view, the sound of Leibniz’s water droplets is so faint that it cannot activate sensory receptors above baseline. This view may be traced to Adrian (1928), who distinguished between two types of changes in the environment: those that are sufficient to excite sensory tissue and those that are not. To extend Adrian, the former are above threshold while the later are not. Importantly, this conception of threshold is defined without recourse to latent sensation or the transition between mental states. Because these thresholds describe properties of receptor systems in the periphery of processing, we refer to them as *peripheral thresholds*. Whether peripheral thresholds exist is a fascinating question. For example, Cornsweet (1970) provided a discussion about the retinal sensitivity for a few photons of light. The question of the existence of peripheral thresholds, however, is not material for our subsequent definition of threshold.

Figure 1 shows that peripheral and mental-state thresholds are orthogonal concepts. Figure 1A shows an example of a peripheral threshold without a mental-state threshold. The model of perception

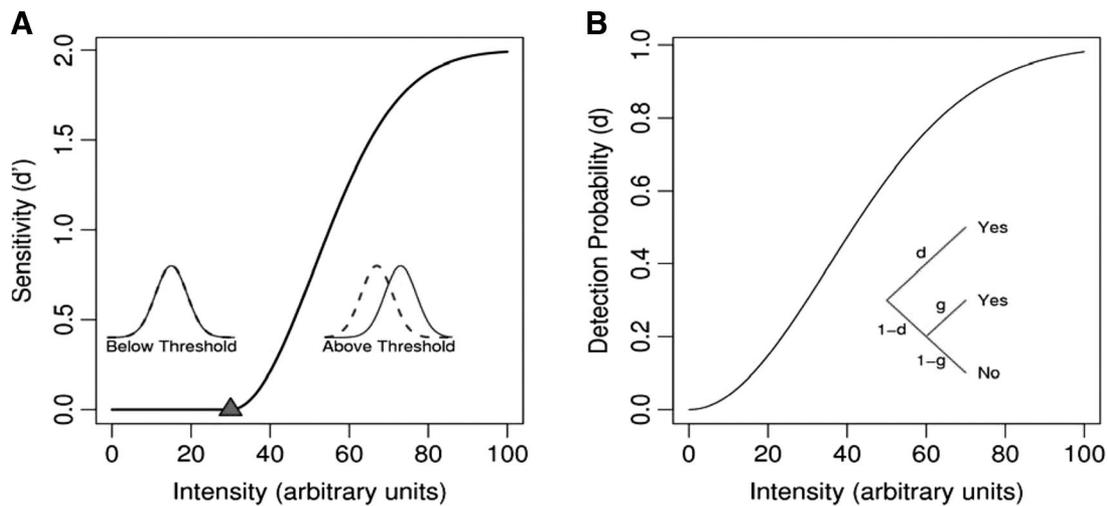


Figure 1. Peripheral and task thresholds are orthogonal concepts. A: An example of a peripheral threshold and no mental-state threshold. B: An example of a mental-state threshold and no peripheral threshold.

is signal detection, and the main graph is a hypothetical relationship between stimulus intensity and sensitivity (d'). As shown, there is a peripheral threshold, denoted with a triangle at an intensity of 30. Stimuli with intensities below this value give rise to a range of latent strengths, but the distribution of these strengths is exactly the same as if there had been no stimulation (see left inset). Stimuli more intense than the peripheral threshold result in distributions of latent states different from baseline, as shown in the right inset. Figure 1B shows the opposite case—the presence of a mental state threshold and the absence of a peripheral one. Responses are assumed to be governed by a high-threshold model (Blackwell, 1953), with d denoting the probability of detection. This probability is zero for a lack of stimulation. For any stimulus intensity value above zero, however, the probability of detection is above zero, indicating that for arbitrarily small intensities, there is some peripheral activity. It is straightforward to construct either cases in which both peripheral and mental-state thresholds exist or cases in which neither peripheral nor mental-state thresholds exist.

Figure 1A illustrates a critical property of peripheral thresholds—they may be interpreted as describing how the distribution of mental states is affected by stimulation. Specifically, stimuli with intensities below the peripheral threshold give rise to the same distribution of mental states as that from the no-stimulation baseline. Stimuli with intensities above threshold, conversely, give rise to different distributions than that from the no-stimulation baseline.

