Double-Judgment Psychophysics for Research on Consciousness: Application to Blindsight

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Can subjectivity be studied objectively? Over the past 100 years a field called psychophysics has developed with objective study of subjectivity as its goal. In this chapter, I develop a double-judgment psychophysical methodology that can help clarify experiments on blindsight. Blindsight is interesting for studying consciousness because it provides a tool for separating conscious from unconscious aspects of vision. A person with idealized blindsight acts as a "visual zombie" for certain stimuli, for he or she makes visual discriminations without visual awareness. A number of philosophers and artificial-intelligence researchers believe that if a person acts as if he sees then he does see. They believe performance alone is sufficient to ensure subjective awareness. The existence of individuals with blindsight makes one doubt this belief.

By comparing the neural circuitry of a blindsight observer to that of a sighted observer, one might learn about the circuitry that is specific to visual awareness. The question always remains, however, whether the blindsight findings are an artifact of methodology (Campion, Latto, and Smith 1983). For that reason it is my goal here to discuss psychophysical methodology in detail.

PURE DETECTION (SINGLE-JUDGMENT)

Let us start by considering the task of detecting a dim flash of light. Until about 1960, detection experiments were done by repeatedly presenting a range of stimulus levels and having the observer make a yes–no judgment on detection. The hit rate is the percentage of times the observer says yes to the stimulus. For example, if the observer saw the stimulus on 40 of the 100 times it was presented, then the hit rate would be 40 percent. The hit rate, p_h, at each stimulus strength was measured. Threshold was often defined as the light level for which the observer's hit rate was 50 percent. We will call this threshold the subjective threshold, $Th_{\text{subjective}}$.

After 1960, researchers became increasingly worried about "the criterion problem." It was found that different observers used different criteria for saying yes or no. A strict-criterion observer would reserve a yes judgment for stimuli seen with high confidence. An observer with a loose criterion would say yes at the slightest suspicion of signal. Or sometimes a person would just hallucinate or guess that a stimulus was present. A person with a loose criterion could have thresholds below those of someone with a strict criterion and could erroneously be thought of as having greater sensitivity, whereas in reality only the criterion had shifted.

Human performance is typically assessed by measuring the *psychometric function* that specifies percentage correct on some perceptual task as a function of stimulus strength. We focus on the example of detecting a spot of light whose contrast varies from 0 to 4 percent. Suppose the performance is given in Table 32.1.

Table 32.1

Stimulus contrast	0%	1%	2%	3%	4%
Probability correct (p_h)	2.5%	2.5%	16%	50%	84%
z-score	−2	−2	−1	0	1

The z-score (bottom row) is a function of probability correct and is often used in its place. The z-score is closely related to standard deviation and to cumulative normal distributions. The probabilities shown in the middle row were chosen to give simple z-score values.

To get a handle on the criterion (otherwise called the guessing or response-bias problem), one needs to measure the guessing rate (false-alarm rate), p_f, the percentage of times the observer said yes to a blank stimulus. In the example in Table 32.1, $p_f = 2.5$ percent because in the blank-field example the stimulus has 0 contrast. Two types of correction for guessing are commonly used:

1. the high-threshold correction

$$P = (p_h - p_f)/(1 - p_f) \tag{32.1}$$

This formula is obtained by requiring P to equal zero when the blank stimulus is presented ($p_h = p_f$) and to equal unity when the hit rate is 100 percent correct ($p_h = 1$).

2. the signal-detection correction.

$$d' = z_h - z_f \tag{32.2}$$

where z_f and z_h are the z-scores for the false alarms and hits. The left side of equation (32.2), called d', is a measure of detectability that is relatively insensitive to response bias. It is common to call the contrast producing $d' = 1$, the objective threshold, $Th_{\text{objective}}$. Given equation (32.2), this threshold occurs at the point where $z_h = z_f + 1$. The beauty in this definition of threshold is its relative independence of the subject's criterion (false-alarm rate).

In a typical pre-1960 experiment, the experimenters tried to keep the false-alarm rate very low. Suppose the hit rate was 50 percent and the false-alarm

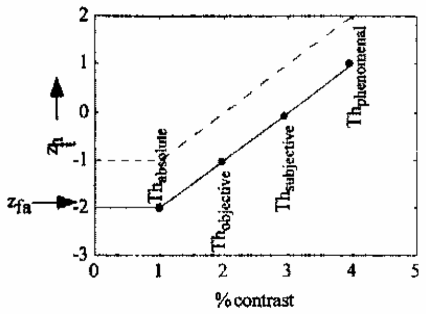

Figure 32.1 A possible psychometric function (transducer function) for a typical detection experiment.

rate was 0 percent. Then the d' would have a tremendous uncertainty because the false-alarm z-score would be poorly estimated. To establish a reliable false-alarm rate, modern psychophysicists attempt to get false-alarm rates greater than 10 percent. Unfortunately, in most clinical studies, including those on blindsight, it is rare to find the false-alarm rate measured accurately.

