CHAPTER

27

Decision and Attention

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ABSTRACT

In real life, individuals are faced with more than one perceptual event on which they have to make distinct decisions. It is shown that for a range of such multistimulus environments, decision behavior departs from optimality in the sense that subjects do not set their decision criteria in accordance with the requirements of each individual event. This behavior is explained in terms of a unified internal representation of the multistimulus environment, presumably resulting from the relaxation of attention to the critical dimension associated with each stimulus. Exceptions are observed for cross-modal (audiovisual) stimulations and for stimuli showing sensory interference. It is proposed that decision behavior and the selection process required to segment sensory objects are intimately related. Response criterion interaction may account for phenomena such as extinction and may be the substrate of a number of contextual effects.

I. INTRODUCTION

Despite the progressive and by now practically completed withdrawal of introspective thought from the field of experimental psychology, or perhaps because of it, a little introspection may guide the reader of this chapter. After all, every research report on attention that saves itself a formal definition of this concept—the overwhelming majority of attentional studies—relies on its intuitive understanding. Intuition tells us that making a decision is by essence an attentional state, that it requires pondering and hence involves an effortful, intentional, voluntary (terms willy-nilly equivalent to free will) component to be contrasted with a default, "relaxed," freewheeling behavior. This being said and inasmuch as intention, volition, free will, and perhaps mental effort remain purely intuitive, ill-defined terms, attention itself, at least its endogenous aspect, stands out as an equally indefinite concept.

The work to be described here bears on human decisional behavior and, more specifically, on a subject's capacity to deal with a number of *decision criteria* when faced with an equal number of distinct events. Technically speaking, this is an exploration into the *psychophysics of decision*. The basic results show that when confronted with a range of equally likely but different-strength events, subjects use a unique decision criterion although optimal behavior requires the use of criteria proportional to the stimuli strengths (see below). We refer to this behavior as to *criterion attraction* and we interpret it as the consequence of a *unitary internal representation* (UIR) of the (physically) distinct events, at least along the dimension under study. *Criterion attraction* (and its underlying UIR) is not observed under all the experimental conditions considered. A survey of the ensemble of our data led us to conclude that the UIR is the instantiation of a default, nonattentional state whereby a number of stimulus dimensions are merged together, hence sparing the observer the sustained effort of keeping them apart in exchange for a negligible loss in performance.

II. HISTORICAL BACKGROUND

By the mid-19th century, Fechner (1860) asked (and answered) the question of how to measure sensation; he thereby founded *psychophysics*. Some 50 years later, the Gestalt school put forward the study of shape perception relying on what could be called *conceptual observation*. Another 50 years later, a group of what one might call "neo-psychophysicists" set forth signal detection theory (SDT) (see Green and Swets, 1966), a set of principles and psychophysical tools by means of which sensation and decision were associated in an unbreakable conceptual tandem. This may have sounded as a more than 50-year-deferred echo to von Helmholtz's (1856–1867) view of perception as an "unconscious inference" process subject to perpetual decision making.

SDT quite rapidly became and has remained the main (and perhaps the only) general framework for measuring and modeling sensory/perceptual processes and for separating them from the decision/subjective part involved in the detection of an event and in its discrimination from other events. Still, SDT allows the measurement of sensation/perception while ignoring the decision parameter, provided that the subject's decisional state remains unchanged. Because such a "simplification" comes along with notable savings in experimental time, it has been extensively used to quantify a great deal of auditory, visual, and attentional processes to the expense of the study of the associated decision processes.[1] Although some recent neurophysiological work has revived interest in the process of perceptual and motor decisions (Schall, 2001), psychophysics and the cognitive sciences as a whole have not followed up. This chapter is such an enterprise.

III. PRECIS OF SIGNAL DETECTION THEORY

The cornerstone of SDT is the distinction it makes between *sensitivity* and *decision criterion*. The former is meant to characterize the processing efficiency of the underlying sensory system, and it increases with stimulus strength. The latter is regarded as the manifestation of a subjective operation whereby individuals decide on (as opposed to react reflexively to) the occurrence of an event based on factors such as expectation and payoff, in addition to its strength. To do so, individuals need to have some knowledge of the internal response distributions evoked by this event or its absence.