Task Thresholds

One problem with peripheral thresholds is that they do not account for loss beyond the peripheral receptors. For instance, it may be that a visual stimulus is sufficiently intense to stimulate the peripheral system yet may not be intense enough to affect central processes of object identification. In this case, the probabilities across mental states mediating object-identification performance are no different than those from the no-stimulation baseline. Hence, we introduce the notion of a task threshold: the maximum stimulus intensity such that probability distributions across mental states mediating performance on a specific task are no different than those from a no-stimulation baseline. To the extent that different tasks recruit different information-processing pathways, responses in a task may be affected by different thresholds. Task thresholds are useful if one makes the following correspondence assumption: Two stimuli give rise to the same true performance levels if and only if they give rise to the same distribution across mental states mediating performance. With this correspondence assumption, the task threshold is the maximum stimulus intensity such that true performance is identical to that from the no-stimulation baseline. These task thresholds are ideal for conceptualizing and assessing subliminal perception.

Figure 2 depicts how task and peripheral thresholds may mediate performance in two tasks, denoted Task A and Task B. Stimuli are shown in the lowest box as a set of bars. The height indicates intensity, and Stimulus 0 serves as baseline. The peripheral threshold, the Task A threshold, and the Task B threshold are depicted as dashed horizontal lines labeled P, A, and B, respectively. All nonbaseline stimuli but Stimulus 1 meet the peripheral threshold, Stimuli 3 and 4 exceed the Task A threshold, and only Stimulus 4 exceeds the Task B threshold. The middle box shows the corre-

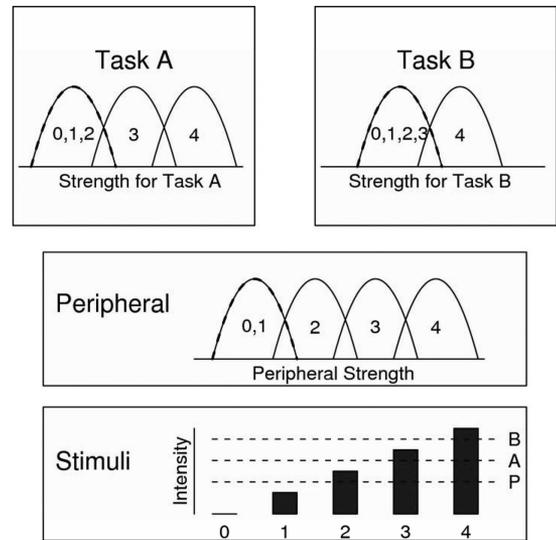


Figure 2. An illustration of task and peripheral thresholds. Stimulus intensity and thresholds are denoted in the lower box as bars and dashed lines (B = Task B threshold; A = Task A threshold; P = peripheral threshold). Resulting activation at peripheral and task levels is shown in the upper three boxes.

sponding distributions of peripheral strengths, that is, the activation in the peripheral system. The distribution for baseline is denoted with a dashed line. Stimuli 1 is too weak to rise above the peripheral threshold; consequently, the peripheral strength distribution is the same as that for baseline. The three stimuli of higher intensity are above the peripheral thresholds and give rise to distributions of progressively greater peripheral activation. For Task A, Stimuli 1 and 2 are below the Task A threshold and, consequently, give rise to the same distribution on task-mediating strength as does the baseline. For Task B, Stimulus 4 is the only one above the Task B threshold; hence, only it gives rise to a distribution of Task B strengths different than baseline. Importantly, task thresholds may exist even if peripheral ones do not, and this fact is demonstrated by Stimuli 2 and 3, which exceed the peripheral threshold but not the Task B threshold. Figure 2 depicts continuous-state processing for illustrative purposes; task thresholds apply to discrete-state models as well.

Subliminal phenomena may be assessed with task thresholds. Subliminal priming, for example, refers to the effects on subsequent behavior of stimuli that may not be detected. Subliminal priming holds if Task A in Figure 2 measures the priming effect of stimuli while Task B measures their detectability. In this case, the task threshold for priming is lower in intensity than that for detection. The phenomenon of priming without awareness (e.g., Bargh, Chen, & Burrows, 1996) may also be implemented as a comparison of task thresholds. The participant crosses an awareness-task threshold when the probability of an “aware” response is greater to a stimulus than it is to an appropriate baseline. In this conceptualization, awareness is not the outcome on any one trial but rather refers to the distribution of outcomes across trials. Perception without awareness may then be defined as the ability to detect or discriminate stimuli that do not meet an awareness-task threshold. This definition of awareness as a change in the distri-

bution of probabilities across task-mediating mental states avoids some of the difficulties associated with more conventional measures (cf. Kunimoto, Miller, & Pashler, 2001; Reingold & Merikle, 1988).