SUBJECTIVE AND OBJECTIVE THRESHOLDS

Figure 32.1 shows a possible psychometric function (also often called the transducer function) for a typical detection experiment. Figure 32.1 shows the hit rate (shown here as the z-score of the hit rate in Table 32.1) versus the stimulus strength. We chose a psychometric function with the shape shown both for simplicity in discussion and also because it is fairly realistic. Between 0 and 1 percent contrast we assume a dead zone in which the stimulus strength has no effect on the hit rate. Above 1 percent contrast we assume the psychometric function is linear, whereby for every 1 percent increase in contrast the z-score increases by 1 unit. The solid line shows the case in which the observer adopts a false-alarm rate of 2.5 percent (a z-score of $z_f = -2$). We indicate four possible definitions for *threshold*:

$Th_{\text{absolute}} = 1$ percent is the contrast that marks the transition from the "dead zone" (flat region) to the linear zone. Recent experiments in my laboratory in collaboration with Christopher Tyler and Tina Beard indicate that the psychometric-function shape shown in Figure 32.1 is quite close to the actual shape except that the transition is not as sharp as depicted. This definition of threshold is rarely adopted because the sharpness of the kink at 1 percent contrast depends on experimental conditions.

$Th_{\text{objective}} = 2$ percent is the contrast where $z_h = z_f + 1$. This is the signal-detection definition of threshold corresponding to $d' = 1$ (see discussion with equation 32.2). For the present example this hit rate would be $z_h = -1$ (corresponding to 16 percent correct) because the false-alarm z-score is $z_f = -2$.

$Th_{\text{subjective}} = 3$ percent is the contrast that marks the point where the hit rate is $p_h = 50$ percent corresponding to $z_h = 0$. This is the point that had been called threshold in pre–signal-detection days. It seemed natural to call threshold the point at which one sees the stimulus 50 percent of the time. For the psychometric function shown in Figure 32.1, the objective threshold is 2/3 the subjective threshold.

$Th_{\text{phenomenal}} = 4$ percent. Here we are inventing a concept that may be relevant to blindsight. This would be the contrast at which the observer begins to have distinct visual subjective awareness of the stimulus. In normal observers it is expected that the phenomenal threshold will equal the subjective threshold. As we will discuss, blindsight observers might use nonvisual cues to set a subjective threshold that is below the phenomenal visual threshold.

The dashed curve in Figure 32.1 is similar to the solid curve except that it is displaced upward by one unit. This displacement is produced by having the observer adopt a looser criterion so that the false-alarm rate is increased from $z_{fa} = -2$ to -1 (probabilities of 2.5 percent and 16 percent). Here the subjective threshold has moved down from 3 percent to 2 percent, to equal the objective threshold. If the observer had instead chosen a stricter criterion, then the psychometric function would have been shifted downward, increasing the subjective threshold and widening the gap between the subjective and objective thresholds. Notice that as the criterion changes the subjective threshold changes, but the objective threshold stays the same because we are assuming the psychometric function keeps the same shape and just moves vertically. This is called the equal-variance assumption.

DETECTION AND IDENTIFICATION (DOUBLE-JUDGMENT)

We now turn to blindsight. An observer with blindsight claims to be blind but is still able to make forced-choice identification judgments. Typically these individuals have lost part of their visual cortex, but as we will discuss, blindsight effects can also be found in normal individuals.

Consider this task—not only detecting a spot of light but also discriminating its position. On one third of the trials we present a spot in position *P*1, on one third of them in position *P*2, and on the remaining third neither spot is presented. We ask the observer to make a yes–no detection decision and also a *P*1–*P*2 location judgment, even when the observer claimed not to see the spot. Let us examine how five types of observers might respond:

The numbers in each row are the four categories of possible responses, where we have presented 200 trials of each condition for 600 total. When doing this type of detection-identification experiment, many trials are needed to have sufficient responses in all the response categories. To clarify