SDT (see Fig. 27.1a) posits that the activity of a sensory system along an arbitrary *sensory continuum* (or processing dimension) is non-null, even in the absence of a stimulus, and that this "reference" or *noise* (N) activity distributes normally over time. The mean and standard deviation, σ, of the N distribution are arbitrarily set to 0 and 1, respectively (standardized normal distribution). More generally, N designs the internal activity evoked by a reference condition (including the absence of any stimulus) against which the observer has to detect any stimulation change or *signal* (S). Depending on whether this change is referred to no stimulation at all or to some invariant reference stimulus, the task is coined *detection* or *discrimination*, respectively. The mean internal response difference between S and N normalized by σ is the SDT sensitivity index, d'. In other words, d' is defined as the S-to-N ratio.

In practice, the observer is randomly presented with N and S trials, each type in a given proportion P so that $P_N + P_S = 1$. The observer is faced with a binary choice: S (i.e., a "yes" response) or N (a "no" response). The conditional measured proportions p(Yes|N), p(Yes|S), p(No|N), and p(No|S) are referred to as *false alarms* (FA), *hits* (H), *correct rejections* (CR), and *misses*, respectively. Referring FA and H rates to the standardized normal distribution yields their standardized scores z(FA) and z(H), that is, their abscissa values (measured in σ units) with respect to the mean of N and of S, respectively. The sensitivity index d' is given by $z(H) - z(FA)$.

SDT posits that there is a point along the sensory continuum where larger and smaller internal response values entail "yes" and "no" responses, respectively. This frontier is called the *criterion*, $c = [z(H) + z(FA)]/2$, typically measured with reference to an unbiased response strategy. If the criterion is measured with respect to the mean of the N distribution, it is referred to as the *absolute criterion*, $c' = z(FA)$. In SDT, c (or c') is optimal (i.e., maximizes the percentage of correct responses) when its corresponding *likelihood ratio*, $\beta = p_S(z = c')/p_N(z = c')$ (read the ratio of the probabilities of the internal responses evoked by the signal and the noise at $z = c'$) is equal to P_N/P_S. Experimental results show (Green and Swets, 1966; Gorea and Sagi, 2000) that human observers are close to optimality only for p_N/p_S ratios close to 1 and are reluctant to unbalance their "yes" and "no" responses in proportion to the N and S probabilities when they are too different. It emerges from the account above that decision is an unconstrained process, fully controlled by the observer's strategy subjected to "free will." In a multistimulus environment, such a process requires distinct internal representations of the different sensory "objects" liable to a decision/response. SDT implicitly assumes that the simultaneous construction of these internal representations is possible and that, as a consequence, a subject's decisional behavior should be the same in single and multidecisional tasks. However, this implication has never been tested and the rules

[1]Of course, what is today abusively referred to as *cognitive* (in opposition to psychophysical) *studies* offers an equivalent modeling based on alternative behavioral techniques involving mostly response time and magnitude estimation techniques. Although these techniques are not discussed here, it should be noted that data collected with any of them are also related to the SDT format analysis: they depend on both sensory and decision parameters.

