Perception: Psychophysics and Modeling

04 | Psychophysics

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WOLFE, J.M. et al. (2015). Parts of the "Introduction", ch. 1, pp. 3–18. *Sensation and Perception*. 4th edition, Sunderland, Massachusetts: Sinauer.

WICHMANN, F. A. and JÄKEL, F. (2018). Parts of "Methods in Psychophysics", pp. 1–19 and 35–36. In John T. Wixted, ed., *Stevens' Handbook of Experimental Psychology and Cognitive Neuroscience*, volume 5. John Wiley & Sons, 4th edition.

Supplementary Literature

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Wickens, T. D. (2002). *Elementary signal detection theory*. New York: Oxford University Press.

What do we mean by "Sensation & Perception?"

Sensation: The ability to detect a stimulus and, perhaps, to turn that detection into a private experience.

Perception: The act of giving meaning to a detected sensation.

Sensation and perception are central to mental life. Without them, how would we gain knowledge of the world?

Psychologists, but also biologists, computer scientists, medical doctors and neuroscientists study sensation and perception.

But psychology is passing into a less simple phase. Within a few years what one may call a microscopic psychology has arisen in Germany, carried on by experimental methods, asking of course every moment for introspective data, but eliminating their uncertainty by operating on a large scale and taking statistical means. This method taxes patience to the utmost, and could hardly have arisen in a country whose natives could be bored. Such Germans as Weber, Fechner, Vierordt, and Wundt obviously cannot; and their success has brought into the field an array of younger experimental psychologists, bent on studying the elements of the mental life, dissecting them out from the gross results in which they are embedded, and as far as possible reducing them to quantitative scales. The simple and open method of attack having done what it can, the method of patience, starving out, and harassing to death is tried ; the Mind must submit to a regular siege, in which minute advantages gained night and day by the forces that hem her in must sum themselves up at last into her overthrow. There is little of the grand style about these new prism, pendulum, and chronograph-philosophers. They mean business, not chivalry. What generous divination, and that superiority in virtue which was thought by Cicero to give a man the best insight into nature, have failed to do, their spying and scraping, their deadly tenacity and almost diabolic cunning, will doubtless some day bring about.

William James (1890), *The Principles of Psychology*, ch. 7.

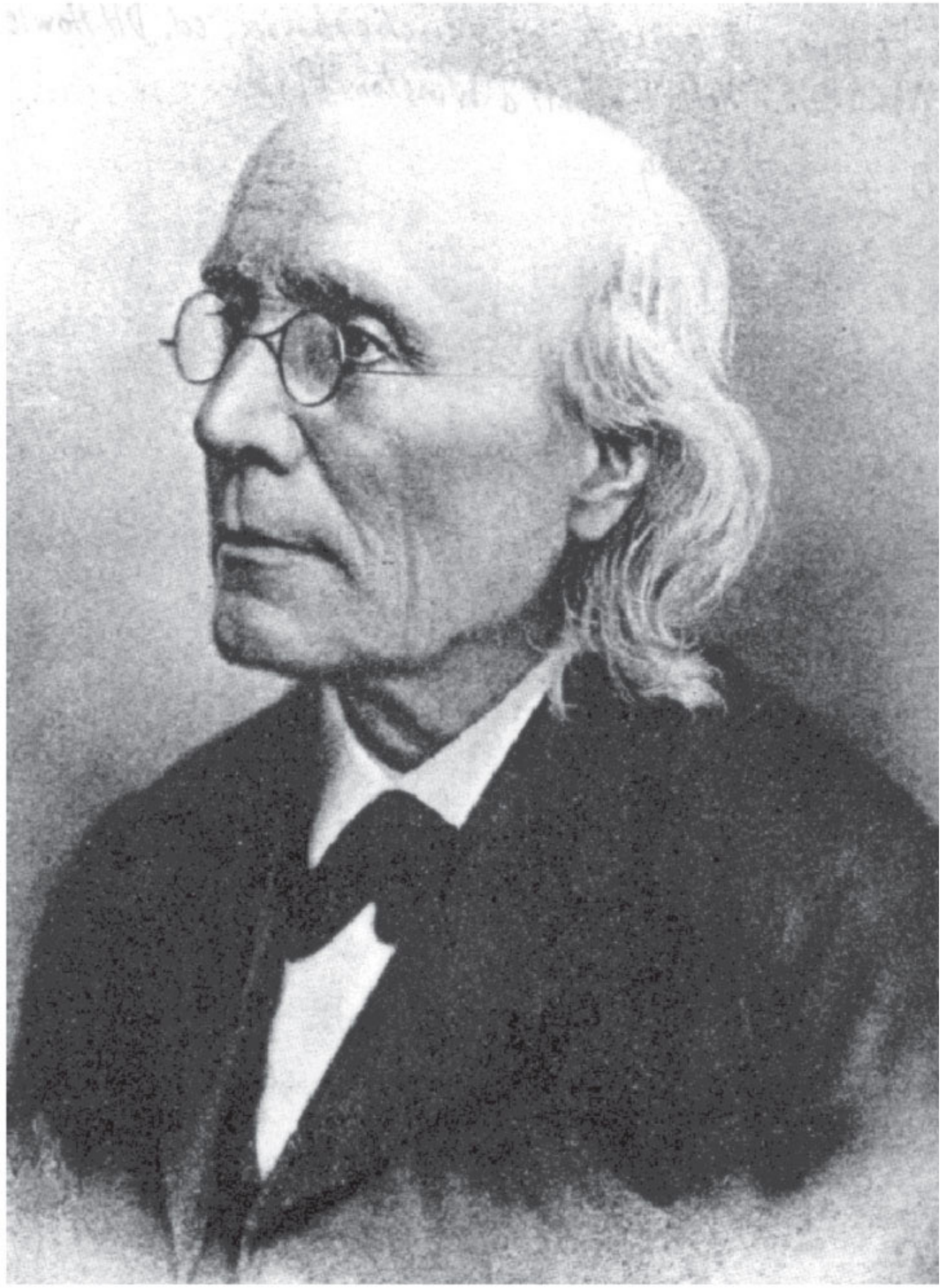
Gustav Theodor Fechner and the dawn of psychophysics

GUSTAV FECHNER (1801–1887) invented "psychophysics" and is often considered to be the true founder of experimental psychology.

FECHNER was an ambitious and hard-working man who worked himself to the point of exhaustion.

Damaged his eyes by staring at the sun while performing vision experiments.

… and, actually, in many respects pretty "extravagant" in his ideas by modern standards, including essays on the souls of plants …



SENSATION & PERCEPTION 4e, Figure 1.3

Gustav Theodor Fechner and the dawn of psychophysics

Fechner thought about the philosophical relationship between mind and matter.

Dualism: The mind has an existence separate from the material world of the body.

Materialism: The only thing that exists is matter, and that all things, including mind and consciousness, are the results of interactions between bits of matter.

Panpsychism: The mind exists as a property of all matter—all matter has consciousness.

Fechner attempted to describe the relationship between the mind and body using the language of mathematics.

Psychophysics: The science of defining quantitative relationships between physical and psychological (subjective) events—“physics on the x-axis and psycho on the y-axis … “

How to measure what we can see?

The Experimental Method

The study of sensation and perception is a scientific pursuit and requires scientific methods.

Thresholds: Finding the limits of what can be perceived.

Scaling: Measuring private experience.

Signal detection theory: A statistical framework to understand how threshold-style decisions are made.

Sensory neuroscience: The biology of sensation and perception.

Neuroimaging: An image of the brain (mind?).

Method of limits: The magnitude of a single stimulus or the difference between two stimuli is varied incrementally until the participant responds differently.

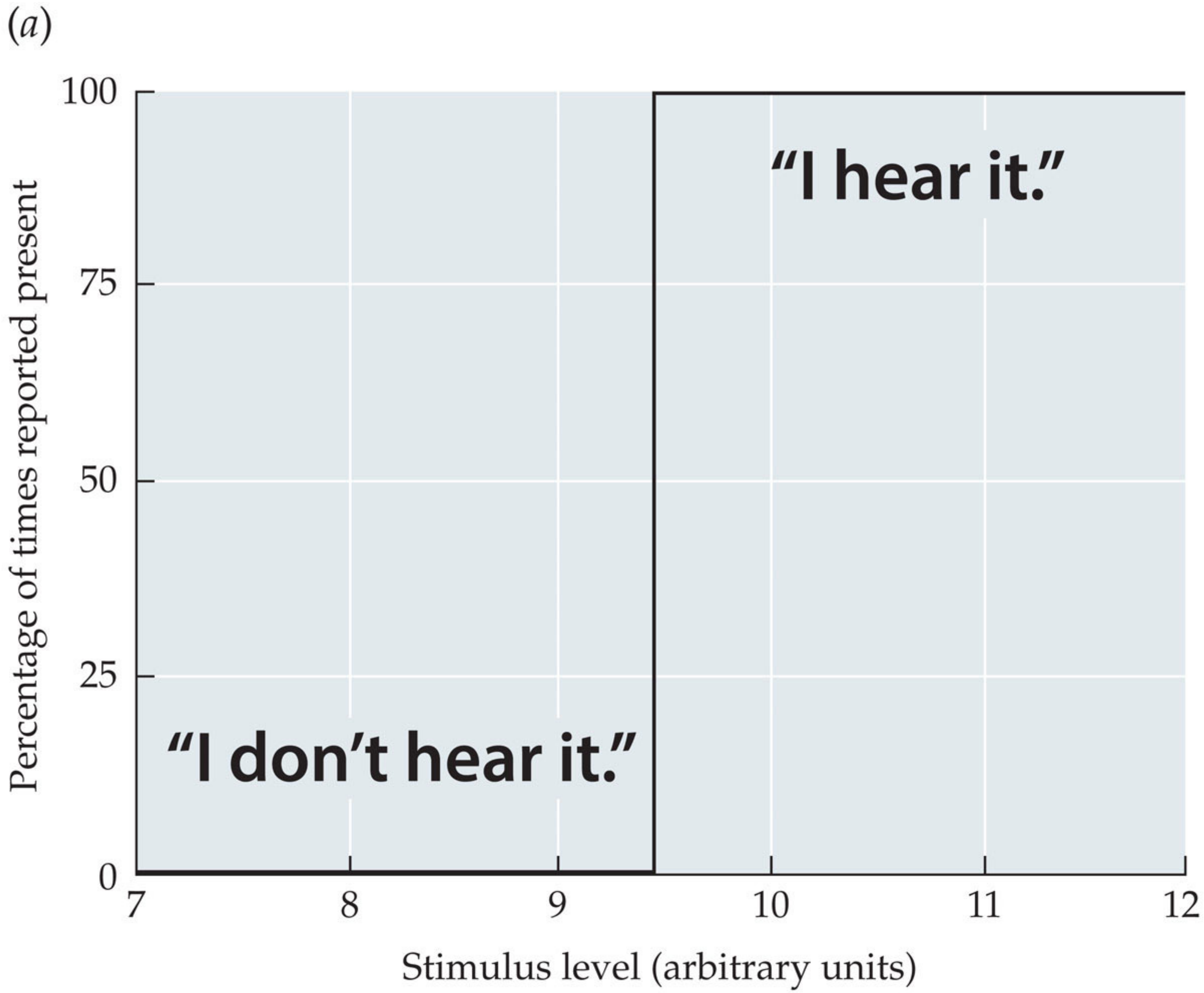
Method of adjustment: Similar to the method of limits, but the participant controls the stimulus directly.