In sum, task thresholds have the following properties: (a) Task thresholds are defined on physical intensity variables rather than on latent sensations. (b) Task thresholds are defined without recourse to underlying mental architecture and, in particular, are compatible with graded perception. (c) Task thresholds are task specific. This task-specificity allows for a large degree of flexibility that may be used in assessing subliminal phenomena. (d) The baseline level of performance associated with below-threshold stimulation is not arbitrary. For example, if participants observe either Stimulus A or Stimulus B on any trial and these two are presented equally often, then the baseline on accuracy is necessarily .50. If d' is the desired dependent measure, then $d' = 0$ serves as the appropriate baseline. This property contrasts with the arbitrariness of stipulating thresholds at a conventional level of performance, such as .75 or .707.

The concept of a task threshold is present to varying degrees in several extant models, including those of Busey and Loftus (1994); Loftus, Duncan, and Gehrig (1992); Nosofsky (1983); Shibuya and Bundesen (1988); Stevens (1972); and Townsend (1981). Consider Busey and Loftus, who modeled the processing of stimuli that are briefly flashed and subsequently masked. The duration of the stimulus serves as the intensity variable, and stimuli of insufficient duration give rise to performance no different than chance. Figure 3 shows a simplified version of their model. Stimuli of all durations are assumed to result in peripheral activation (see the four curves corresponding to durations of 20, 30, 40, and 50 ms). There is a bound on this activation (see dotted line). Performance is modeled as an increasing function of the area under the curve and above the bound (see hatched areas). In Figure 3, curves for durations of 40 ms and 50 ms have nonzero area above the bound, hence, these

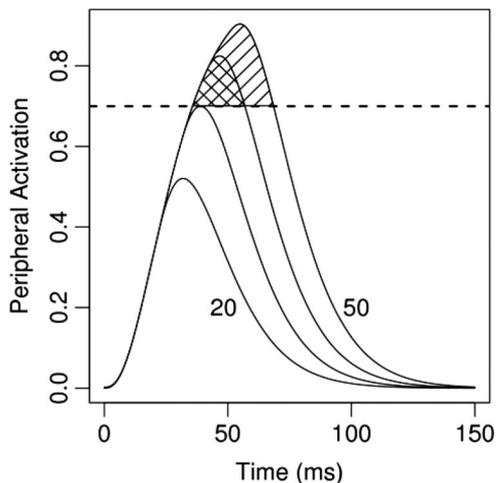


Figure 3. A simplified version of the Busey and Loftus (1994) model. Peripheral activation is shown for stimuli of 20, 30, 40, and 50 ms. A bound is placed on this activation, and the probability of detection is a function of the area under the curve and above the bound (see hatched areas). Only durations above 30 ms yield activation above the bound. Hence, the duration of 30 ms serves as a task threshold.

durations yield performance above baseline. Durations of 20 ms and 30 ms, in contrast, have no such area and yield performance at baseline. The model in Figure 3, therefore, implements a task threshold at a duration of 30 ms.

Measuring Task Thresholds

Although the proposed definition of task threshold is advantageous from a theoretical perspective, it entails substantial methodological complexities. The main problem is one of precision—it is difficult to determine if near-baseline levels of observed performance reflect baseline or slightly-above-baseline true levels. For instance, consider two-choice paradigms in which .50 is the at-chance baseline. Figure 4 shows the expected 95% confidence intervals (CIs) on accuracy as a function of sample size for two levels of true accuracy: .50 and .52. The CIs from one level of accuracy exclude the other level after about 2,400 trials. Restated, the power of excluding chance with a true accuracy of .52 with 2,400 trials is only 1/2. Unfortunately, it is rarely practical to run several thousand trials per participant per condition.

