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Recognition Decision Criterion in Human Episodic Memory Based on Signal Detection Theory Framework

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Historically, memory studies have focused more on the accuracy of memory reports than the decision processes responsible for translating memory evidence into overt judgments of remembering. Indeed, these decision processes have often been treated as nuisance variables whose influence must be removed so that the accuracy of different observers or experimental conditions can be reliably compared. Recently however, there has been a renewed interest in the mechanisms that support decision-making in memory and the degree to which these mechanisms are flexible, adaptive, and separable. This review examines various characteristics of criterion (role of criterion, variables that influence criterion setting, flexibility or shift of criterion, multiple decision criteria) and recognition memory models in terms of this decision process.

Key words : Decision Criterion, Recognition Memory, Signal Detection Theory (SDT)

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In the long history of memory research, the main interest has been in the accuracy of memory reports as a function of factors such as individual subject differences, or experimental manipulations. However, even at the outset it was clear that estimating accuracy often required key assumptions about the mapping of subjects' internal memory evidence onto overt reports (Snodgrass & Corwin, 1988). When formalized, these assumptions represent basic decision models, which if correct, allow researchers to estimate two independent mnemonic variables; accuracy *and* the decision strategies (heuristics or bias) that observers employ when providing memory reports. The purpose of the present review is to specify and clarify the role of (criterial) recognition decision process, and to delineate how this decision process is related to the adaptive behavior during recognition memory judgment.

To initially illustrate the distinction between accuracy and decision strategy it is helpful to consider some examples before formal models are discussed. If we only consider the observers' percentage correct during recognition memory task, we might simply conclude that two subjects who both showed 90% hit responses (*hit* rate - "yes" response rates to studied items) are equally good at memory performance. However, if one of the observers showed a 10% false alarm rate (*false alarm* - the misclassification of a lure as belonging to the studied item category) whilst the other showed a 40% false alarm rate, it would be unreasonable to conclude that they showed the same memory performances. The outcome, the high rate of hit responses, of the latter observer may result from his/her strong tendency or willingness to say "yes" rather than purely from high memorability. Even a more concrete everyday example further supports this distinction. During a typical police line-up where eyewitnesses are asked to identify the perpetrator of a crime from a group of similar looking individuals, one assumes that the memory accuracy or precision of the eyewitness does not change simply as a function of what the police biases him or her to believe. However, identification performance is indeed suggestible as a function of whether or not the witness is let to believe the suspect is in the line up (i.e., Zaragoza, Payment, Ackil, Drivdahl, & Beck, 2001). In other words, the investigator can affect the mapping of the observer's evidence onto the identification/recognition decision. As seen in these cases, decision performance may be based not only on accuracy (precision) but also on response tendency (willingness to say a particular response type). Both factors are equally important in decision processes since they represent two main properties on which nearly all decisions may be based: *Evidence* and *Threshold*[1].

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1) This term will be replaced with decision criterion or decision rule later in the main body since threshold can be confused with the high-threshold theory in recognition memory that assumes

Two components that govern recognition decision process *Evidence* is the information used in forming a conclusion or judgment (e.g., a signal strength of auditory stimuli, the type of cards in one's hand in gambling). During a recognition memory task, the level of the familiarity of test item is important evidence for recognition judgments. Observers make judgments when they think there is a sufficient evidence that a (memory) signal actually exists. Since the evidence reflects the amount of information contained within a stimulus, it is assumed that one's accuracy can be improved via the manipulation (i.e., increase) of the strength level, for example, by repeating the presentation of study stimuli in a memory task (strengthening the memory trace) or by using distinctive stimuli to be recognized, detected, or discriminated.

On the other hand, the *threshold* is an observer's reference point on the decision variable axis where a response can be elicited only when the information level exceeds that point. The role of mapping one's *thresholding (or criterial)* process to the evidence, becomes apparent if we consider cases in which people show different decision behavior based on the potential consequences of the decision. For example, if subjects are rewarded for detecting studied items, yet face no punishment for incorrectly classifying lure items, then it would be advantageous to rapidly shift the criterion to a more lax position, thus increasing the correct detection rate and increasing reward.