Method of constant stimuli: Many stimuli, ranging from rarely to almost always perceivable, are presented one at a time.

Adaptive methods: Latest development; here an algorithm selects the next presentation intensity based on the intensity of the stimulus and the response history of the subject. At least several dozen variants exist, both non-parametric ("up-down methods") as well as parametric (typically Bayesian) ones.

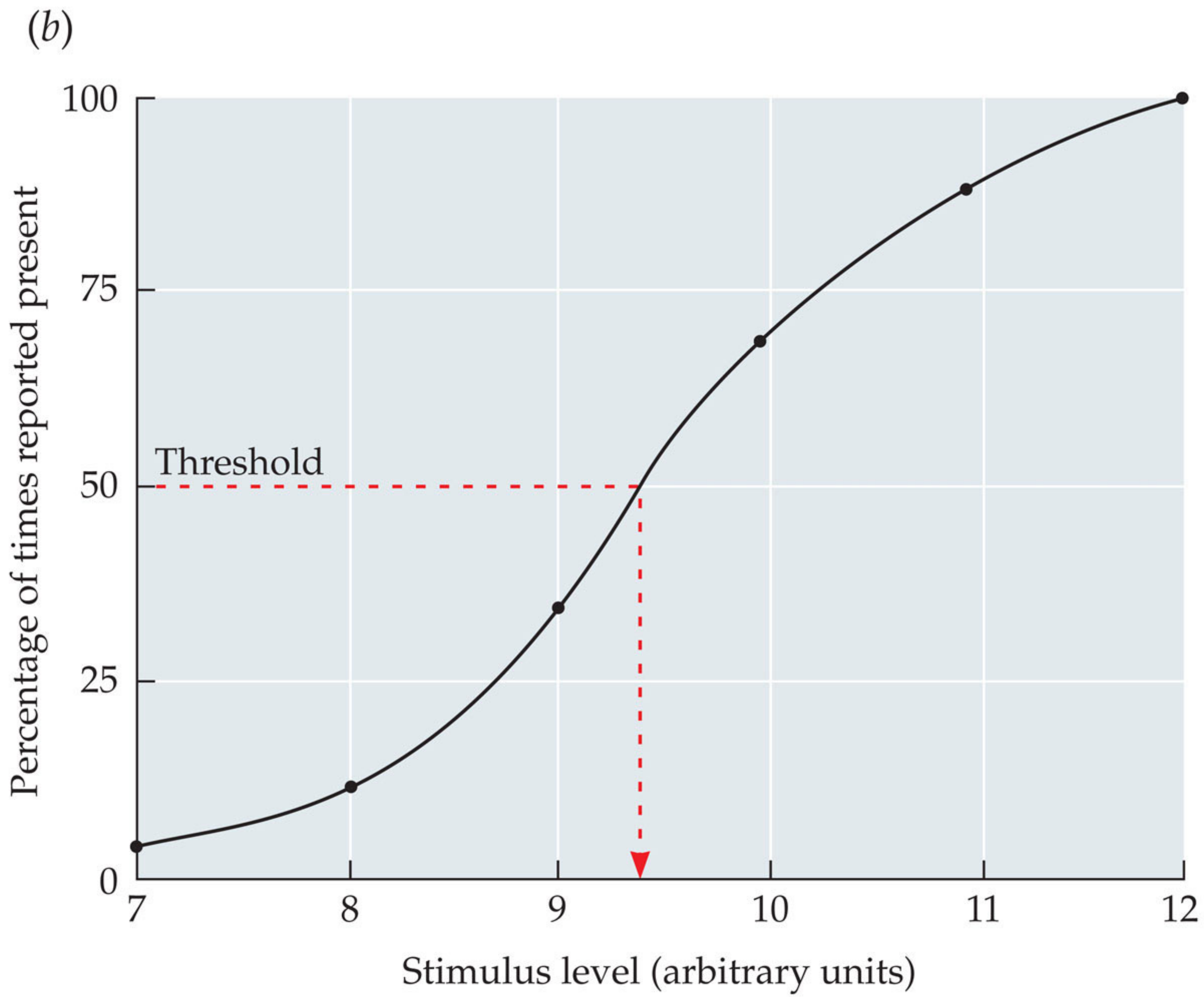
Magnitude estimation: The participant assigns values according to perceived magnitudes of the stimuli. (The previous four methods measure JNDs; magnitude estimation or scaling experiments attempt to directly measure the intensity of the "private" experience.)

Method of triads with ordinal embedding: View three stimuli and select two that are "most similar" to one another or, alternatively, select the "odd-one-out". Then try and find a (multi-dimensional) space in which to embed all the stimuli such that the distances in the space reflect the similarity judgements.