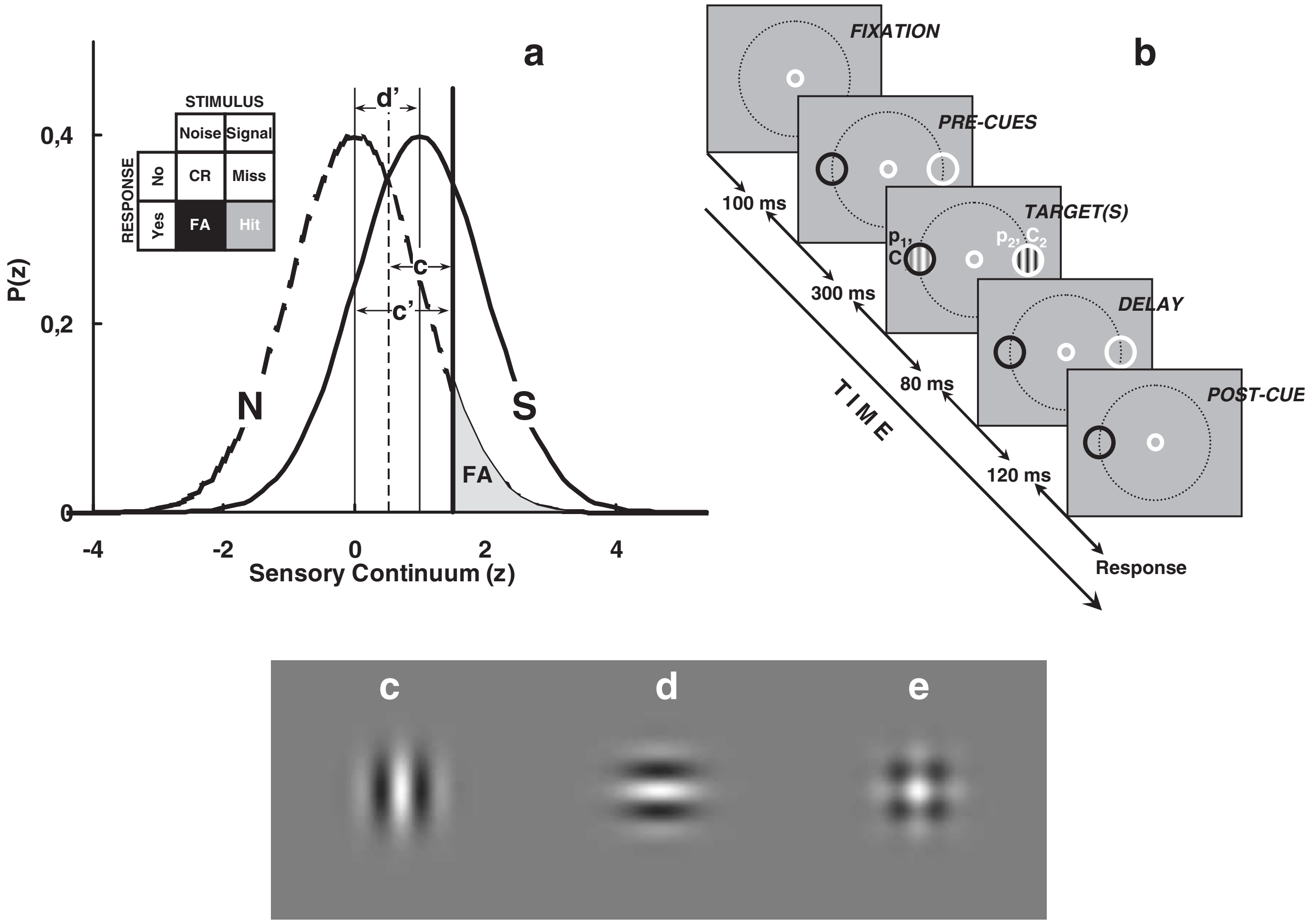

FIGURE 27.1 (**a**) Standard signal detection theory (SDT) framework for the dual-criterion experiments. Gaussian functions describe the probability density, $p(z)$, of the internal response distributions (in standard z scores, abscissa) for the noise [N: $p_N(z)$] alone (dashed curve) and for the signal + noise [S: $p_S(z)$]. Thin vertical lines show their means with sensitivity ($d' = z\text{H} - z\text{FA}$, with zH and zFA the z scores for the observed correct target detectia, Hit, and False Alarm rates) being the distance between these means ($d' = 1$ in this case) measured in units of the noise standard deviation, σ_N, and assuming that N and S are normally distributed with $\sigma = \sigma_N = \sigma_S$. The "absolute" criterion is defined as $c' = -z\text{FA}$. Defined in this way, criteria are independent of the univariance assumption (i.e., $\sigma_S = \sigma_N$), because they depend on the N distribution only. The corresponding values of the likelihood ratio criterion, $\beta = p_S(z = c')/p_N(z = c')$, characterize observers' response bias independently of d'. Error rate is minimized when $\beta = P_N/P_S$, (with P_N and P_S the a priori N and S probabilities) but experimental results show that observers adopt a more conservative behavior with β's closer to one (Green and Swets, 1966). The vertical dashed and continuous heavy lines show optimal criterion for $P_S = 0.5$ and $P_S = 0.25$, respectively. The shaded area denotes the FA rate for the latter case. (**b**) One trial sequence with two unequal contrast stimuli, a condition referred to as dual-different. The color of the pre-cues is systematically associated with a given contrast (and probability of occurrence) so that observers have full knowledge of the stimulus to be presented in each circle. The post-cue specifies the stimulus/location to be reported on (partial report paradigm). Dual-same (i.e., equal contrast stimuli) and Single (only one and the same stimulus presented at a time) conditions yield response criteria close to those predicted by standard SDT, whereas the dual-different condition yields a unique response criterion, contrary to SDT predictions. (**c**, **d**, **e**) Respectively a vertical and horizontal Gabor patch and their superposition in a "plaid." The segregation of the two plaid components is rather difficult.