One way to gain the requisite precision is to pool data across participants. We have recently proposed modified item response theory (IRT) models for accurately measuring thresholds. In Morey, Rouder, and Speckman (2008), Morey, Rouder and Speckman (in press), and Rouder, Morey, Speckman, and Pratte (2007), we have provided extensive development. Here, we provide a brief overview of these measurement models for the two-choice case with a baseline of .50 in which stimuli are presented at several different intensity levels. The task threshold is the maximum intensity such that performance is at the .50 baseline. Conventional IRT models are incompatible with task thresholds because performance is modeled as being above baseline for all stimuli.

The task-threshold measurement model is developed as follows: Consider each intensity level as an item. Let p_{ij} denote the true probability of correct performance for the i th participant to the j th level of intensity, $i = 1, \dots, I, j = 1, \dots, J$. We characterize each participant with an ability parameter α_i and each item (i.e., each level of intensity) with a difficulty parameter β_j . Participant abilities are treated as zero-centered random effects; item difficulties are treated as fixed effects. A task threshold is implemented by assuming that performance is at baseline if an item is more difficult than a participant is able (i.e., $\beta_j > \alpha_i$). Likewise, performance is above threshold if the participant is more able than the item is difficult (i.e., $\alpha_i \geq \beta_j$). The following model incorporates task thresholds:

$$p_{ij} = \begin{cases} \Phi(\alpha_i - \beta_j); & \alpha_i \geq \beta_j; \\ .5 & \alpha_i < \beta_j; \end{cases} \quad (1)$$

where Φ is the cumulative distribution function of the standard normal (i.e., the normal ogive). Task thresholds for individual participants are estimated by finding intensities with values of β_j closest to α_i . Functional relationships between intensity and difficulty may be proposed. For instance, Morey et al. (in press) found a linear relationship between the logarithm of duration and item difficulty for the identification of digits. The measurement models are based on parametric assumptions including the shape of the normal ogive and the additivity between item difficulty and participant ability. These assumptions may be checked by conven-

tional diagnostics such as inspecting residuals for misspecification (e.g., Pedhazur, 1997).

Do Task Thresholds Exist?

The question of whether task thresholds exist is fundamental for the many claims of subliminal phenomena. The question, however, is difficult to answer. Figure 5 shows accuracy data from Loftus et al. (1992) for two participants. Targets were digits that were briefly presented and subsequently masked. Because there were 10 digits in the design, the chance baseline in this task corresponded to .10 (dotted line). Dashed lines show the fit of a task-threshold model with thresholds at 60 ms and 80 ms, respectively. This fit is reasonable and demonstrates the plausibility of task thresholds. Although the data are consistent with task thresholds, they are also consistent with trajectories that have no task threshold. The solid lines, for instance, show the predictions of a nonthreshold model based on a log-normal link function. Though it is not obvious from the graph, the solid lines are above the baseline for all positive values of duration, indicating a lack of a task threshold.

The fact that nonthreshold models can mimic threshold behavior complicates the assessment of whether thresholds exist. In fact, appropriately chosen nonthreshold models can predict performance arbitrarily close to baseline with arbitrarily sharp rises from it. They are, therefore, more flexible than threshold models. Assessing the existence of thresholds will necessitate a sophisticated model-selection approach that penalizes flexibility, such as Bayes factors (Kass & Raftery, 1995; Myung & Pitt, 1997). The development of such an approach is an involved endeavor that is outside the scope of this note.

Conclusion

In summary, we have provided a definition of threshold that is independent of underlying mental architecture without being unduly arbitrary. A stimulus is below a task threshold if and only if

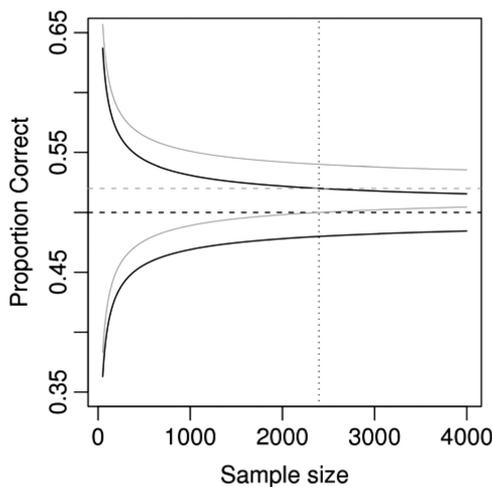


Figure 4. Expected 95% confidence intervals as a function of sample size for true accuracies of .50 (dark lines) and .52. (light lines). The vertical line at a sample size of 2,395 shows where the power to detect the difference is 1/2.