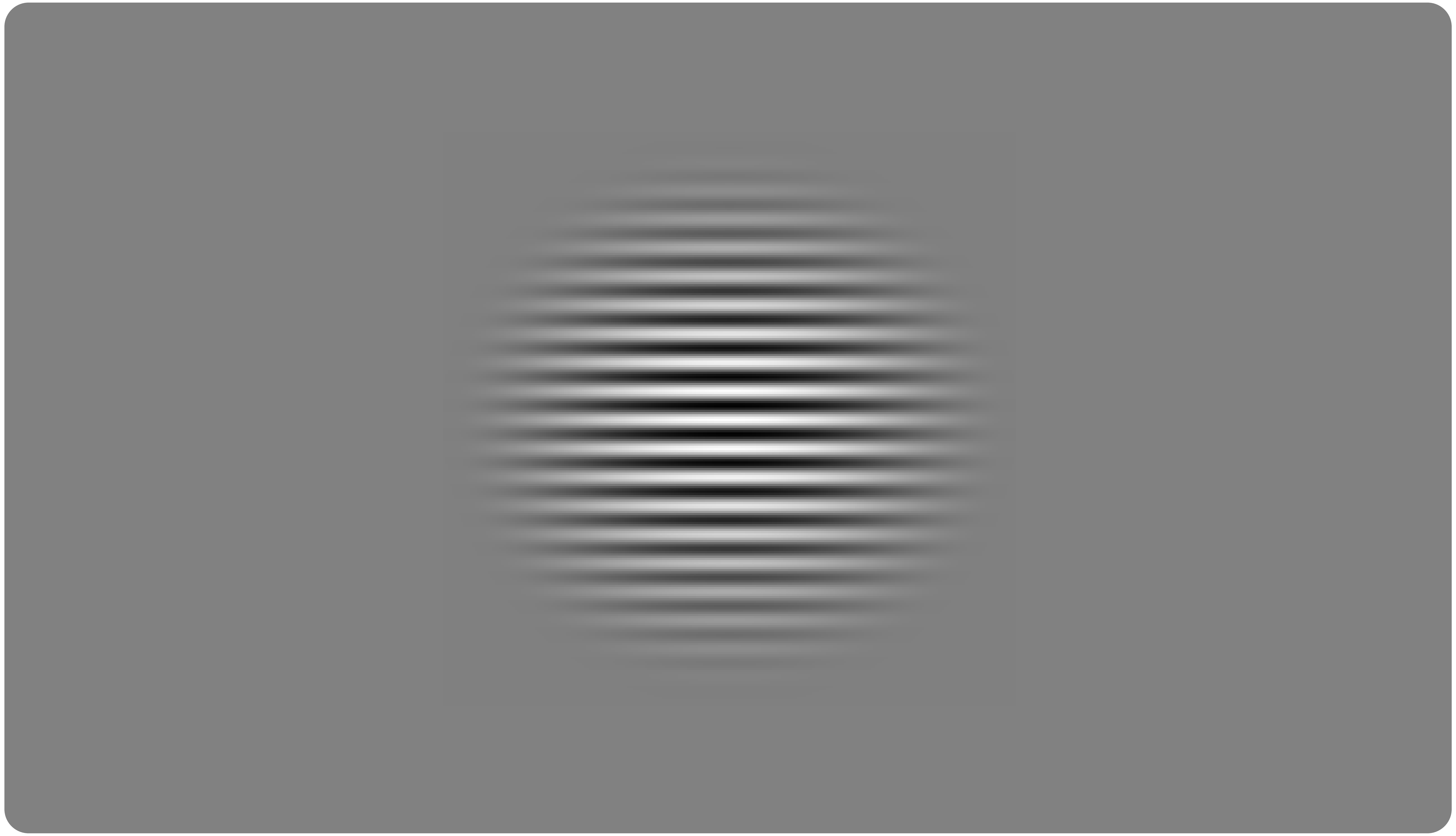


SENSATION & PERCEPTION 4e, **Figure 1.6 (Part 1)**

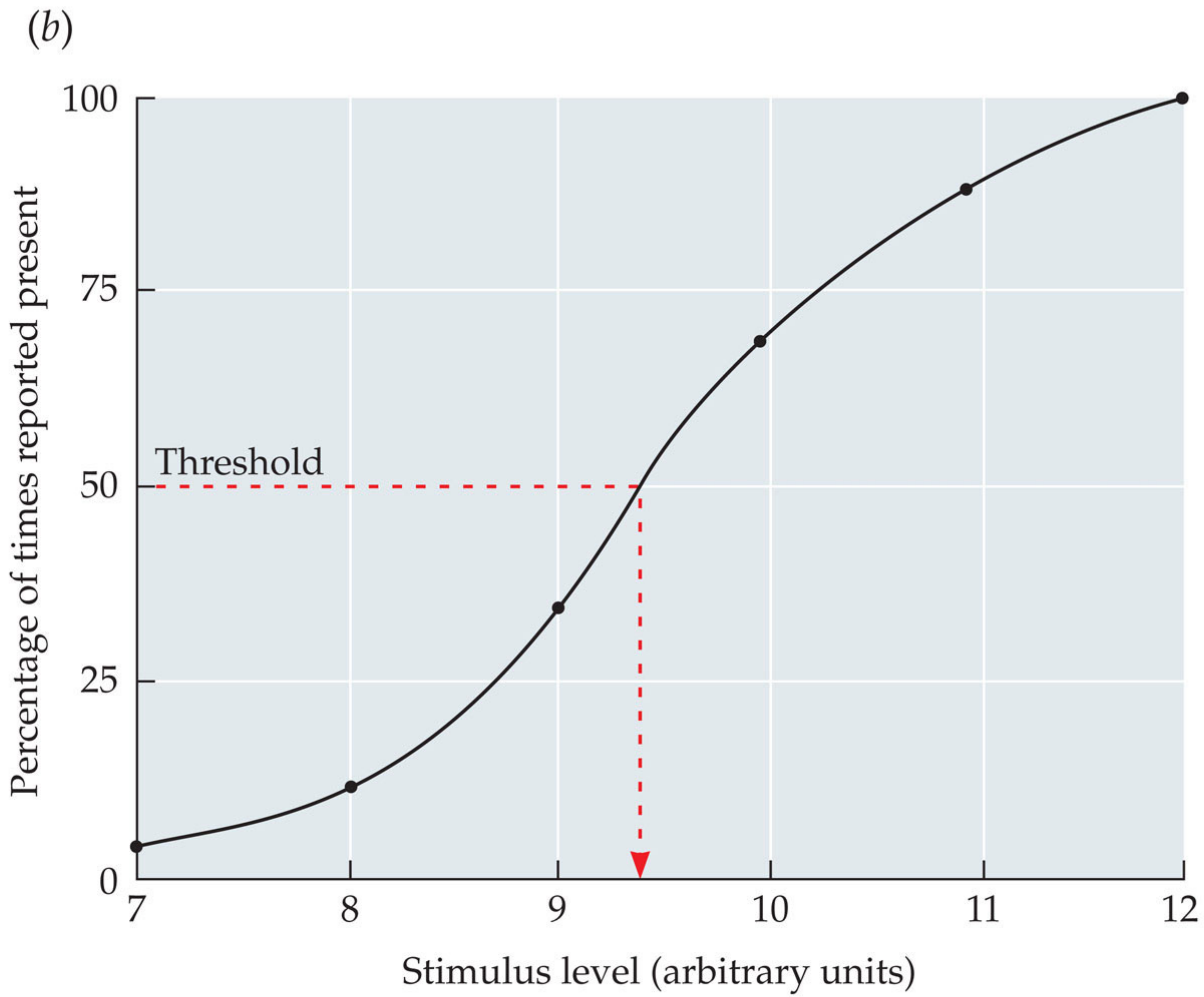
Psychophysical Methods—Threshold



SENSATION & PERCEPTION 4e, **Figure 1.6 (Part 2)**



Psychophysical Methods—constant stimulus



SENSATION & PERCEPTION 4e, Figure 1.6 (Part 2)

Psychophysical Methods—method of limits

Trial series

Intensity (arbitrary units)

	↓1	↑2	↓3	↑4	↓5	↑6	↓7	↑8
20	Y						Y	
19	Y		Y		Y		Y	
18	Y		Y		Y		Y	
17	Y		Y		Y		Y	
16	Y		Y		Y		Y	Y
15	Y	Y	Y	Y	Y	Y	Y	Y
14	Y	N	Y	N	Y	N	Y	Y
13	N	N	Y	N	Y	N	N	Y
12		N	N	N	N	N		N
11		N		N		N		N
10		N		N		N		N
	13.5	14.5	12.5	14.5	12.5	14.5	13.5	12.5

Crossover values (average = 13.5)

***SENSATION & PERCEPTION* 4e, Figure 1.7**

Psychophysical Methods—adaptive methods

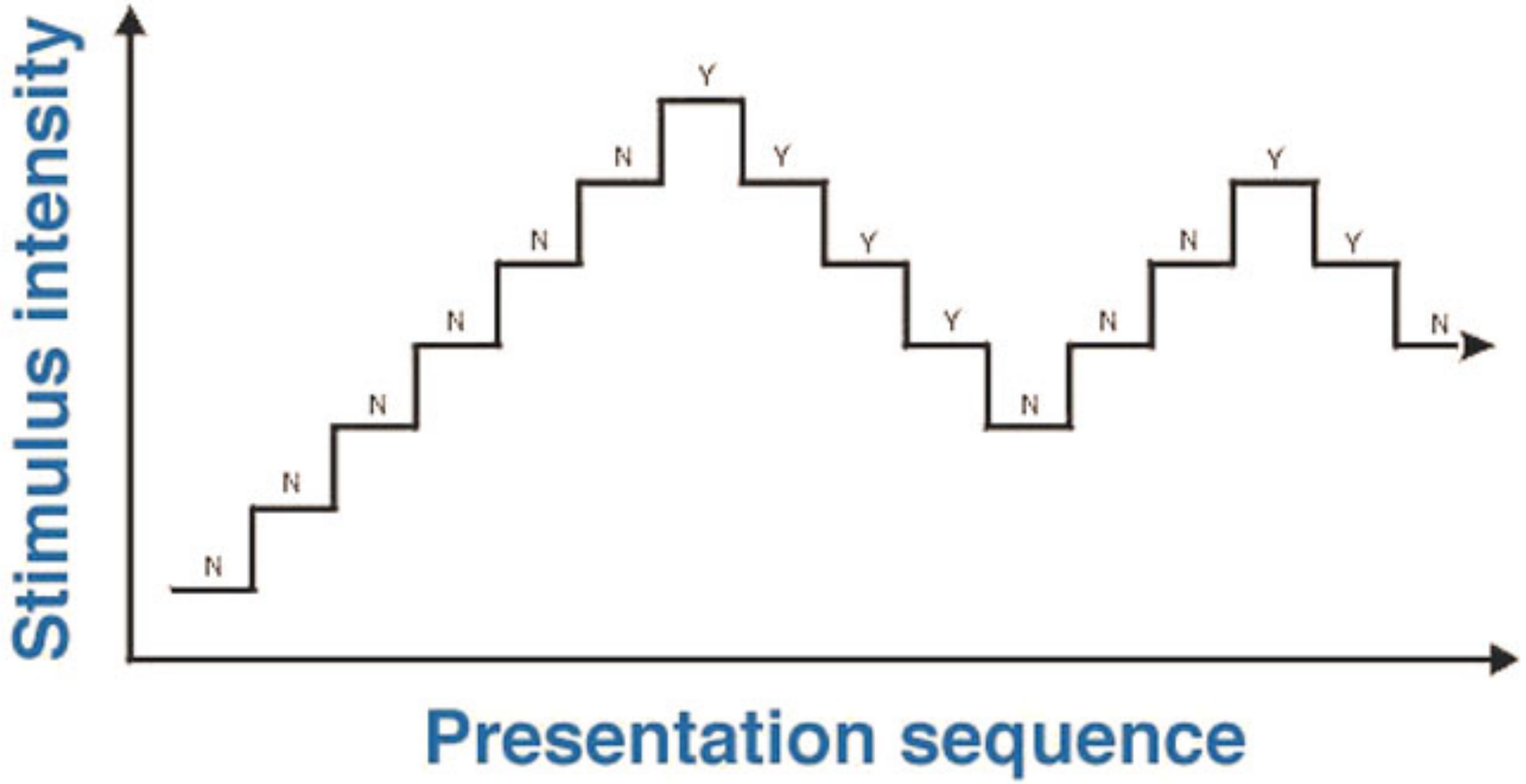


Figure 12. Staircase method. Y = Yes, the stimulus can be seen and N = No, the stimulus cannot be seen.