governing the putative interference of multiple criteria remain unknown.

The experiments described here focus on a subject's capacity to handle multiple internal representations. Their outcome points to a strong limitation of this capacity with its implications on decision behavior. The observed constraint in handling multiple internal representations may be thought of as being rooted in the selection process required to segment sensory objects. Hence, the present query is susceptible of throwing new light on the attentional process as a whole.

IV. *CRITERION ATTRACTION* AND ITS INTERPRETATION, THE *UNIQUE INTERNAL REPRESENTATION*

A. The Basic Phenomenon

A few years ago we presented data supporting the notion that in a multidecision visual task involving different-strength (i.e., contrast), noninterfering stimuli (Gabor patches) (Figs. 27.1c,d) presented simultaneously (Fig. 27.1b), observers behave nonoptimally, in the sense that for equally likely signals, they adopt, contrary to SDT prediction, one single decision criterion despite the fact that they have full knowledge of the stimulus properties, that is, of their contrasts and occurrence probabilities (Gorea and Sagi, 1999, 2000). Observers do use distinct criteria when the different targets appear with different probabilities; however, these criteria were found to be strongly biased toward each other, as if mutually attracted. Figure 27.2 illustrates the optimal and unique criterion behavior for two equally likely signals within the standard SDT format (Fig. 27.2a) and, as actually measured (idealized representation), under single, dual-same, and dual-different conditions (Fig. 27.2b; see caption). While stimuli of different strengths should yield distinct response criteria whether presented in isolation (single condition) or simultaneously (dual-different), the latter condition yields a *unique criterion* (UC). Interestingly, this is the case only if observers are asked to judge each of the two stimuli within the same experimental block. If, instead, they are always asked to judge one and the same stimulus out of the two, their response behavior shifts back to optimal (in the SDT sense), suggesting that the UC is a consequence of mixing *decisions* about stimuli rather than just mixing stimuli. Indeed, in agreement with SDT, these decisional interactions do not affect sensory aspects of