Table 32.2

	"No" responses		"Yes" responses			d' values		
	$N-P1$	$N-P2$	$Y-P1$	$Y-P2$	Total	d_D	d_{In}	d_{Iy}
1. Blind observer								
$P1$ stimulus	84	84	16	16	200			
$P2$ stimulus	84	84	16	16	200	0	0	0
Blank stimulus	84	84	16	16	200			
2. High-threshold observer (guesses if no detection)								
$P1$ stimulus	50	50	84	16	200			
$P2$ stimulus	50	50	16	84	200	1	0	2
Blank stimulus	84	84	16	16	200			
3. Signal-detection (equal-variance) observer								
$P1$ stimulus	84	16	84	16	200			
$P2$ stimulus	16	84	16	84	200	1	2	2
Blank stimulus	84	84	16	16	200			
4. Idealized blindsight observer (not using detection information)								
$P1$ stimulus	141	27	27	5	200			
$P2$ stimulus	27	141	5	27	200	0	2	2
Blank stimulus	84	84	16	16	200			
5. Observer 3 again, with a different criterion								
$P1$ stimulus	141	27	27	5	200			
$P2$ stimulus	27	141	5	27	200	1	2	2
Blank stimulus	97	98	2	3	200			

the meaning of the table, consider observer 5. He was shown the stimulus in the $P1$ location 200 times. This observer correctly identified the position on 141 of the 168 times that he claimed not to see the stimulus. That could be considered a striking case of blindsight. Here is how we calculate the last three columns. The detection d', d_D is based on equation 32.2, where the hit rate is based on the responses to either the $P1$ or $P2$ stimulus (they are symmetric in each of the five observers in the table) and the false-alarm rate is based on responses to the blank stimulus. One ignores the $P1$–$P2$ identification judgment when calculating d_D. The identification d', d_I is shown in the rightmost two columns. It is calculated separately for the yes responses and no responses. Consider, for example, d_{Iy} for observer 2. On the yes responses, he had 84 percent correct ($z = +1$) on the $P1$ judgment and 84 percent correct ($z = +1$) on the $P2$ judgment. The identification d', is the sum of the two, giving $d_{Iy} = 2$. For the "no" responses he had only 50 percent correct leading to $d_{In} = 0$, as shown in the next-to-last column. Further details can be found in Klein (1985).

The first observer is truly blind because the response to either light flash is the same as to the blank stimulus. The next two observers say yes in 100 of 200 trials for either the $P1$ or $P2$ stimulus corresponding to a 50 percent hit rate ($z_h = 0$) and say yes in 32 of 200 blank trials, corresponding to a 16 percent false-alarm rate ($z_f = -1$), giving $d_D = z_h - z_f = 1$ (third-to-last column) and so the stimulus is just at the objective detection threshold ($d_D = 1$ is the commonest definition of threshold in signal-detection theory). The 16 percent false-alarm rate corresponds to the dashed curve in Figure 32.1. The second observer does not have blindsight, for he has no position-identification information on the trials with a no response (the trials in which he misses the stimulus and must guess the position). That is, $d_{In} = 0$ in the second-to-last column. This observer follows the predictions of high-threshold theory. The third observer, following the predictions of signal-detection theory, has position information even if the detection signal is below his criterion and he says he doesn't see it. As we will discuss, this observer could be said to have blindsight. The fourth observer is of the type commonly considered an ideal blindsight observer, having no stimulus detection ($d_D = 0$), though making good position-identification judgments, $d_{In} = d_{Iy} = 2$. The last observer is the same as the third except with a different criterion, to make him look more like a typical blindsight observer. We have chosen the criterion and stimulus strength so that observer 5's responses to the stimuli are identical to those of observer 4. On the detection judgment, observer 5 has a false-alarm rate of 2.5 percent, the same as depicted by the solid line. Observer 4 is interesting. He is able to make the $P1$–$P2$ discrimination as well as the normal observer (5), but he did not detect the spot ($d_D = 0$). Two interpretations of observer 4's data are possible:

1. The observer had no awareness of the stimulus—he thought he was pressing the buttons on the response box at random and was surprised by the correct identifications. It turns out that this type of surprising behavior is not too unusual. It is quite common for new normal observers to have blindsight results on experiments. They are often surprised at how well they are doing even when they have no phenomenal awareness of the stimulus. With practice they typically become consciously aware of the proper cue (a cue they have previously been using unconsciously).

2. The observer had no *visual* awareness, but did have awareness either amodally (a feeling) or through a nonvisual modality, such as sensing that his eyes moved to $P1$ or $P2$. The observer could use this nonvisual information for the position judgments, but he decided not to use it for the detection judgment, possibly because he misinterpreted the instructions. Incidentally, eye-care clinicians report that patients are sometimes misdiagnosed as blind in peripheral vision because they misunderstand the clinician's instructions when their peripheral vision is measured. The instructions (fixate on a central dot while paying attention to their periphery) may be confusing.

The measurements leading to Tables 32.1 and 32.2 are usually thought of as objective measurements for which the person is using all available cues.