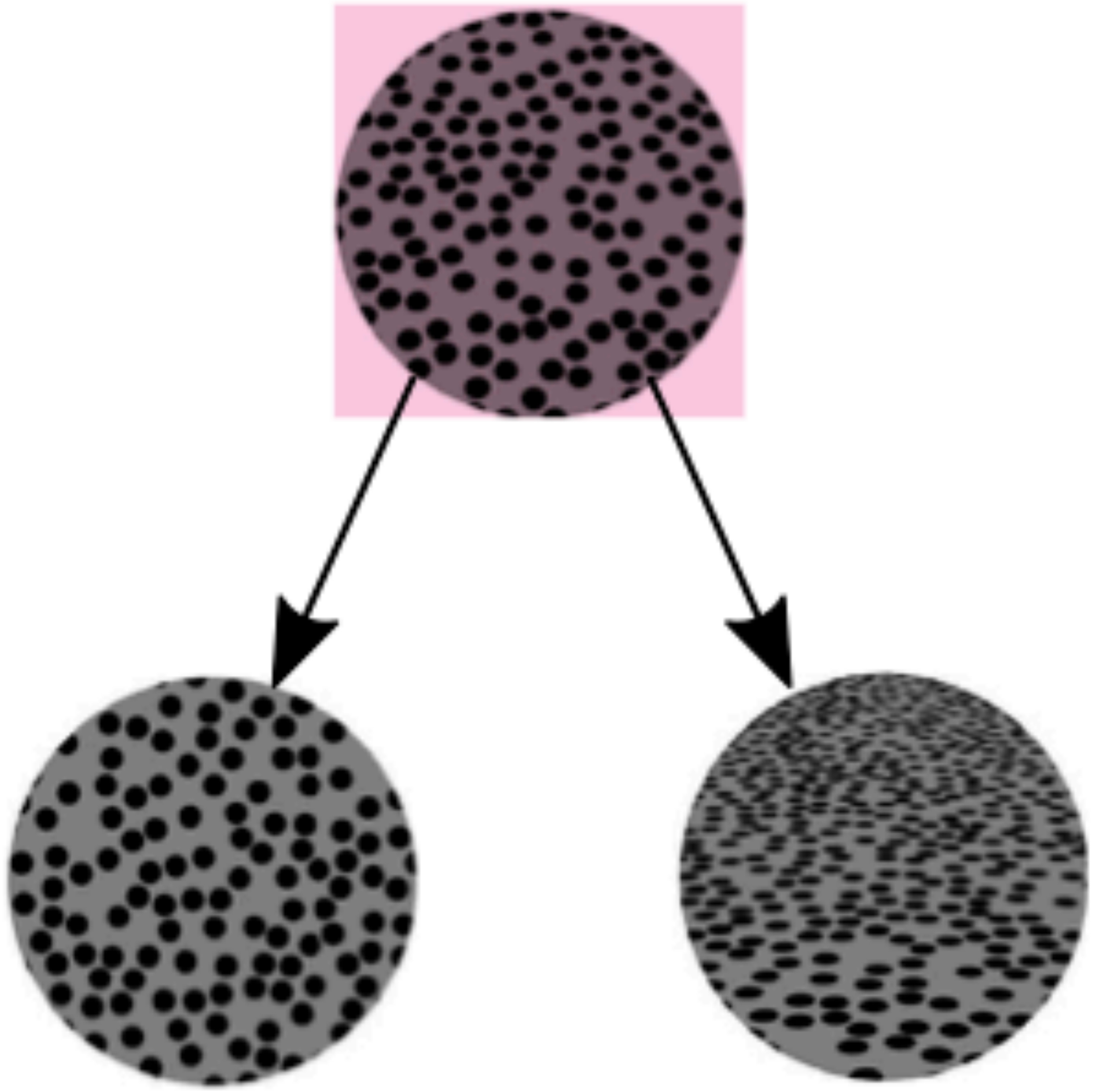
Psychophysical Methods—magnitude estimation

Intensity = 50

Intensity = ?

Psychophysical methods—method of triads (or triplets)

(a)



(b)

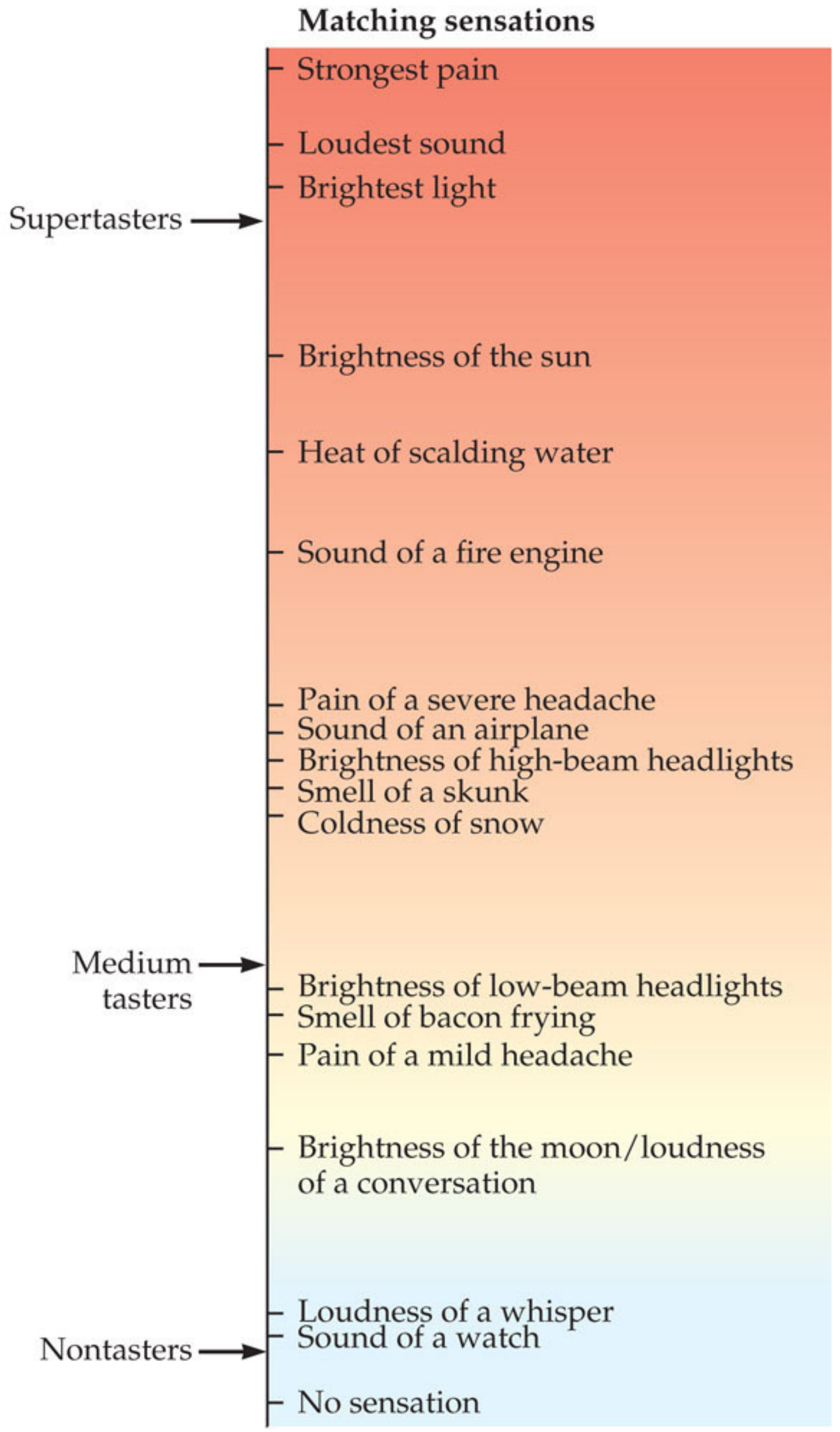
https://openreview.net/pdf?id=rklhqkHFDB

Psychophysical Methods—cross-modality matching

The participant matches the intensity of a sensation in one sensory modality with the intensity of a sensation in another.

Useful method for allowing people to classify how dull or intense a flavor is.

Supertaster: An individual whose perception of taste sensations is the most intense.



SENSATION & PERCEPTION 4e, **Figure 1.9**

Foundational psychophysical laws

Psychophysical "Laws"

Psychophysics adopted several new concepts for understanding sensation and perception.

Two-point threshold: The minimum distance at which two stimuli (e.g., two simultaneous touches) can be distinguished.

Just noticeable difference (JND): The smallest detectable difference between two stimuli, or the minimum change in a stimulus that can be correctly judged as different from a reference stimulus; also known as difference threshold.

Absolute threshold: Minimum amount of stimulation necessary for a person to detect a stimulus (typically 50% of the time).

Weber’s law (1846)

Ernst Weber discovered that the smallest change in a stimulus that can be detected is (very often) a constant proportion of the stimulus level.

Weber’s law: The principle describing the relationship between stimulus and resulting sensation that says the JND is a constant fraction of the comparison stimulus. (Note: Fechner called Weber’s empirical findings the “Weber’s law”!)

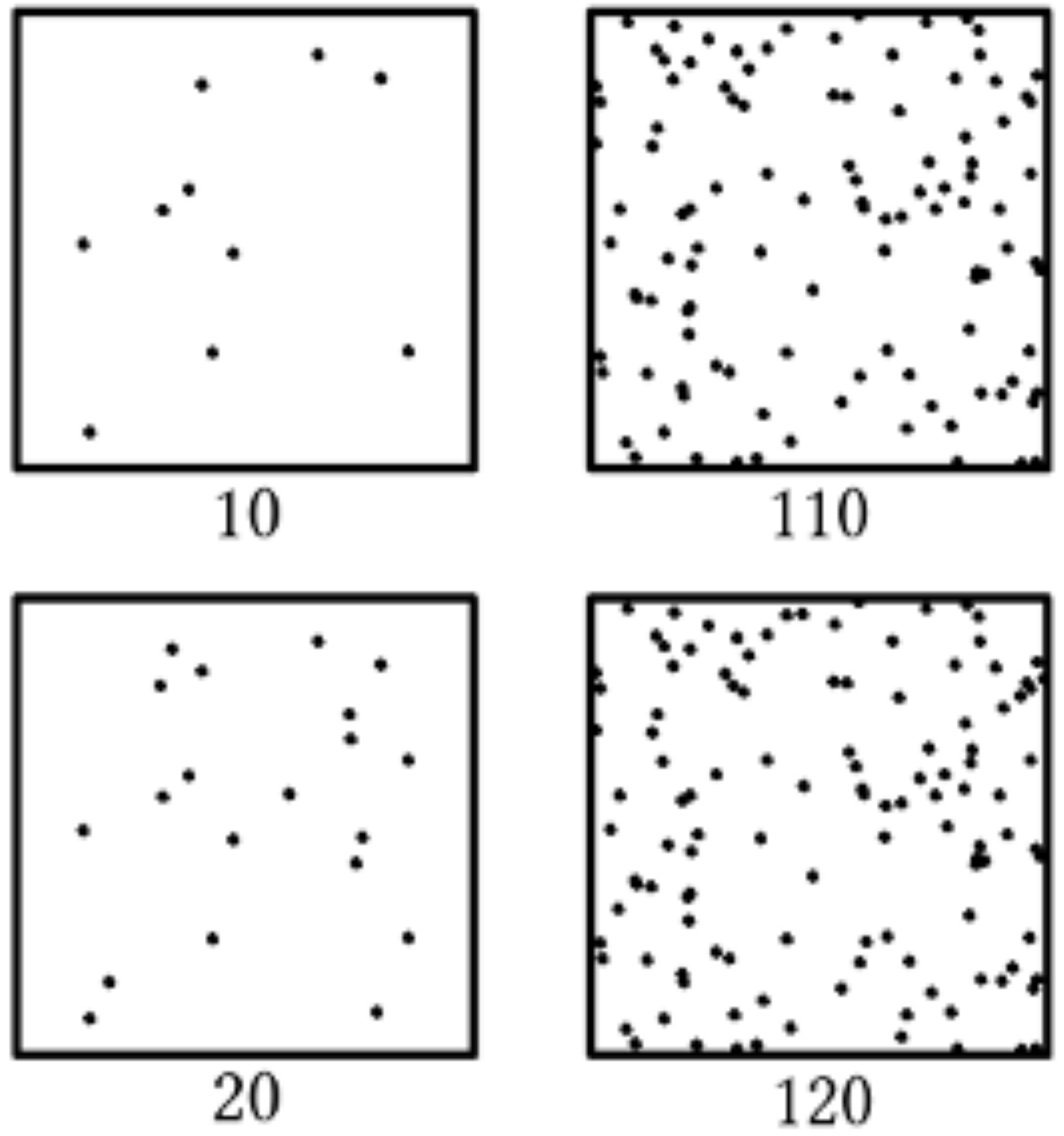
Thus, larger stimulus values have larger JNDs and smaller stimulus values have smaller JNDs.