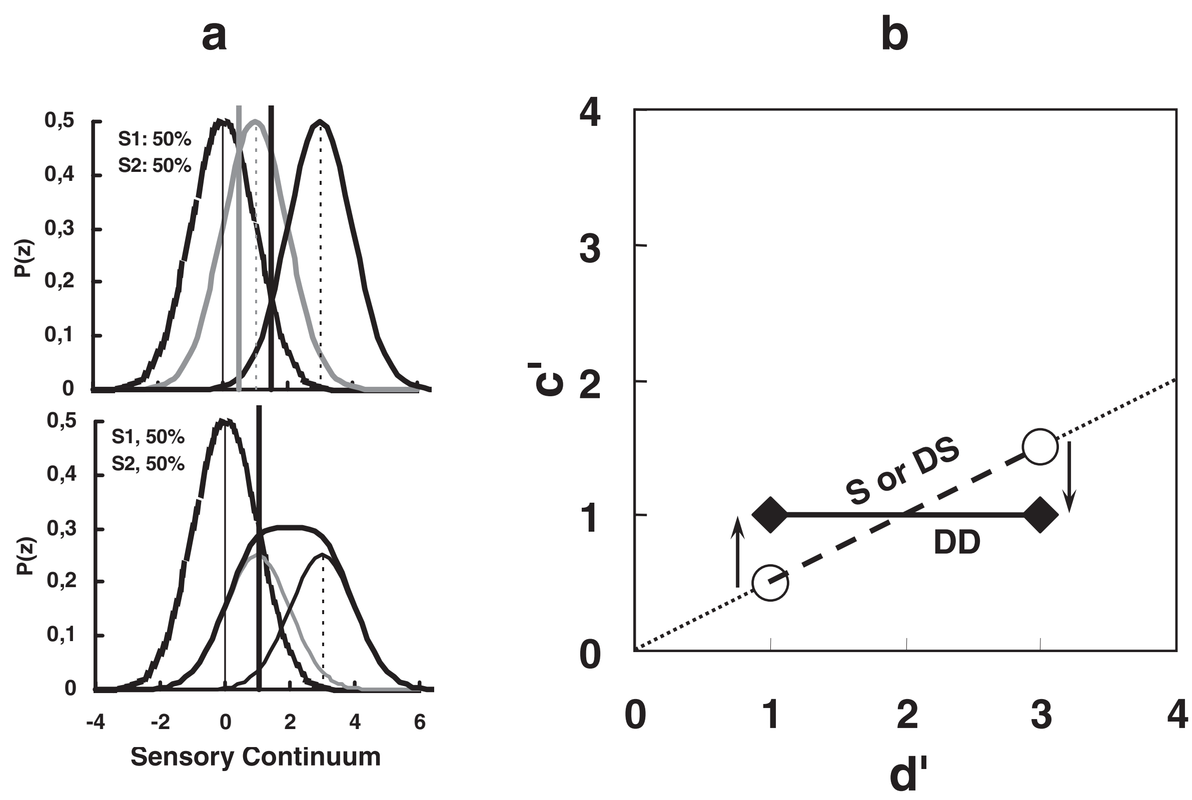

FIGURE 27.2 Optimal (top panel in (**a**) and the circles linked by the dashed line in (**b**)) and nonoptimal (the unique criterion predicted by the unique internal distribution model of Gorea and Sagi (2000) (bottom panel in (**a**) and diamonds linked by the continuous line in (**b**)) absolute criteria (*c*′) for two known, equal-probability but different *d*′ stimuli. Optimal behavior was observed under conditions where only one stimulus was presented within an experimental block (Single, S, case) or where two identical *d*′ stimuli were mixed in one block (dual-same, DS, case). The unique criterion was observed when two different *d*′ stimuli were mixed in one block (dual-different, DD, case) despite the fact that pre-cues indicated the type of stimulus to be presented on a trial-by-trial basis. SDT predicts optimal behavior in all cases. Arrows in (**b**) indicate the criterion shifts for the low- and high-*d*′ stimuli.

target processing as estimated by the measured sensitivity, d'.

Gorea and Sagi (2000) showed that *criterion attraction* is in quantitative agreement with predictions based on the notion that observers represent a multistimulus environment as a UIR to which each stimulus contributes in proportion to its probability of occurrence (bottom panel in Fig. 27.2a). Such behavior is equivalent to "relaxing" the selection process of the appropriate internal response distribution in view of a decision, hence obscuring the separation of the sensory objects according to their (contrast) properties. This direct link between criterion attraction and selective attention points to the fact that our experimental paradigm provides a new tool for studying the latter. It suggests that, in addition to short-term and/or working memory limitations on the selective attention process (see Chapters 83 and 100), the latter is also constrained by the decisional context of a specific task.