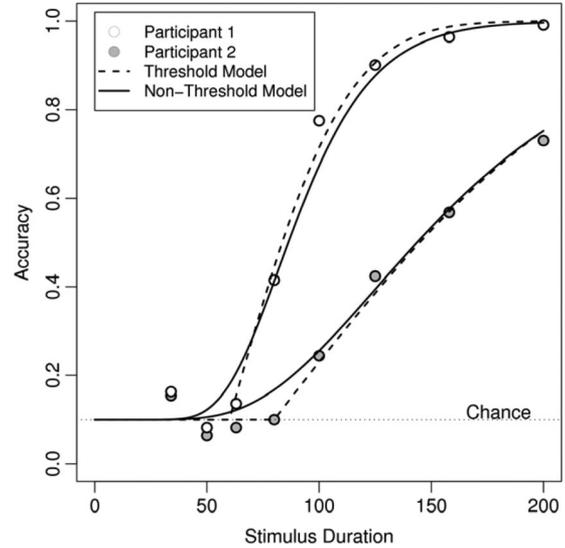


Figure 5. Digit identification performance for two participants from Loftus et al. (1992). Accuracy is plotted as a function of stimulus duration. The dotted line indicates the chance baseline. Predictions of a threshold and nonthreshold model are indicated with dashed and solid lines, respectively. The threshold model is given as follows: Let p and d denote the accuracy and duration, respectively. Then $p = 1.8 \times \Phi((d - \theta_1)/\theta_2) - .8$ for $d > \theta_1$, and $p = .1$ otherwise. In this model, θ_1 denotes the threshold, and θ_2 denotes the rate of improvement after threshold is reached. The nonthreshold model is implemented as a log-normal link function: $p = .1 + .45 \times (1 + \text{erf}((\log d - \mu)/\sigma\sqrt{2}))$, where $\text{erf}()$ is the Gaussian error function. This link implies that there is no task threshold, that is, p is greater than the .1 baseline for all positive values of d . Data for Participants 1 and 2 adapted from "On the Time Course of Perceptual Information That Results From a Brief Visual Presentation," by G. R. Loftus, J. Duncan, and P. Gehrig, 1992, *Journal of Experimental Psychology: Human Perception and Performance*, 18, p. 532, Figure 3. Copyright 1992 by the American Psychological Association.

the resulting performance on a measure is identical to that from an appropriate baseline. The definition is sufficiently general to allow for subliminal priming, which may be defined as lower thresholds for priming measures than for identification measures. The measurement of these task thresholds may be done by pooling information with modified IRT models. With this definition and the associated measurement models, researchers can incorporate thresholds into models of cognition and perception more profitably than is currently afforded. Whether there truly are task thresholds is an unresolved question but one that can hopefully be addressed by modern model-selection techniques.

References

Adrian, E. D. (1928). *The basis of sensation*. New York: Norton.
 Bargh, J., Chen, M., & Burrows, L. (1996). Automaticity of social behavior: Direct effects of trait construct and stereotype activation on action. *Journal of Personality and Social Psychology*, 71, 230–244.
 Blackwell, H. R. (1953). *Psychological thresholds: Experimental studies of methods of measurement* (Bulletin No. 36). Ann Arbor: University of Michigan, Engineering Research Institute.
 Boring, E. G. (1950). *A history of experimental psychology* (2nd ed.). New York: Appleton-Century-Crofts.