length = 100

length = 103

length = 303

length = 300



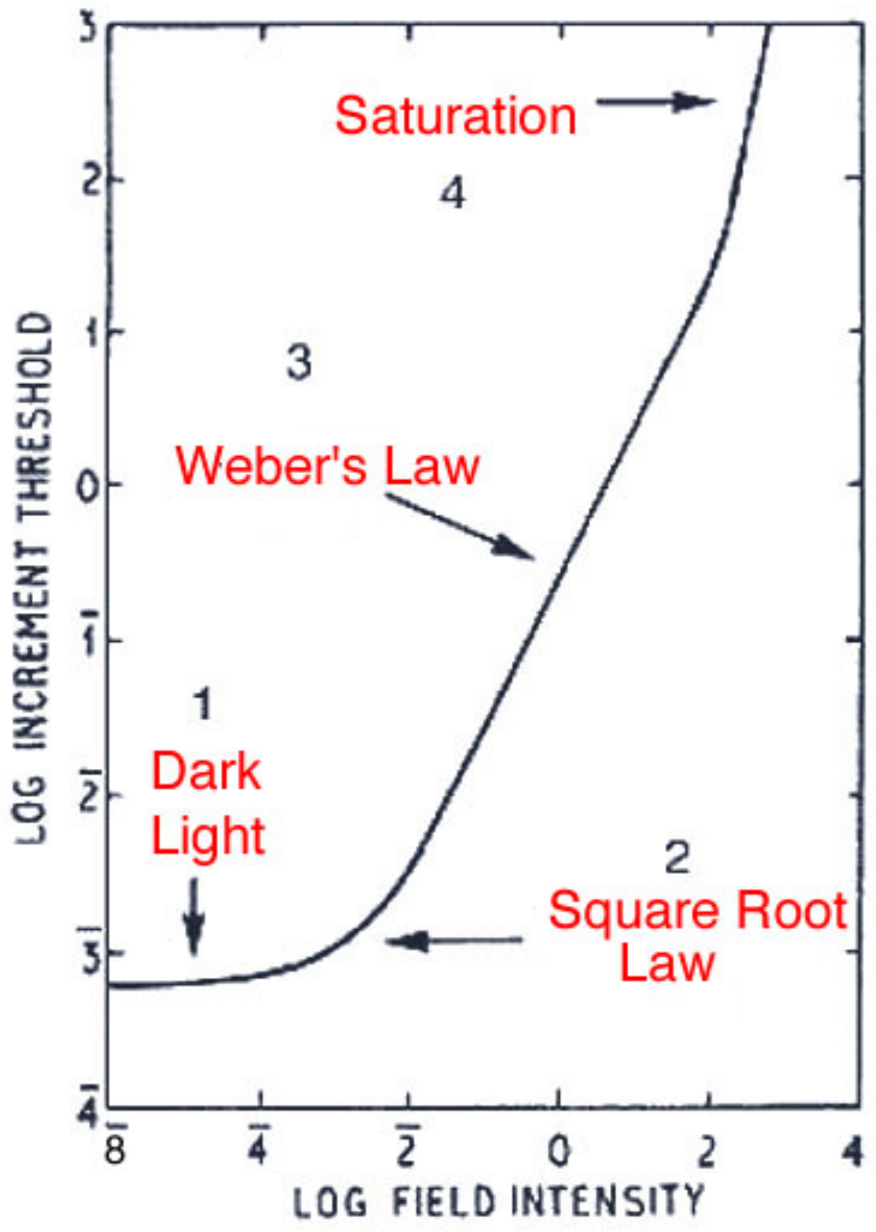
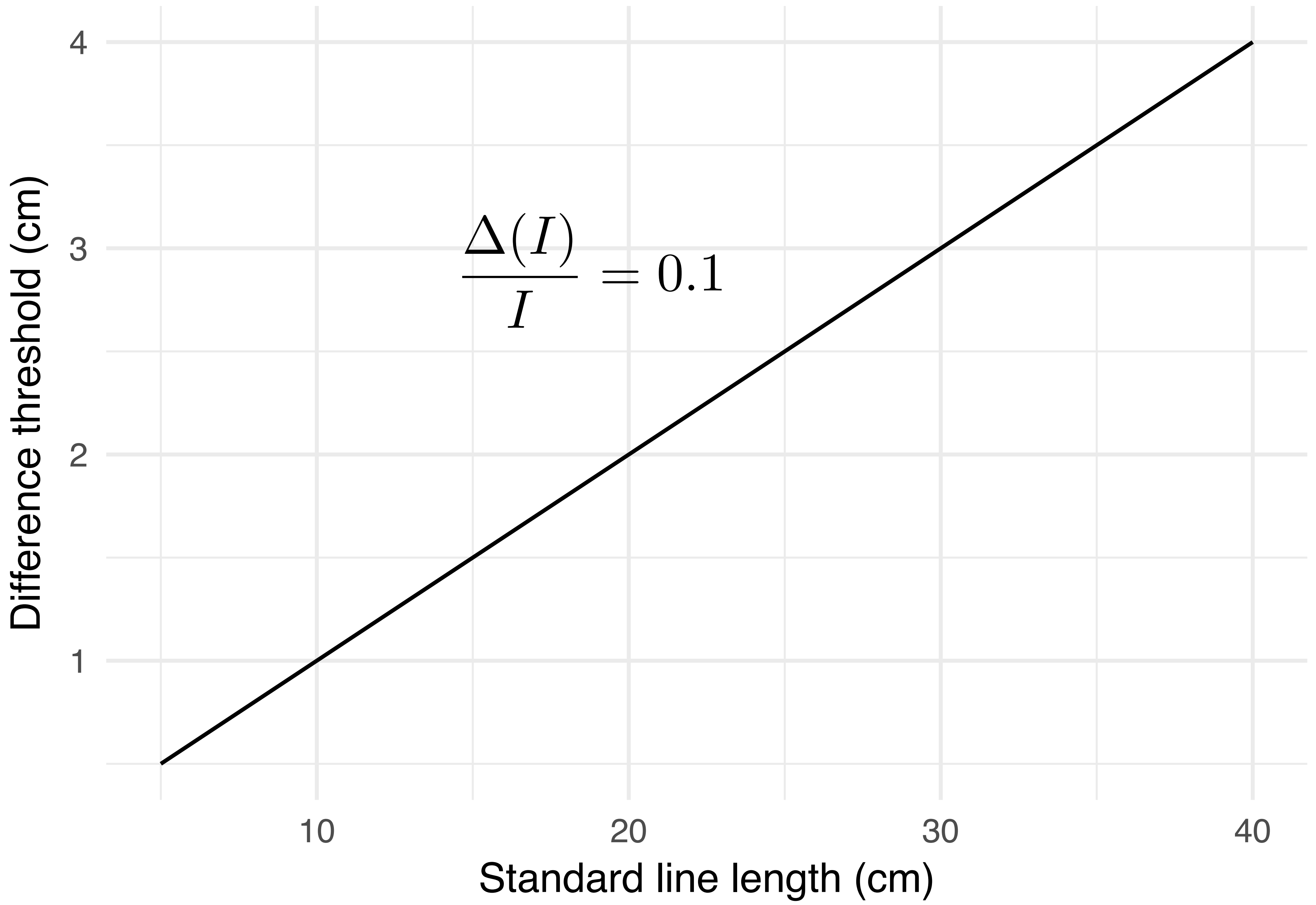


Figure 12. Schematic of the increment threshold curve of the rod system. Aguilar and Stiles' data from Davson (Davson's Physiology of the Eye, 5th ed. London: Macmillan Academic and Professional Ltd, 1990).

Weber's law (1846)