B. The Unique Criterion and Extinction

One intuitive way to rephrase the criterion attraction behavior is to say that, in multiple-stimulus environments, the weaker (less visible) stimuli are reported less frequently (the associated criterion shifts upward along the sensory continuum) and the stronger (more visible) stimuli are reported more frequently (the criterion shifts downward) than when they are presented in isolation. The UC is a particular case of this behavior. Reporting less frequently the presence of a weak stimulus in the presence of a (sensory noninterfering) stronger one is reminiscent of the neuropsychological phenomenon of extinction. Extinction patients (most of whom are also heminegligent) (Halligan and Marshall, 1998; see Chapter 58) fail to report a stimulus presented in the hemifield contralateral to their stroke but only when it is accompanied by another stimulus presented in the ipsilateral field. It is therefore possible that extinction, and perhaps hemineglect, be, at least in part, the consequence of a criterion shift (Gorea and Sagi, 2002).

On the assumption that extinction (and hemineglect) patients present a sensitivity loss in the hemifield contralateral to the injury, their sensory world is split in two, a normally salient one (ipsilateral to the injury) and a less salient one. Such a saliency imbalance is analogous to the two different-strength stimuli used in our original experiments (Fig. 27.1b) and should induce in these patients a unique criterion behavior as assessed in the laboratory with normal subjects. That is to say, patients should report events occurring simultaneously in their damaged and healthy fields respectively *less* and *more* frequently than when they are presented in isolation.

To evaluate the analogy between stroke-related extinction and its "natural" counterpart, we tested the latter with identical targets displayed (1) at the same eccentricity in opposite hemifields shown in preliminary tests to yield different sensitivities (up to 3 d' units), (2) at different eccentricities, and (3) with targets of equal contrast but of different spatial frequency. All these manipulations were intended to entail sensitivity differences for identical-contrast stimuli. It was always the case that observers used higher response criteria for the less visible targets (as much as 3 times more "not seen" responses: extinction) and lower response criteria for the more visible ones (about 1.3 times more "seen" responses: *counterextinction*) when these stimuli were mixed in one experimental block. These observations were recently extended to suprathreshold stimuli by means of a contrast matching procedure: when presented with two unequal (up to a factor of 20) contrast stimuli displayed simultaneously in their left and right hemifields, observers perceive the lower-contrast stimulus up to one order of magnitude less contrasted than when presented in isolation. Taken together, the threshold and suprathreshold data suggest that extinction in stroke patients may well be one among many other perceptual contextual effects involving observers' decisional behavior. Whether or not these observations can be integrated within the framework of the current attentional theories of extinction (and hemineglect) remains undecided.

C. Toward a Generalization

The experiments described above provided a moderate basis for the generalization of our original conjecture of the *unity of the internal representation* (UIR) of a multistimulus environment. However, the modality for which they were performed (vision), the stimuli (Gabor patches of same or different orientations or spatial frequencies) and the task used (simultaneous contrast detection) necessarily restricted the generality of the UIR hypothesis.

Additional experiments extended this concept to visual-contrast *discrimination* tasks[2] (Gorea and Sagi, 2001) and to *sequential* presentations of different contrast or loudness increments mixed in one experimental block, but failed to do so for mixtures of visual and

[2]In these experiments, equal (dual-same) or different (dual-different) contrast increments were added to equal- or different-suprathreshold-contrast Gabor pairs. The realization of the UC under such conditions allowed the disentangling of signal from noise in the discrimination process, a more than one-century-old problem in psychophysics.

auditory stimuli presented either simultaneously or sequentially and for simultaneous pairings of either binaural loudness increments or contrast increments applied to a vertical and to a horizontal Gabor patch *spatially overlapping* (a "plaid" stimulus, Fig. 27.1e) (Gorea and Sagi, 2003).

The absence of criterion attraction for cross-modal presentations supports the intuitive conception that contrast and loudness are distinct perceptual (and physiological) dimensions that cannot be merged or confounded. The manifestation of criterion attraction for sequential intramodal presentations confirms the notion that it results from the confusion of the internal representations evoked by these stimuli and not from their sensory interference. In fact, sensory interference (resulting from the cross-talk between the underlying processing channels and revealed by a *d*′ drop in the dual-task relative to single-task conditions) seems to promote an independent decisional behavior (absence of criterion attraction), as was observed in the simultaneously presented binaural loudness increments and for the "plaid" presentations (despite the large pitch difference of the former—700 and 2000 Hz—and the maximal orientation difference of the latter—90°).