Thus the results of all observers other than the truly blind observer 1 might be examples of blindsight. Consider observer 2, whom we previously claimed to be devoid of blindsight. When the observer is says "yes, I see it," he may be using nonvisual cues, for although the stimulus is at the objective threshold ($d_D = 1$), he may be below the phenomenal threshold. Thus, even observer 2 might still be lacking visual awareness, the trait of blindsightedness.

For me, the most surprising aspect of actual research on blindsight (as opposed to the idealized gedanken experiment in Table 32.2) is that the methodology is sloppy. The tendency has been that because the subjects are patients one need not use careful psychophysical methods. More research is needed using double-judgment signal-detection methods such as those shown in Tables 32.1 and 32.2. The main signal-detection study on blindsight is that of Stoerig, Hobner, and Poppel (1985). She measured the hit rates for a range of false-alarm rates and found d' values between .1 and .9. These values are above the absolute threshold but below the objective threshold of $d_D = 1$. At these low d' levels we would expect the observer to be phenomenally blind. One does not begin to *see* stimuli until d_D values are 2 and above. It would have been interesting to know if Stoerig's subject could discriminate an X from an O with an identification d_I greater than 1 when the detection d', d_D, was less than 1.

It would be useful to have a blindsight study in which the observer's objective, subjective, and phenomenal detection thresholds were documented (defined above). It is claimed that some observers' phenomenal thresholds are so high that they cannot be measured. It would be nice to do careful experiments on these observers, measuring their identification threshold, d_I above and below their objective and subjective thresholds. To my knowledge this experiment has not yet been done. By sharpening our definitions of the multiple thresholds, we can bring greater clarity to blindsight studies.

BLINDSIGHT IN NORMAL OBSERVERS

One can find blindsight in normal individuals if eye movements are used as the motor response. One robust experiment was carried out by Scott Stevenson at the University of California Berkeley School of Optometry. He presented the same dynamic random dot noise to the observer's two eyes. A relative shift in the patterns to each eye was introduced. The amount of the shift is called the *disparity*. The observer's task was to keep the patterns fused. Stevenson found that the eyes were able to make the proper vertical or horizontal vergence eye movements (the vertical disparity range was limited to about 1°) to keep the two patterns in register. Practiced observers had absolutely no awareness of motion by the pattern or of their eyes for vertical motion, and yet the eyes "knew" how to move appropriately. For vertical greetings and horizontal motions, again the eyes automatically kept the gratings in register, but this time the observers had strong phenomenal awareness of depth corresponding to the disparity. The first case with the vertical disparity is blindsight because the eye-movement system responded correctly without subjective awareness. I like this example because simply rotating the stimulus by 90° turns subjective awareness on and off. The physiologists may be able to trace the circuitry of the vertical and horizontal disparity systems and discover what is special about horizontal disparities that produces phenomenal visual awareness. One possibility is that it is a learned response, whereby the horizontal separation of the eyes causes horizontal disparities to be correlated with depth. If an animal were raised from infancy with periscopes so that the eyes had a vertical optical separation, then the phenomenal awareness might switch, and vertical disparities might lead to phenomenal awareness.

One might not be surprised by Stevenson's result because it is well known that the neural pathway controlling eye movements goes through the superior colliculus subcortical pathway rather than through the V1 cortical pathway (which seems to be the consciousness pathway). It is commonly believed, however, that fusion of *dynamic* random dot patterns requires V1 processing. That requirement implies that both the consious horizontal disparity and the unconscious vertical disparities are to be found in V1 activity. By studying the differences in the two types of activity one might learn a good deal about the awareness pathways. Rafal et al. (1990) showed that a stimulus in the blind temporal visual field (the right field for the right eye) influences eye movements. These eye movements could be used as a cue to stimulus attributes, even though phenomenal awareness was missing. It is claimed that blindsight individuals can not only move their eyes to targets but also point and give oral reports about target location. This ability might be expected because all output systems are motor systems that might be linked. Reports that have really surprised me say that blindsight individuals can perform visual discriminations such as "X" from "O". Further controlled experiments such as those discussed earlier (with "X" and "O" replacing positions *P*1 and *P*2) should be carried out.

DISCUSSION

A number of controversial issues are associated with blindsight. Further discussion is needed among researchers working with blindsight patients and among philosophers who desire to clean up our choice of words for describing the blindsight phenomenon. The recent research of Stoerig and Cowey (1997) and Cowey and Stoerig (1997) does increase one's confidence that blindsight for detection is real and is associated with V1 lesions. That direction of research needs to be extended beyond detection to object discrimination, as discussed in the preceding paragraph.

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