Furthermore, criterion shift can govern performance just as much, if not more than, as the accuracy of the observer. In an evolutionary sense, observers may depend on selection behaviors that provide correct responses, and may be indifferent about whether the correct response is obtained due to the high accuracy or to a shifted criterion. Thus an observer who is skilled at strategically positioning the criterion to maximize high reward outcomes will often be successful and may in fact be able to compensate for a memory system with reduced accuracy or resolution.

all-or-none style of memory decision.

Criterial Processes in Recognition Memory

Recognition memory is a form of memory retrieval where a binary decision ("Old" vs. "New") is typically required upon the presentation of an item that was either presented in a prior study phase or not. The *criterion* issue in recognition memory was raised in early 70's (e.g., Gordon & Clark, 1974) but has been overlooked in the research field. Gordon and Clark suggested that in more traditional recognition studies only the hit rate was analyzed to explain differences in memory performance. However, several recognition memory researchers also suggested that the biased consideration of accuracy alone in memory performance might result in a weak evaluation of the decision performance (Donaldson, 1996; Snodgrass & Corwin, 1988), since the percentage of "old" responses to a particular item type is some combination of sensitivity and criterial response.

This review will focus on the decision rule, or *decision criterion*, in recognition memory judgments to explain the principle of recognition decision in terms of how individuals set reference points to decide how much information they need to recognize memory items. That is, formulating decision criteria represents a process that regulates translation (i.e., select, screen, transform, transfer, or threshold) of memory information (familiarity of items) into an overt action by specifying and filtering how much information is needed before making different types of decision responses (e.g. binary 'old/new' recognition of an item). The main part of this paper will review various aspects of decision criterion and the related debate. Specific questions to be addressed will be; (1) What kinds of variables influence criterion placement? and (2) How labile and flexible is the criterion change across trials in adjusting the response tendency or bias? (3) Is there also a non-criterial recognition process? I will first breifly consider the framework known as Signal Detection Theory (SDT), which developed its own criterion measures that allow underlying decision criterial processes to be expressed.

Signal Detection Theory and Response Measures

History and Development of Basic SDT

The general theory of signal detectability was fully developed in the early 1950's by mathematicians and engineers. Its application in psychology focused on the theory's ability to provide a way of controlling and measuring criterion that an observer uses in making decisions, as well as measuring the observer's sensitivity to discriminate the signal from noise (Green & Swets, 1974). The theory and its concepts form the theoretical basis of a wide range of cognitive decision models including sensory detection (Smith, 1995; Usher & McClelland, 2001), perceptual discrimination (Link, 1975), memory recognition (Banks, 1970; Parks, 1966; Ratcliff, 1978), and conceptual categorization (Ashby, 2000; Nosofsky & Palmeri, 1997).

Figure 1 presents the equal variance normal probability density distributions (or likelihood distribution, or probability density) of continuous amount of evidence values for noise and signal in detection decisions. The probability that a value that is above any point on the x-axis will occur is the proportion of area under the distribution curve above that point (ex. K in Figure 1 represents the false alarm proportion) (Macmillan & Creelman, 1991). Since there is an overlap between two distributions, the decision

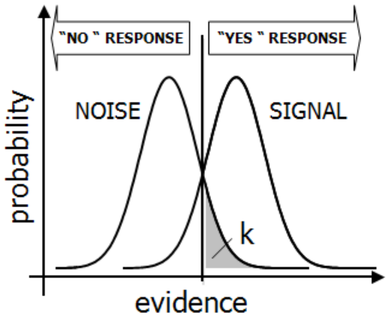

Figure 1. Example of the equal variance signal detection theory model of perceptual discrimination. Normal probability density distributions of signal and noise.

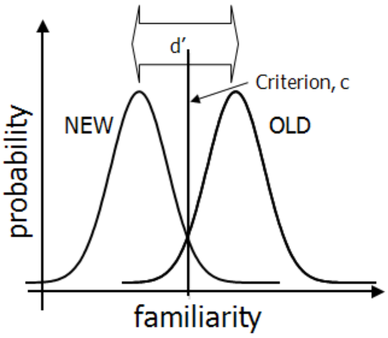

Figure 5. Sensitivity and Criterion. Example of the density distributions of continuous amount of memory evidence values for new and old items in recognition memory. Accuracy estimate d′ is the distance between the means of two distributions divided by the standard deviation. 'c' denotes the SDT estimate of bias that is the relative position of "Old/New" decision criterion with respect to the intersection of two distributions.

criterion is needed to decide the amount of information needed to select. Based on this framework, criterion-related characteristics such as allocation, movement, tendency, and bias can be expressed in a mathematical way.