$$\frac{\Delta(I)}{I} = k$$

$$\Delta I = kI$$



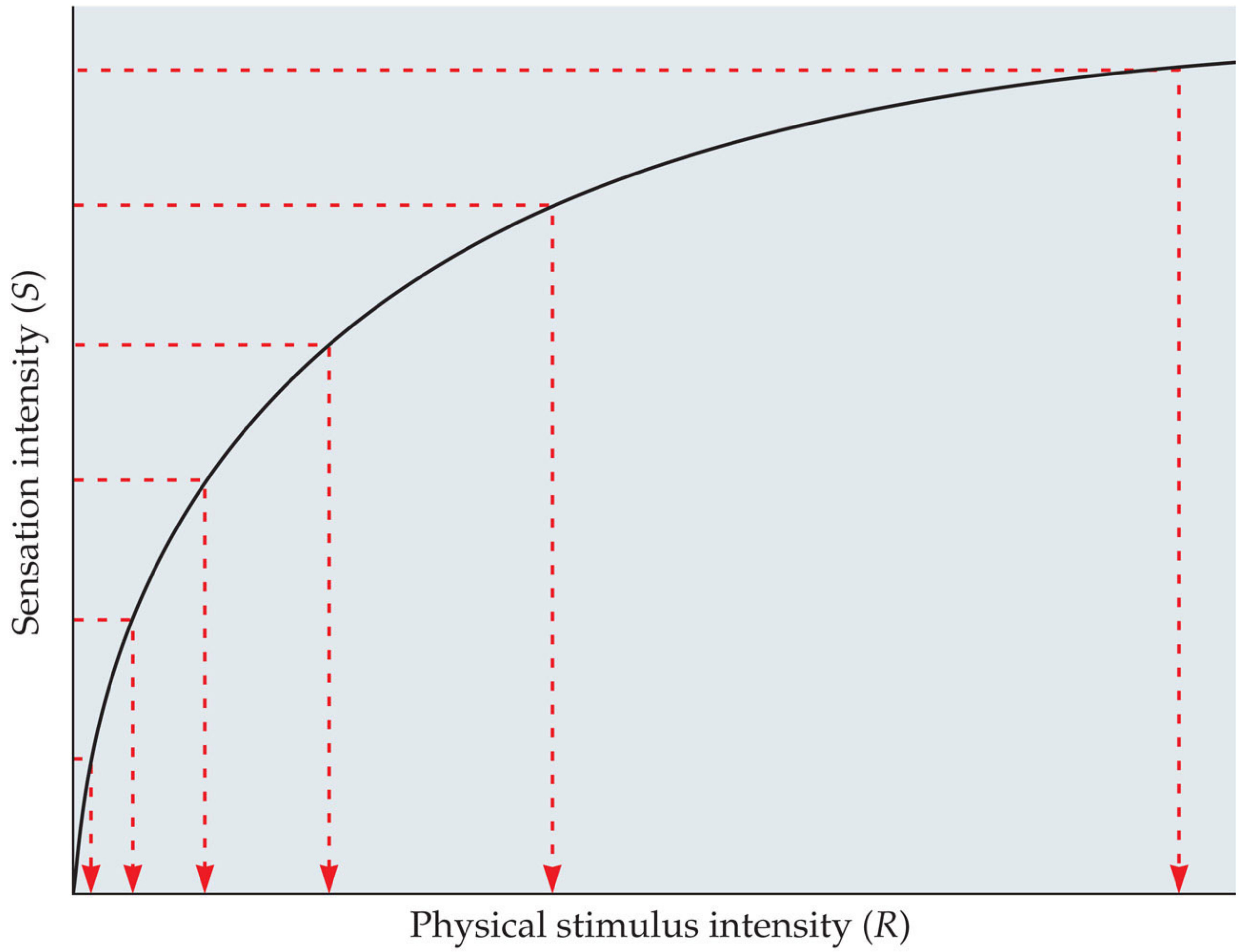
Weber's law shows that physical measurement scales will be insufficient or inappropriate to describe the mind (the perceptual difference between lines is not the same as their physical difference)

But it's not really a "Law" like Newton's Laws: it's a description of empirical observations

- Why does it happen?
- Could a perceptual scale be derived directly from JNDs?

Fechner's law (1860)

(Sometimes called the Weber-Fechner-law):
A principle describing the relationship between stimulus magnitude and resulting sensation magnitude such that the magnitude of subjective sensation increases proportionally to the logarithm of the stimulus intensity. JNDs are always accompanied—caused?—by equally large changes on a (putative) internal sensation axis.



SENSATION & PERCEPTION 4e, Figure 1.5

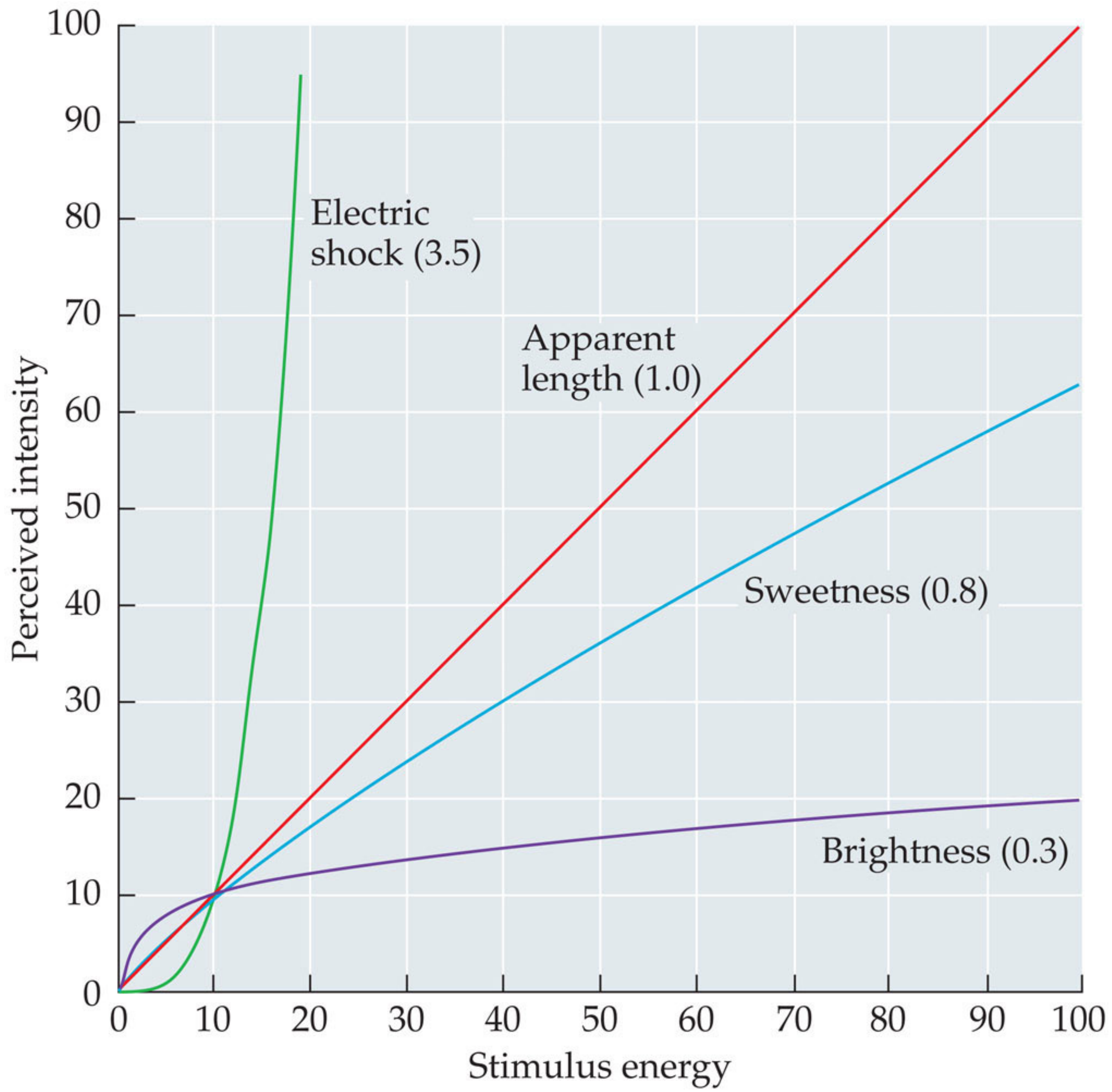
$$S = k \log(I)$$

Stevens' Law (1956)

Magnitude estimates are well described by Stevens' (1956) power law.

$$S = aI^b$$

Sensation (S) is related to a (possibly scaled) stimulus intensity (I) by an exponent (b).



SENSATION & PERCEPTION 4e, Figure 1.8

Signal detection theory and the status of thresholds

(a)

SENSATION & PERCEPTION 4e, Figure 1.6 (Part 1)

Decision Theory Applied to Perception & Cognition:
Peterson, Birdsall, and Fox (1954); seminal textbook by Green and Swets (1966), see Supplementary Literature.

A psychophysical theory that quantifies the response of an observer to the presentation of a signal in the presence of (inevitable) *internal noise*.

Internal noise: Assumption that even in the absence of any external stimulus there is (variable) internal activity in the nervous system (c.f. the spontanous, non-zero firing rates of all neurones ever measured in the nervous system of any animal).

Decision-axis: For binary problems there is always a one-dimensional sufficient statistic independent of the dimensionality of the observation space.

Often applied in a simple binary (or "diagnostic") setting with only four possible outcomes:

Hit: Stimulus is present and observer responds "Yes."

Miss: Stimulus is present and observer responds "No."

False alarm: Stimulus is not present and observer responds "Yes."

Correct rejection: Stimulus is not present and observer responds "No."

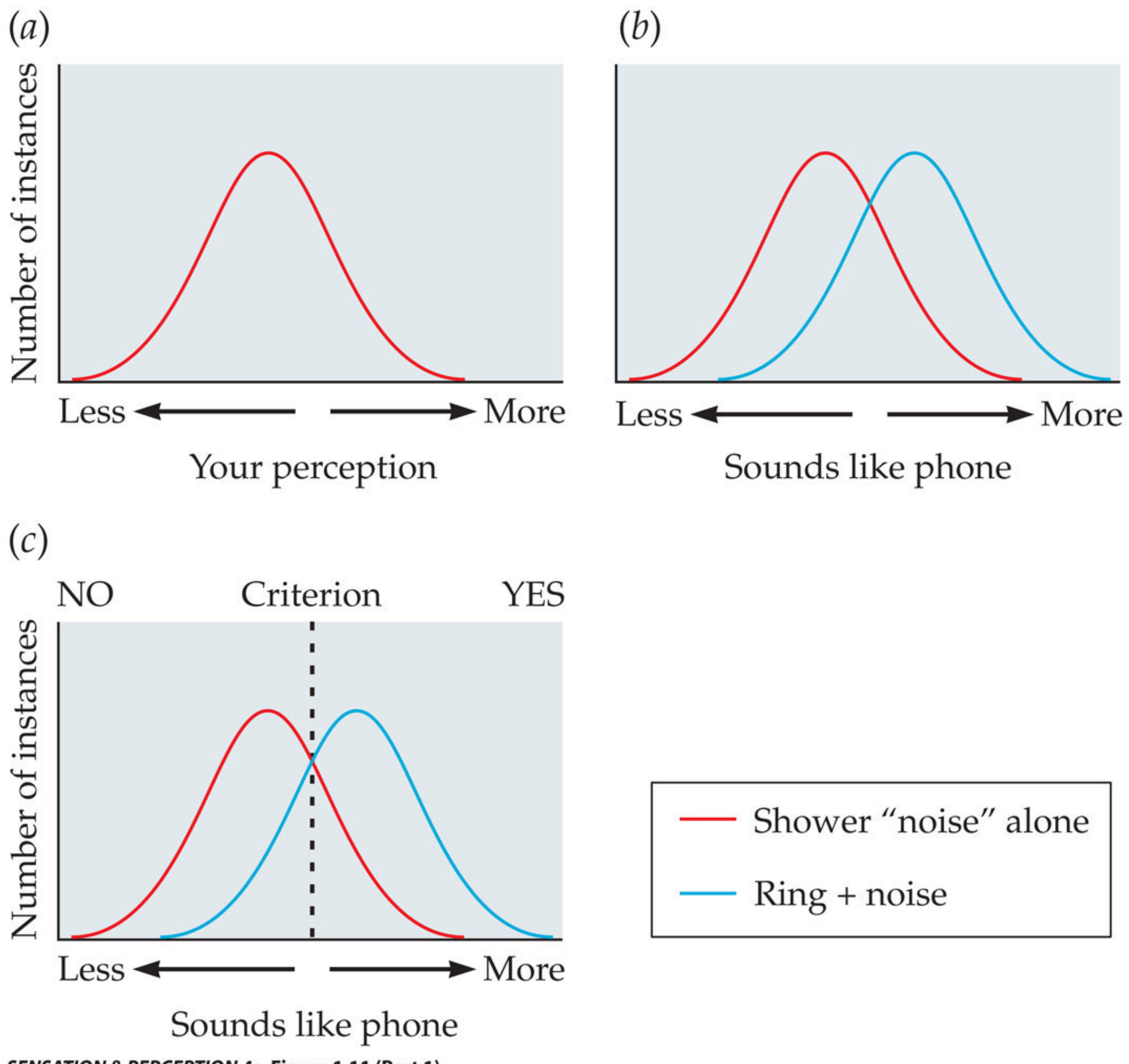
Signal detection theory makes a distinction between an observers' ability to perceive a signal and their willingness to report it. These are two separate concepts:

Sensitivity vs. **Criterion**

Sensitivity: A value that defines the ease with which an observer can tell the difference between the presence and absence of a stimulus or the difference between stimuli.

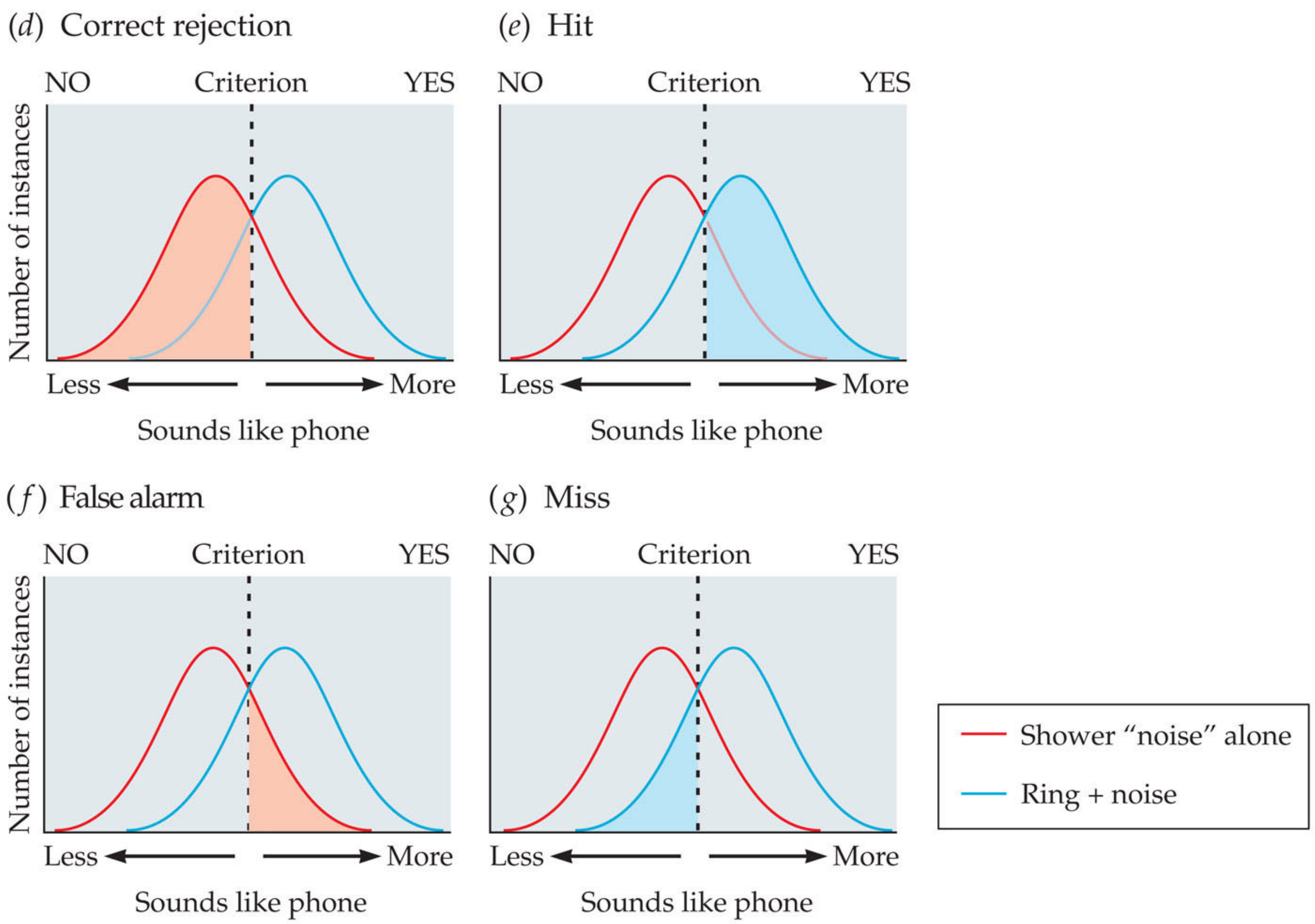
Criterion: An internal "threshold" that is set by the observer (note: decision, not sensory). If the internal response is above criterion, the observer gives one response. Below criterion, the observer gives another response.

Signal Detection Theory



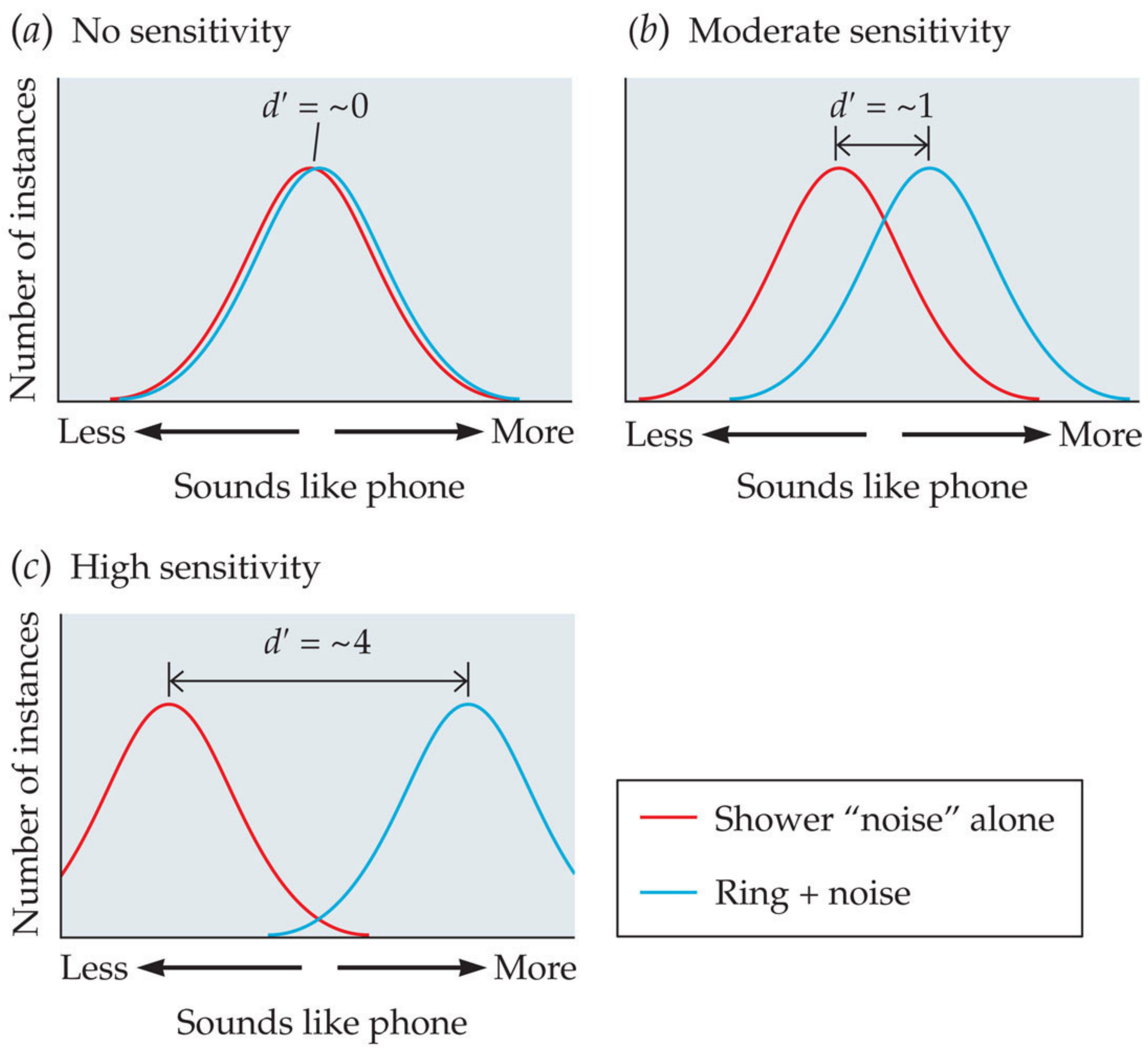
SENSATION & PERCEPTION 4e, Figure 1.11 (Part 1)

Signal Detection Theory



SENSATION & PERCEPTION 4e, Figure 1.11 (Part 2)