- Busey, T. A., & Loftus, G. R. (1994). Sensory and cognitive components of visual information acquisition. *Psychological Review*, *101*, 446–469.
- Cornsweet, T. N. (1970). *Visual perception*. New York: Academic Press.
- Dehaene, S., Artiges, E., Naccache, L., Martelli, C., Viard, A., & Schurhoff, F. (2003). Conscious and subliminal conflicts in normal subjects and patients with schizophrenia: The role of the anterior cingulate. *Proceedings of the National Academy of Sciences, USA*, *100*, 13722–13727.
- Dehaene, S., Naccache, L., Le Clech, G., Koechlin, E., Mueller, M., & Dehaene-Lambertz, G. (1998, October 8). Imaging unconscious semantic priming. *Nature*, *395*, 597–600.
- Egan, J. P. (1975). *Signal detection theory and ROC analysis*. New York: Academic Press.
- Fechner, G. T. (1966). *Elements of psychophysics*. New York: Holt, Rinehart & Winston.
- Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics*. New York: Wiley.
- Greenwald, A. G., Abrams, R. L., Naccache, L., & Dehaene, S. (2003). Long-term semantic memory versus contextual memory in unconscious number processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*, 235–247.
- Greenwald, A. G., Draine, S. C., & Abrams, R. L. (1996, September 20). Three cognitive markers of unconscious semantic activation. *Science*, *273*, 1699–1702.
- Greenwald, A. G., Klinger, M., & Schuh, E. (1995). Activation by marginally perceptible (“subliminal”) stimuli: Dissociation of unconscious from conscious cognition. *Journal of Experimental Psychology: General*, *124*, 22–42.
- Kass, R., & Raftery, A. (1995). Bayes factors. *Journal of the American Statistical Association*, *90*, 773–795.
- Kunimoto, C., Miller, J., & Pashler, H. (2001). Confidence and accuracy of near-threshold discrimination responses. *Consciousness and Cognition*, *10*, 294–340.
- Li, W., Zinbarg, R., Boehm, S., & Paller, K. (2008). Neural and behavioral evidence for affective priming from unconsciously perceived emotional facial expressions and the influence of trait anxiety. *Journal of Cognitive Neuroscience*, *20*, 95–107.
- Loftus, G. R., Duncan, J., & Gehrig, P. (1992). On the time course of perceptual information that results from a brief visual presentation. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 530–549.
- Luce, R. D. (1963). A threshold theory for simple detection experiments. *Psychological Review*, *70*, 61–79.
- Morey, R. D., Rouder, J. N., & Speckman, P. L. (2008). A statistical model for discriminating between subliminal and near-liminal performance. *Journal of Mathematical Psychology*, *52*, 21–36.
- Morey, R. D., Rouder, J. N., & Speckman, P. L. (in press). A truncated-probit item response model for estimating psychophysical thresholds. *Psychometrika*.
- Myung, I.-J., & Pitt, M. A. (1997). Applying Occam’s razor in modeling cognition: A Bayesian approach. *Psychonomic Bulletin & Review*, *4*, 79–95.
- Nosofsky, R. M. (1983). Information integration and the identification of stimulus noise and criterial noise in absolute judgment. *Journal of Experimental Psychology: Human Perception and Performance*, *9*, 299–309.
- Pedhazur, E. J. (1997). *Multiple regression in behavioral research*. Monterey, CA: Wadsworth.
- Reingold, E. M., & Merikle, P. M. (1988). Using direct and indirect measures to study perception without awareness. *Perception & Psychophysics*, *44*, 563–575.
- Rouder, J. N., Morey, R. D., Speckman, P. L., & Pratte, M. S. (2007). Detecting chance: A solution to the null sensitivity problem in subliminal priming. *Psychonomic Bulletin & Review*, *14*, 597–605.
- Shibuya, H., & Bundesen, C. (1988). Visual selection from multielement displays: Measuring and modeling effects of exposure duration. *Journal of Experimental Psychology: Human Perception and Performance*, *14*, 591–600.
- Stevens, S. S. (1972, September 1). A neural quantum in sensory discrimination. *Science*, *171*, 749–762.
- Swets, J. A. (1961, July 21). Is there a sensory threshold? *Science*, *134*, 168–177.
- Tanner, W. P., Jr., & Birdsall, T. G. (1958). Definition of d' and n as psychophysical measures. *Journal of the Acoustical Society of America*, *30*, 922–928.
- Townsend, J. T. (1981). Some characteristics of visual whole report behavior. *Acta Psychologica*, *47*, 149–173.
- Van Opstal, F., Reynvoet, B., & Verguts, T. (2005). How to trigger elaborate processing? A comment on Kunde, Kiesel, and Hoffmann (2003). *Cognition*, *97*, 89–97.

Received April 4, 2008

Revision received May 6, 2009

Accepted May 8, 2009 ■