Sensitivity and Criterion

Sensitivity (d', d-prime): Sensitivity means the ability to distinguish between stimuli (signal vs. noise, old item vs. lures). As depicted in Figure 2, it is the distance between the means of two distributions divided by the standard deviation of the lure distribution, scaled in z units with common variances. Sensitivity in terms of the distance between the two distributions can be adjusted by the manipulation of strength of evidence on the continuous scale. The amount of evidence triggered by the presentation of items is can be thought of as familiarity and, for example, the repeated exposure to the item in the study phase will increase the mean of the old item's familiarity and will shift the old item distribution toward the right on the familiarity axis compared to the single exposed old item distribution.

Decision criterion: The other important measure in SDT is decision criterion, which in the simplest case specifies the strength value (e.g., intensity of physical signal, familiarity of recognition item) above which an item is judged to be relevant for decision ("target" or "old"). This index is intended to measure the subject's willingness to say "Yes/Old". In Figure 1 and 2, it is located exactly halfway between the means of target and lure distribution. Any other decision criterion beyond this midpoint represents response bias or tendency in favor of alternative decisions (liberal (lax) vs. conservative (strict)).

As Macmillan and Creelman (1991) mentioned, the sensitivity measure d' should depend on stimulus parameters, but is untainted by a response bias that measures the subject's tilt toward one response or the other ("yes" or "no"). That is, SDT assumes that sensitivity and criterion are two independent working mechanisms. Thus, SDT provides the ability to compare sensitivity between operators that may have different decision criteria. On the other hand, the distributions may stay the same so that one's overall performance is the same while the criterion is changing according to the biased tendency. As a result, partitioning response performance into sensitivity and bias allows us to consider different strategies to improve performance by independently manipulating the influence of two mechanisms (i.e., repetition of presentation during encoding vs. strict verbal instruction during retrieval).

Recognition Memory under SDT Framework

Since Banks (1971) and Parks (1966) presented the idea that recognition memory (verbal retention and memory response) is a form of signal detection theory, SDT has been applied in the explanation of various recognition judgments such as yes/no recognition, item/associative memory, alternative forced choice decision, sameness judgment, etc. by using the measures (*sensitivity, criterion*) derived from it. SDT framework has often been used to explain recognition memory behaviors perhaps for largely three reasons. First, it originally explained binary response behaviors such as detection of signal ("It is a target" vs. "It is a noise"). Likewise, recognition memory paradigms also ask participants to respond in a binary manner ("It is an old item" vs. "It is a new item"), and secondly, recognition judgment is analogous to the signal detection behavior. The recognition process includes the evaluation of the familiarity level of items with a reference point to detect the evidence of old items. The familiarity level of a memory item is equivalent to the level of strength of signal. Lastly, to-be-recognized items with different familiarity levels are assumed to be statistically distributed as the SDT assumes two normal distributions with equal variances for the signal and noise distributions.

Memory models using SDT framework mostly hold that subjects calculate a continuous familiarity value for each item in a recognition task. Familiarity is a continuous variable representing the evidence of an item's previous occurrence (Gillund & Shiffrin, 1984; Hirshman & Master, 1997). In recognition memory, it is assumed that the evidence underlying lure (new) items varies according to factors such as prior frequency of exposure, recency of exposure, and similarity to other items stored in memory. As items are encoded during study, memory evidence or strength is augmented, yielding a target distribution falling to the right of the lure distribution (Figure 2). Because the evidence distributions overlap, observers must use a single evidence value to parse the continuum into the two required response options. This value is referred to as the decision criterion and depicted in the Figure 2 (criterion, c). If an item's value falls above the criterion the item is categorized as "Old", whereas if it falls below, it is categorized as "New". Overall, the recognition retrieval process is assumed to be a classification process in a broad sense.