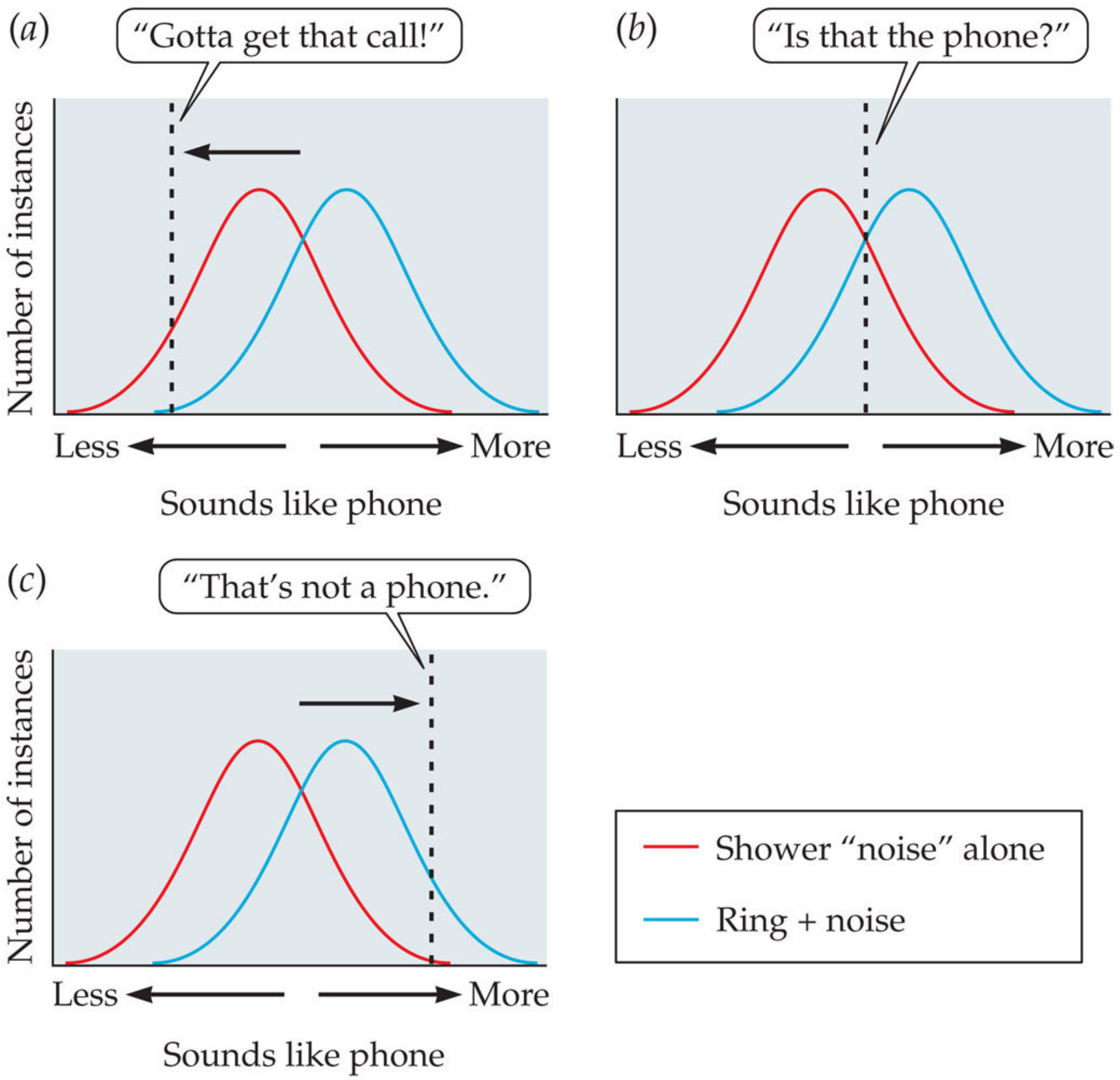
Signal Detection Theory



SENSATION & PERCEPTION 4e, Figure 1.12

Sensitivity to a stimulus is illustrated by the separation between the distributions of your response to noise alone and to signal plus noise

Signal Detection Theory



SENSATION & PERCEPTION 4e, Figure 1.13

For a fixed sensitivity (often called *d'*), all you can do is change the pattern of your errors by shifting the response criterion

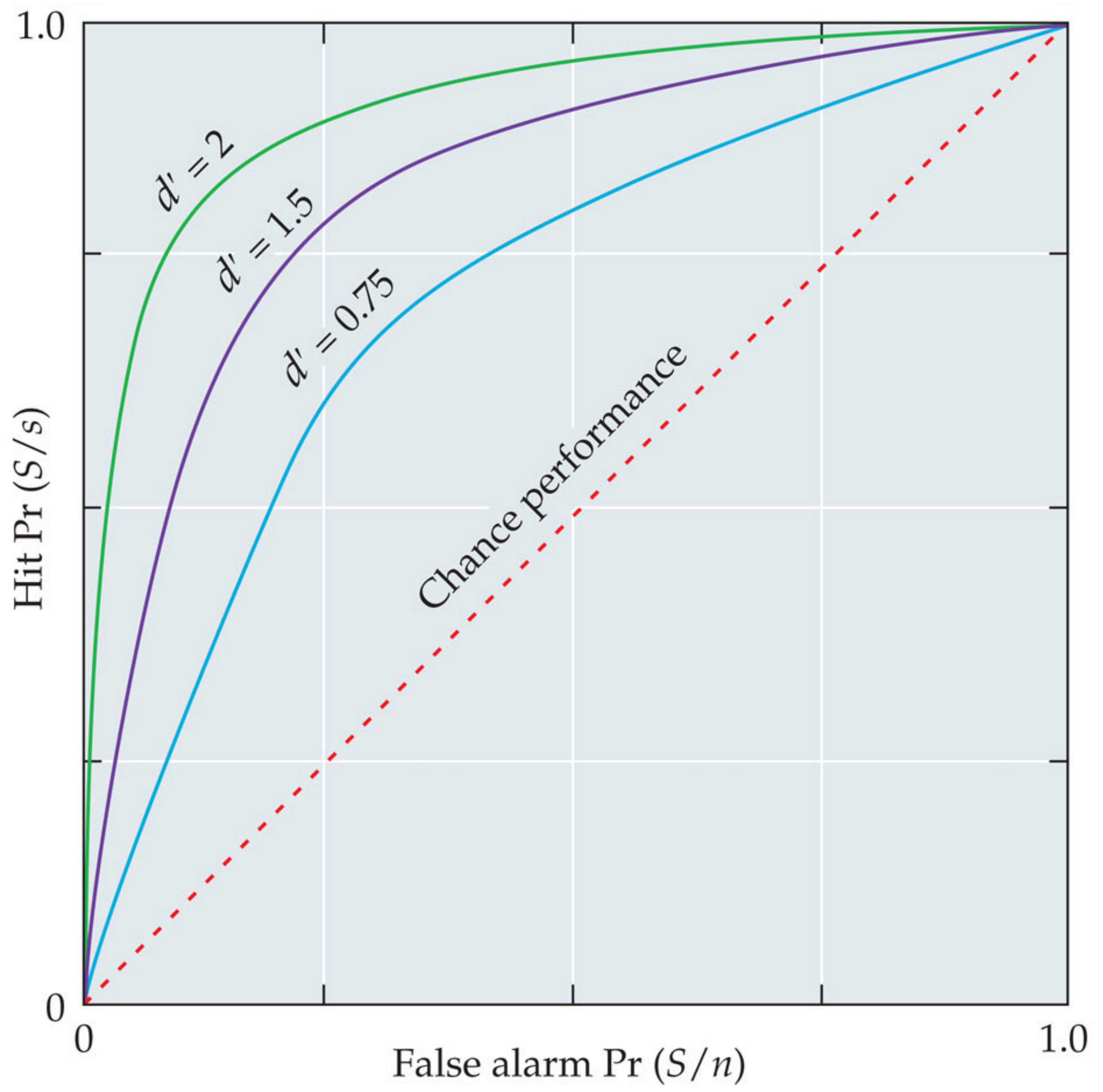
Receiver operating characteristic (ROC): In studies of signal detection, the graphical plot of the hit rate as a function of the false alarm rate.

Chance performance will fall along the diagonal.

Good performance (high sensitivity) "bows out" towards the upper left corner.

Plotting the ROC curve allows one to predict the proportion of hits for a given proportion of false alarms, and vice-versa.

Changes in criteria move performance along a curve but do not change the shape of the curve.



SENSATION & PERCEPTION 4e, **Figure 1.14**

Appeals of Signal Detection Theory

Allows separation of sensory (“hardware”) and motivational (“psychological”) components of a perceptual decision.

Optimal placement of **criterion** (λ) to maximize proportion correct can be easily calculated: If prior probabilities of signal and noise trials are equal and costs are assumed equal, too, then simply place λ where likelihood ratio is equal. (Independent of exact shape of the densities!)

Assuming signal and noise densities to be Gaussians with the same variance, the normalized distance between the means of the densities is called d’ (d-prime). This is a criterion-free measure of task difficulty; λ informs about the motivational state. (Many nice experiments in the 50s and 60s changing costs of hits, false alarms etc.)

Warning: Proportion correct is a function of the criterion λ for single-interval designs.

A task that is criterion free?

Rather than asking a yes-no question, can we design a task that only depends on sensitivity?

2-alternative forced choice (2-AFC) and 2-interval forced choice (2-IFC) procedures are theoretically best as they are criterion free (assuming observers adhere to a differencing rule/ pick the interval with the larger activity on the decision-axis).

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If using a differencing rule, percent correct in 2-AFC/2-IFC corresponds to the area under the receiver-operating curve (AUC): ideal!

Unfortunately (?) “takes perception out of perception research.”

Think of other decision problems, e.g. diagnose by a doctor. “Yes-no” is the typical setting, a 2-AFC setting is basically not possible outside the laboratory.

Interval bias in forced-choice procedures?

… no, don’t worry too much, can be “calculated out”!

JND-style measurements most precise, reliable and immune to (unwanted) extraneous influences (mood, time of day, etc.); method of constant stimulus (blocked) preferable to adaptive procedures.

Rating and scaling experiments much less reliable and immune; important to provide an anchor as well as the extremes of the scale.

Method of triads—triplet questions—appears to be a good way to measure sensation. A doctoral student in my lab, David Künstle, is currently exploring such methods together with ordinal embedding improvements co-supervised by Prof. Ulrike von Luxburg.

The End

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