In short, criterion attraction occurs neither across sensory modalities nor for interfering stimuli within the same modality. Whether it occurs across dimensions within the same modality is presently under investigation.

V. DECISION AND ATTENTION

In the present experiments, observers had to decide between the absence or presence of one specific stimulus among two (see Fig. 27.1b). To do so optimally, they should have relied on its corresponding internal representation to evaluate the likelihood that the evoked internal event represents that stimulus. According to SDT, had the two stimuli differed exclusively in their contrast (or loudness), their discriminability should have equaled exactly the difference in their detectability *d*′-*s*. Nonetheless, the two stimuli could also be discriminated based on other physical characteristics, such as their location, orientation, spatial frequency, or suprathreshold intensity of the pedestals to which the increments were applied. In the reported experiments, the sequential and "plaid" (Fig. 27.1e) presentation formats are two extreme cases of the stimulus difference along the critical *detection* dimension for their segregation. In the sequential case, stimulus identification is simply not needed as each temporal interval is unambiguously associated with one and only one stimulus; this case yields a UC. In the plaid case, the orientation difference between the stimuli does not ensure their perfect (within-object) discrimination, which can be improved based on the difference between the contrast increments associated with each orientation; this case yields optimal decision behavior. The overall picture appears to be the following: As long as the stimuli can be *unambiguously* discriminated, or segmented into distinct objects based on attributes not relevant to the detection task (a condition *not* fulfilled with interfering stimuli that activate overlapping processors, hence hindering their segmentation), observers, willingly or not, "disregard" or "relax" their attention to the less salient differences, that is, of contrast or loudness, and perform a pure detection task with no loss in sensitivity. That is, they merge the internal response distributions evoked by the different contrasts (or loudnesses) corresponding to the different objects into a unitary one and, by so doing, fail to segment these objects (or within-object dimensions) based on their intensive characteristics. In fact, this "conjecture" becomes self-evident in the face of pure logic: the observed unique criterion along a given dimension amounts to splitting the events along that dimension into two and only two states, call them noise and signal, with no room left for further discriminating different signal states along that dimension (Fig. 27.3). Hence, although the information required for such a discrimination is available to the perceptual system, it is not used, yielding zero discrimination ipso facto. The fact of using (optimal behavior) or discarding (UC) available sensory information is the modus operandi of selective attention, and as such, decision behavior and selective attention are inevitably related.[3]

The relationship between UC and discrimination performance seems logically indisputable. Can it be tested empirically? Presumably not. The reasons are both technical and conceptual. Leaving the technicalities on the side, we briefly dwell on the conceptual part. As mentioned, the format of our standard task allows observers (on most but not all occasions) to ignore the tagging of the internal response distributions evoked by each of the two stimuli, while still performing the detection task without loss in *d*′. Using attentional jargon, this amounts to saying that the "allocation" of attention into the primary component of the task, detection, leaves no attentional "resources" for its secondary component, discrimination. This

[3] It is of no intuitive doubt that decision (as opposed to a reflex response) and endogenous attention (as opposed to the drawing of attention by a "popout" event) are both rooted in the even fuzzier concepts of intention and free will.