The Characteristics of Recognition Decision criterion

A main question to be addressed first is: what factors may affect the criterion setting during episodic recognition judgments? In addition the main body will discuss how people voluntarily shift criterion placement for recognition memory judgments in a trial-by-trial manner by adaptively adjusting their tendencies. Finally, I will also examine whether there are discrete memory processes for which decision criteria are unnecessary.

Variables that Influence Criterion in Recognition Memory Task

During a typical old/new recognition memory paradigm, there can be largely three types of factors that can influence the decision criterion component in recognition judgments: stimulus-related factors, encoding-related factors, and test-related factors (e.g., Benjamin & Bawa, 2004; Brown, Lewis, & Monk, 1977; Hirshman, 1995; Stretch & Wixted, 1998). The stimulus-related factors include variables inherent to certain stimulus classes, such as word frequency or picture clarity that can influence criterion. For example, Brown and colleagues (1977) showed that some subjectively memorable distractors such as familiar names of relatives make people set a strategically stringent criterion when they recognize those items (Brown *et al.*, 1977), and subsequently yielded more accurate memory performance. Thus, the stimulus characteristics influence rated memorability and also criterion placement.

Stimulus-based factors are inherent to the stimuli without any strategic adjustment or manipulation on the part of subjects. In typical recognition memory paradigms, however, the memorability of stimuli is given mostly by the nature of, or the extent of, the encoding activity rather than by the stimulus itself (e.g., level of processing). Hirshman (1995) found that different presentation times for memory items elicited different uses of criterion: a more stringent criterion for the items with longer presentation, a more lax criterion for items with shorter presentation. Hirshman assumed that subjects estimated the approximate range of familiarity according to the duration of the presentation, and that they used the information in decision processing. The findings of Stretch and Wixted (1998) showed that strength-based *mirror effects,* in which hit rates and false alarm rates move in opposite directions with an experimental manipulation of learning, can also be interpreted as subjects incorporating an assessment of encoding operations into decision standards of recognition.

Lastly, it is assumed that test-based factors purely reflect the decision standards of recognition if the stimulus properties and encoding conditions are constant in the experiment. For example, it was mostly payoffs that were manipulated and the proportions of old and new items were varied to examine how test conditions and factors influence decision criterion setting (Healy & Kubovy, 1978; Ratcliff, Sheu, & Gronlund, 1992). Regarding test-based factors, Benjamin and Bawa (2004) reported findings in which test phase varied in makeup: the test conditions contain foils with different levels of plausibility as prior study items. In the test phase that contained foils which were highly plausible as prior study items (i.e., members of the same categories), people used relatively high criterion. They suggested that this test-based manipulation showed that subjects could adjust their decision criterion on an item-by-item basis by using information about the degree of learning for categorically related material.

Overall, these studies imply that decision criterial decision process is critical factor that decides the episodic recognition performance. What remains unclear is that the extant evidence is highly mixed with respect to the ability of subjects to adaptively reposition recognition decision criteria. More details of recent experiments will be reviewed in the next section with respect to the flexibility issue of decision criterion.

Adaptive criterion shift in recognition memory judgment: Fixed vs. Flexible Decision Criterion

Fixed Criterion: Despite its intuitive appeal and the clear adaptive advantage, there is scant evidence about criterion flexibility during recognition judgments. For example, Stretch and Wixted (1998) tested the assumption that participants readily adjust the decision criterion *during* the course of a recognition test (e.g., Miller & Wolford, 1999) by manipulating the verbal item strength differentially via repetition of presentations (three times - strong list vs. once - weak list) during encoding. Using the strength manipulation of items, the researchers reasoned that subjects might have used a higher decision criterion in the strong conditions relative to the weak conditions since one would anticipate fairly strong evidence if the items had been encountered. However, the false alarm rates[2] were nearly identical while the hit rates changed by the manipulation of strength. They suggested that the identical false alarm rates indicate that the criterion in the subjects did not move around in the within-list condition.

Morrell and colleagues (2002) also manipulated strength of items in two different categories (e.g., places and professions), and they explicitly informed the category-strength manipulation so that people would not overlook the difference (Morrell, Gaitan, & Wixted, 2002). Even with the explicit manipulation the results showed the same false alarm rates for both categories suggesting that people adopt a single rigid decision criterion and maintain it throughout the recognition test.

More recently, Verde and Rotello (2007) presented observers with test lists that seamlessly abutted two blocks each containing either strongly or weakly encoded targets intermixed with novel lures. They hypothesized that, for example, when transitioning from a strong target block to a weak target block, subjects should adjust the criterion downward because signals exceeding their old/new criterion would suddenly become increasingly rare, suggesting that they were too stringent in their chosen criterion (see also Glanzer & Adams,1990). Nonetheless, the false alarm rates remained fixed, suggesting that observers' criteria were insensitive to persistent changes in the average strength of the items during testing.

Why are people less likely to shift criterion in within-list conditions? The rigid criterion is important in terms of saving effort to shift criterion item-by-item during the recognition test given that the rigidity might represent a consistent response patterns on the part of subjects. In addition, most experimental conditions in the laboratory, indeed, have not provided much incentive to change criterion trial-by-trial. However, the results lack explanation pertaining to the adaptive behaviors that people can adopt in decision-making process. Furthermore, the above studies would suggest a strong limit on subjects' abilities to use global test list regularities as cues to more effectively reposition recognition decision criteria.

Flexible Criterion: By contrast. there are studies that indeed reported several instruction methods yielding flexible memory criterion shifts when presented *prior to* testing. These include instructing subjects to favor either high

2) The assumption is that lure distributions of different groups have the same strength of evidence for the members of the distribution and that, with the other variables constant, the false alarm rates would change only according to the different placement of criterion, whereas hit rates could be changed by the item strength manipulation, such as the repetition of category members.

confidence "old" or "new" responses (Azimian-Faridani & Wilding, 2006), providing them with either veridical or misleading information about upcoming target-lure ratios (Hirshman & Henzler, 1998; Rotello, Macmillan, Reeder, & Wong, 2005; Strack & Foerster, 1995), or informing them about differences in relative monetary payoffs for certain outcomes (Van Zandt, 2000). In all cases, it is important to note that the shift reflects an adjustment that occurs *prior to* testing as a function of explicit instruction, and that it reflects subject's explicit understanding of test list characteristics or contingencies that, in the long run, make one response option relatively more desirable or profitable than another.

Two other recent studies also reported trial-by-trial criterion adjustment as a function of semantic list characteristics of the retrieval probes *during* testing. For example, Benjamin and colleague using manipulations of lure item plausibility demonstrated that subjects were capable of capitalizing on semantic/conceptual characteristics of probes that are predictive of memorability during testing (Benjamin & Bawa, 2004; Benjamin, 2003). More specifically, some tests contained foils that were highly plausible as prior study items and others contained more implausible foils. The subjects who took a test with more plausible distractors set a higher decision criterion than did subjects who took a test with less plausible distractors.

Likewise, observers also appear to adopt a stringent criterion for items that are personally distinctive and known (for example a picture of one's favorite coffee shop) versus those that may be perceptually similar but unknown (an unknown coffee shop) (Dobbins & Kroll, 2005). Such shifts can be in accord with the subjective memory heuristic postulated by Brown and colleagues (1977) that assumes that memory decisions are informed by subjective expectancies about the memorability of encounters with personally unique and relevant stimuli. In both cases above the heuristic assumes that subjects expect to recover vivid or strong recognition information for personally distinctive items or for the items with plausible distractors, and hence apply a stricter decision criterion to such items compared to unknown, non-distinctive stimuli.

More recently and importantly with respect to the adaptive change in criterion placement during episodic recognition, Han and Dobbins (2008) demonstrated trial-by-trial criterion learning by manipulating feedback contingency during test in the absence of explicit instruction or global test list characteristic changes. In their study, different groups of subjects received systematically misleading feedback for certain types of errors (false positive reinforcement), and this procedure shifted the relative criteria of participant groups. For example, observers in the "strict" group receive correct feedback for hits, correct rejections, and false alarms, but are incorrectly informed that misses were in fact correct responses. The false feedback induced criterion shifts that appear quite durable, continuing for considerable periods even when feedback is removed or shifted to fully correct feedback, indicating that observers are extremely sensitive to feedback contingencies given on a trial-by-trial fashion during testing and that they learn to avoid negative outcomes by repositioning the decision criterion. More recent study suggests that this feedback-based recognition criterion learning is parallel to the one in the associative learning mechanism in the non-episodic learning such as probabilistic classification learning or information integration (Han & Dobbins, in press).