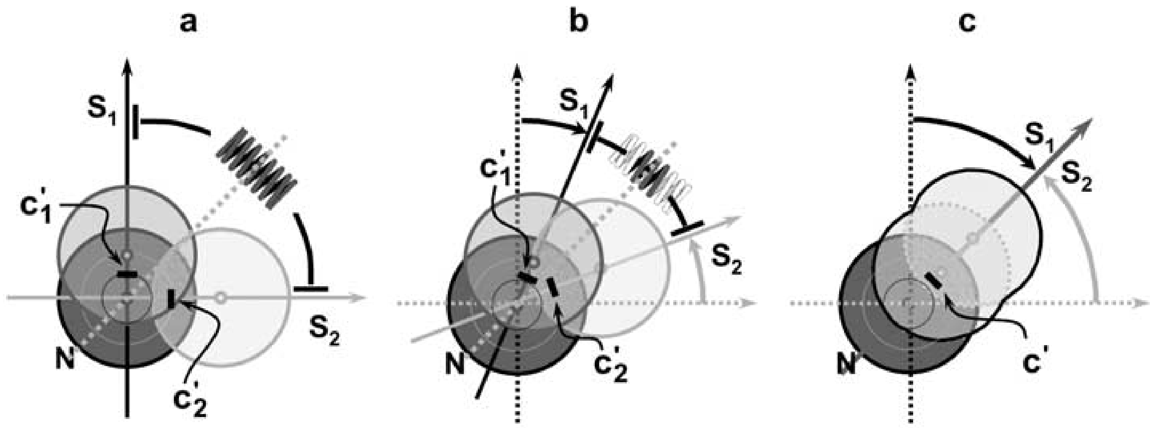

FIGURE 27.3 Three "attentional states" yielding noise (N, disk centered at the origin)- and stimulus (S_1 and S_2)-evoked internal representations (remaining two disks) given that S_1 and S_2 do not interfere at the sensory level. Internal representations, decision axes, and response criteria (*c*′) are (**a**) independent (attention is ON), (**b**) partially mixed (attention fluctuates), or (**c**) entirely merged (attention is OFF). The intersections of the decision axes with the dotted concentric circles within the noise (N) internal distributions are the optimal (in the SDT sense) locations of the criteria. Attention is represented as an expander spring that keeps the decision axes apart.

account does not prejudge the limitation of such resources as it is perfectly conceivable that, had they been asked to also discriminate the two signals, observers could have done so without dropping their detection *d*′ (Watson and Robson, 1981). The point here is that, as long as *not* measured, the discrimination performance should logically be blank and normal otherwise. This conceptual conundrum appears to prevent a direct test of the logical implication of the UC. It may, however, inspire future theoretical and empirical apprehensions of the attentional fact.

Attentional effects have always been measured and interpreted as they pertain to performance, that is, to sensitivity. At the same time, *selective* (endogenous) attention unequivocally refers to a fact of choice or strategy. Nonetheless, attentional effects, in general, and selective attention effects, in particular, have not been referred as yet to shifts of the *decision/response criterion*. The typical way of evading this obvious temptation was to expose the fact that selective attention (hence choice criterion) modulates the number of potential noise sources and, ultimately, sensitivity (i.e., the signal-to-noise ratio) (Lu and Dosher, 1998). This inclination has been formalized in the framework of an *uncertainty theory* (Green and Swets, 1966; Pelli, 1981). SDT's postulate that sensitivity is independent of the response criterion, together with the general consensus on what is meant by selective attention, apparently discouraged an experimental and theoretical effort focused on the attention–decision tandem. The present studies are but the shy beginning of such an enterprise. They suggest at least one new definition of attention (i.e., *a decision preparatory state*) and link it to the notion of stimulus dimensionality as it is determined by the task and to the dimensionality of the task itself as it is (consciously or not) formulated by the observer. This conceptual chain lends itself to a future expansion of the notion of sensory *objecthood* (see Han et al., 2003) as it relates to decision and attention processes.

VI. CONCLUSION

The preceding discussion of the implications of decisional behavior on the attentional process remains by and large speculative. We believe nonetheless that it may well be integrated within the wider conceptual spectrum of older (for a review, see Boring, 1942) and more recent (e.g., Gilchrist et al., 1999; Adelson, 2000) context theories (including Gestalt, adaptation-level, and other anchoring effects). Most importantly, we believe it offers for the first time, as far as we know, a means of linking perception, decision, and attention into a conceptually united whole. It is our opinion that in the last decade, perception and attention investigations have lacked more than ever new conceptual frameworks. The present review is a modest contribution to that avail.

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