In total, on the basis of these several recent empirical findings, it may be reasonable to assume that people change their decision criteria capitalizing on the item properties such as the duration of presentation that may change trial by trial. Furthermore, the test variables, such as payoffs or feedback about the performance, which can give incentives to people, also enables adaptive criterion shifts as accuring decision preferences that track the overall reinforcement probabilities for different memory decision.

Are some recognition processes "non-criterial"? Dual Process Model vs. Two-criteria Model To this point we have assumed that recognition evidence is continuous and that a single adaptive retrieval process (recognition criterion) governs responses. However, there have been indeed several memory models which assumed that recognition memory could be based on two distinct forms of memory (e.g., Yonelinas, 2002; Tulving, 1985). Moving on, I will address how the consideration of criterion process can provide the implication for the recent debate such as dual process recognition memory versus two-criterial memory process.

***Dual Process Theory*:** In his old studies, Tulving (1985) developed a method to directly measure the different states of awareness about the memory retrieval processes by requiring subjects to answer the Remember/Know questions for their recognition of items. Under these models, it is assumed that people distinguish between two distinct retrieval states; *Recollection* and *Familiarity* (Jacoby & Dallas, 1981; Mandler, 1980; Yonelinas, 1994, 2002), and critically, *Recollection* involves conscious reflection triggered by having encountered an item before that leads a participant to say "I remember". This conscious recollection involves the recall-like process of the event together with specific associative and contextual information (Gardiner, Ramponi, & Richardson-Klavehn, 1998). Recollection seems to be a retrieval process that recovers *discrete* information, and requires additional explanation such as a high-threshold theory that works in an all-or-none manner, other than the single criterion assumption on the strength-based memory decision axis. The other mechanism relies upon the assessment of the *familiarity* of the event in the absence of recollective reflection. The recognition judgment based on this familiarity mechanism is labeled "I know" or "It is familiar" by the participant. The Yonelinas (2002) proposed that familiarity is assumed to reflect the assessment of "quantitative" memory strength information in a manner similar to that described by signal detection theory (in that it requires criterion on the continuous evidence scale). In contrast, recollection is a threshold retrieval process that employs "qualitative" contextual information about a previous event (Dobbins, Kroll, Yonelinas, & Liu, 1998; Yonelinas, 1994, 1997, 1999; Yonelinas, 2001a, 2001b).

Several studies have used the manipulation of experimental conditions in attempting to examine if two response types (*Remembering* and *Knowing*) represent two distinct mechanisms. Gardiner (1998) found that levels of processing manipulations affected the proportion of remember (R) responses but had no effect on the proportion of know (K) responses. After the dissociation between R and K responses was reported, many studies have investigated the extent to which R and K responses can be dissociated by different experimental variables (Dunn, 2004; Gardiner et al., 1998; Gardiner & Richardson-Klavehn, 2000). For example, Yonelinas and Jacoby (1995) showed that increasing size congruency between study and test stimuli increased remember responses and decreased know responses. Gardiner and Java (1990) demonstrated that non-words produced more know responses than did words, while another study showed that low- and high-frequency words produced an equal number of know responses (Gardiner & Java, 1990). In addition, Gardiner et al. (2002) also provided evidence that remembering and knowing reflect two qualitatively different memory processes (Gardiner *et al.*,2002).

Recently, Verfaellie and colleagues (2001) examined whether recognition memory of amnesic patients can be improved by relaxing decision criterion (Verfaellie, Giovanello, & Keane, 2001). They used the Remember/Know paradigm and pointed to an improved accuracy in amnesia as a result of manipulation (e.g., instruction to relax criterion) and showed it was associated with enhanced familiarity-based criterion shift rather than the recollective memory. Recent fMRI studies by Yonelinas et al. (2005) also revealed the differences between remember and know response related activations (Yonelinas et al., 2005). These empirical results that showed consistency with the assumption that R and K responses reflect different forms of memory retrieval gave rise to the viewpoint called the *dual-process interpretation* of RK paradigm.

In summary, the dual-process models suggest a non-criterial process, *recollection,* and a "Remember" response of the subjects during recognition memory that reflect a *discrete* recollection process. The model proposes that the two criteria for recollection and familiarity mechanisms do not work on the same axis. More specifically, the criterion setting for familiarity ("Know" response) works like the criterion in signal detection theory framework, which is strength-based. In contrast, the criterion for recollection means an all-or-none threshold, which does not have analogous (strength-based) decision behavior. It argues that recollection is (1) not based on continuous evidence information, (2) criterion free in the SDT sense, and (3) open to introspection.

Two-Criteria Model: Although the measures of "Remember" or "Know" responses are assumed to represent the recollection or familiarity respectively, the underlying system can be inconsistently expressed with the constraints of remember/know responses. That is, as Gardiner et al. theorized, the reports of remembering/knowing may not reflect the contribution of recollection and familiarity, but rather, they reflect subjective states of different awareness that are completely orthogonal to the recollection/familiarity memory (Gardiner & Richardson-Klavehn, 2000; Gardiner, Ramponi, & Richardson-Klavehn, 1999). For example, remember and know responses can represent two different levels of confidence (two criteria) or item strength in recognition judgments. As a result, remember and know responses do not always produce results that are in agreement with results from other methods for estimating recollection and familiarity (e.g., Yonelinas, 2002). Thus, the question can be phrased, "Do multiple memory responses such as remember/know always represent multiple distinct processes?" More specifically in the SDT terminology, "Does *remembering* always represent a *discrete* process that is an all-or-none and criterion-free mechanism, relative to the *knowing* which is based on continuous strength of evidence?"

The findings by Hirshman and Master (1997) are indeed consistent with a single-process model with two criteria for Remember/Know paradigm, emphasizing the dependence of remember and know judgment on common underlying processes. They assumed that, as in the Figure 3, subjects placed two criteria on the familiarity axis to determine their remember/know judgments. A

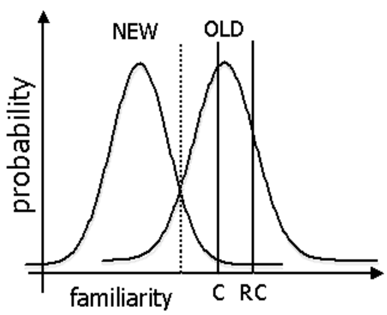

Figure 3. Two criteria model for Remember/Know responses

first criterion, denoted C (overall criterion), is used to make old-new decisions, and a second criterion, denoted RC (remember criterion), is used to make remember-know decisions. Items whose familiarity is above RC will be given remember responses, and items whose familiarity is between the two criteria will be given know responses.

Within the same conditions and procedures through which the dual-process models have often been proposed, Donaldson (1996) also successfully explained the remembering and knowing processes by posting double decision criteria on the same familiarity decision axis that SDT assumes. He assumed that if the remember responses represent nothing more than conservative "Yes" responses, then the sensitivity measure of memory (d' or A'), which is independent of decision criterion and is calculated on remember responses, should not show any difference from that calculated on the overall recognition "yes" responses because it should come from the same familiarity decision axis. From the meta-analysis of 80 conditions, and from their own experiment with R/K follow-up responses, he found that the sensitivity or discrimination as indexed by the d' or A' statistics is the same for overall recognition and for remember responses.

On the continuum, several researchers suggest that remembering and knowing reflect stringent and lenient decision criteria, respectively, rather than two qualitatively different mechanisms (Donaldson, 1996; Hirshman & Master, 1997; Inoue & Bellezza, 1998; Dunn, 2004). In this account, the instructions to respond "Remember" or "Know", for example, are interpreted by participants as asking them to adopt more and less stringent criteria, respectively. Therefore, two different criteria can show different degree of changes by a variable that influence criteria and yield R/K dissociations.

Perhaps. the advantages of the two-criteria model are, first, it provides a simple explanation for multiple memory processes based on the same decision axis. More specifically, the model makes it unnecessary that people should make an effort to change the type of decision axis or decision rules across familiarity and recollective memory. Secondly, the model explains the data by showing the effect of variables that have the same effect on remember hit rates and know hit rates. The data that also show the selective effect either on the remember hit rate or on the know hit rate, or their crossover interaction (i.e., double dissociation), can be explained by the two-criteria model. However, the model is not suitable to account for the recent neuroimaging findings that suggest the distinct neural substrates for either mechanisms (see Yonelinas, 2002).

In summary, although the remember-know response has been regarded as important since it measures the different states of awareness believed to underlie memory retrieval (Dunn, 2004), there still remains the debatable issues related to the question "Do the different memory processes require multiple criteria on the same decision axis such as familiarity evidence scale?" By considering the criterial decision processes, the answer for the question might be "They are not *required*, but people *can* formulate multiple criteria on the same decision axis according to the type of responses they *need* to make" since some variables still influence both remember and know responses while other variables do not, or do so selectively.

Conclusion

Decision performance can be based not only on accuracy (precision) but also on response tendency (willingness to say a particular response type). Both factors are equally important in decision-making processes since they represent two main properties on which nearly all decision processes may be based: *Evidence* and *Criterion.* The present review has focused on the role of the second aspect, *criterion* mechanism, in human recognition memory using the mathematical measures and theoretical concepts developed in Signal Detection Theory (SDT). SDT provides a useful tool to express the criterion mechanisms as a *process* that strategically works independently of memory evidence. We discussed the various characteristics of criterion process in terms of SDT framework, including variables that influence criterion, and most importantly we revisited the recent evidence that suggest adaptive flexibility of criteria. Finally, derivative recognition memory models such as Remember/Know judgments were discussed to see if we can assess the models in terms of decision criterion; a discrete process vs. two-criteria judgment. Based on these considerations, the present review suggests that setting up decision criteria represents a process that regulates translation of memory contents into action. Decision criterion is needed to gate memory information into actions related to any decision, judgment, or evaluation such as binary 'old/new' recognition of an item. Furthermore, current empirical research suggests that criterion mechanisms use the stimulus information flexibly and adaptively in a beneficial way according to the observer 's response tendency.

Based on the current review, future work examining the different neural substrates upon which criterion shifts achieved through explicit instruction versus those achieved through reinforcement learning (e.g., Han & Dobbins, 2008) is warranted. With regard to flexible criterion, the characteristics of shift can also be further explored. For example, do the criterion effects transfer between different types of memory stimuli? If we shift criterion during recognition judgments for word stimuli, would the shifted criterion also be observed for pictures intermixed in the test list? This also naturally leads to the question of whether memory abnormality or difficulty shown in the neuropsychological patient population or the elderly may be due to the failure to flexibly adjust the decision criterion during testing. Although these questions remain unanswered, isolating the crucial criterial process nonetheless will offer opportunities to understand the dynamics of largely adaptive recognition decision process in human episodic judgments.

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일화기억에서의 재인 의사결정준거:
신호탐지이론을 바탕으로

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오랫동안 대부분의 기억연구들은 결과로서 나타나는 기억 반응의 정확률에 주된 관심을 가져왔고, 상대적으로 저장된 기억 정보들이 외현적인 기억 판단 반응으로 실제 이어지기까지 어떤 의사결정 과정을 거치게 되는지에는 관심을 덜 가져왔다. 실제로 그 동안은, 서로 다른 개인들 간에, 혹은 다른 두 실험 조건들 간에 나타나는 수행의 정확도를 신뢰성 있게 비교하기 위해서, 실험 참가자가 보이는 각기 다른 의사결정 성향은 오히려 실험적으로 제거되고 통제되어야 하는 변인 (Nuisance variable)으로 여겨져 왔다. 하지만 최근 들어, 이 기억 판단에 있어서의 의사결정 과정에 대해 새로운 관심이 생겨나고, 이 기제가 얼마나 유연하고 적응성 있으며, 독립적인 기제로서 기억 판단에 영향을 미치는지에 대해 연구가 진행되고 있다. 본 논문에서는 재인기억에서의 의사결정 준거가 지니는 다양한 특징들 (예, 의사결정 준거의 역할, 준거설정에 영향을 미치는 변인들, 준거의 변화와 유연성, 다중 의사결정 준거 등)에 대해 살펴보고 이와 관련된 재인기억 모형들을 개관하였다.

주요어 : 의사결정 준거, 재인기억, 신호탐지이론