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Modeling confidence and response time in associative recognition

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ABSTRACT

Research examining models of memory has focused on differences in the shapes of ROC curves across tasks and has used these differences to argue for and against the existence of multiple memory processes. ROC functions are usually obtained from confidence judgments, but the reaction times associated with these judgments are rarely considered. The RTCON2 diffusion model for confidence judgments has previously been applied to data from an item recognition paradigm. It provided an alternative explanation for the shape of the z-ROC function based on how subjects set their response boundaries and these settings are also constrained by reaction times. In our experiments, we apply the RTCON2 model to data from associative recognition tasks to further test the model's ability to accommodate non-linear z-ROC functions. The model is able to fit and explain a variety of z-ROC shapes as well as individual differences in these shapes while simultaneously fitting reaction time distributions. The model is able to distinguish between differences in the information feeding into a decision process and differences in how subjects make responses (i.e., set decision boundaries and confidence criteria). However, the model is unable to fit data from a subset of subjects in these tasks and this has implications for models of memory.

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Introduction

Associative memory is memory for combinations of items (i.e., do you remember whether these items were presented together or separately during the study list). Compared to simple item recognition memory (i.e., do you remember an item or not) associative recognition shows greater declines with age (e.g., Bastin & Van der Linden, 2006; Craik, Luo, & Sakuta, 2010; Naveh-Benjamin, 2000, 2012; Ratcliff, Thapar, & McKoon, 2011), is less susceptible to decay and interference (Hockley, 1992), has different patterns of false alarm rates (Hockley, 1994; Malmberg & Xu, 2007), has a different time course (Gronlund & Ratcliff, 1989), and shows different word frequency effects (Clark, 1992), among other differences.

In this paper, we apply the RTCON2 model to an associative recognition task for which subjects used a six-point scale to rate the confidence with which they believed a pair of test items had or had not appeared together earlier in the experiment. This is the more common method of collecting confidence responses, especially in memory research, although some researchers have had subjects make a two-choice response followed by a confidence rating (Baranski & Petrusic, 1998; Merkle & Van Zandt, 2006; Pleskac & Busemeyer, 2010; Van Zandt, 2000; Van Zandt & Maldonado-Molina, 2004; Vickers, 1979; Vickers & Lee, 1998, 2000). In the model, evidence is accumulated toward a set of decision thresholds and the relative heights of these thresholds explains both the location and shape of subjects' reaction time distributions and also the shape of their z-ROC functions. This means

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that z-ROC shape does not solely provide information about memory representations as has been assumed to date but also reflects individual differences in how subjects use confidence response scales. Application of the RTCON2 model to associative recognition is especially interesting because this type of memory task often produces z-ROC functions with different shapes than item recognition, and these differences have previously been used to motivate the development of various memory models (Glanzer, Hilford, & Kim, 2004; Hilford, Glanzer, Kim, & DeCarlo, 2002; Kelley & Wixted, 2001; Qin, Raye, Johnson, & Mitchell, 2001; Slotnick & Dodson, 2005; Slotnick, Klein, Dodson, & Shimamura, 2000; Wixted, 2007; Yonelinas, 1997, 1999) and in neuroscience research (Eichenbaum, Yonelinas, & Ranganath, 2007; Henson, Rugg, Shallice, & Dolan, 2000; Kim & Cabeza, 2007; Kirwan, Wixted, & Squire, 2008; Moritz, Glascher, Sommer, Buchel, & Braus, 2006; Rissman, Greely, & Wagner, 2010; Stark & Squire, 2001; Wais, 2011; Yonelinas, Hopfinger, Buonocore, Kroll, & Baynes, 2001). However, these memory models typically focus only on the kind of evidence being fed into a decision, ignore or over-simplify the process of making a decision based on that evidence, and may not produce the same estimates of evidence that a full decision model would. In contrast, our research attempts to model the process of making confidence-judgments in an associative recognition paradigm and investigate to what degree experimental findings can be accounted for with a decision-making model.

In an associative recognition memory experiment, participants study pairs of words and are then asked to distinguish between pairs of words that were previously studied together ("intact") or studied separately ("rearranged"). In an item recognition memory experiment, participants study individual items and are then asked to distinguish between items that were previously studied ("old") and items that were not previously studied ("new"). Most of the work investigating either type of recognition memory has relied on Signal Detection theory (Banks, 1970; Bernbach, 1967; Donaldson & Murdock, 1968; Egan, 1958; Grasha, 1970; Kintsch, 1967; Kintsch & Carlson, 1967; Lockhart & Murdock, 1970; Norman & Wickelgren, 1969; Ratcliff, McKoon, & Tindall, 1994; Ratcliff, Sheu, & Gronlund, 1992; Yonelinas, 1994). In the signal detection framework, it is assumed that each tested pair has some value of associative strength that is normally distributed for each category of tested items (for example, "intact" or "rearranged" word pairs). The intact/rearranged decision can then be modeled by placing a single criterion on a dimension representing the associative strength of the test items. If the associative strength value for a test item is above the criterion, then an 'intact' response is made; otherwise, if the associative strength value is below the criterion, then a 'rearranged' response is made. Bias toward one of the response choices can be modeled by changes in the placement of the decision criterion, and multiple response options (such as confidence judgments) can be modeled by including additional decision criteria.

In confidence judgment procedures, subjects rate their confidence that an item is intact or rearranged using a response scale with levels ranging from 'very sure intact' to 'very sure rearranged'. To model these multiple response options, additional decision criteria are used to divide the memory strength dimension into multiple response regions. Fig. 1 depicts two normal distributions, one for intact items and one for rearranged items, and three possible decision criteria. These decision criteria partition the match dimension into four response regions corresponding to four confidence categories: from left to right, high confidence rearranged, low confidence rearranged, low confidence intact, high confidence intact. As the decision criterion moves from left to right, both the hit and false alarm rates decrease.

These decision criteria can then be used to create receiver operating characteristic (ROC) functions, which are plots of the hit rate ("intact" responses to intact word pairs) against the false alarm rate ("intact" responses to rearranged word pairs). To create an ROC function from the data, each criterion is treated as if it were the only criterion and the hit and false alarm rates for that criterion are calculated and plotted against each other as a single point on the ROC curve. Hit and false alarm rates are calculated first for the rightmost criterion, representing the highest confidence intact category, then for the two rightmost categories (adding together the number of responses in those two categories), then for the three rightmost, and so on.

These hit and false alarm rates are frequently converted to *z*-scores, resulting in a function called a z-ROC. The assumption of normal distributions of memory evidence predicts linear z-ROC functions with a slope equal to the ratio of the standard deviations of the "intact" and "rearranged" item distributions (Ratcliff et al., 1992). The lower portion of Fig. 1 depicts the z-ROC function obtained

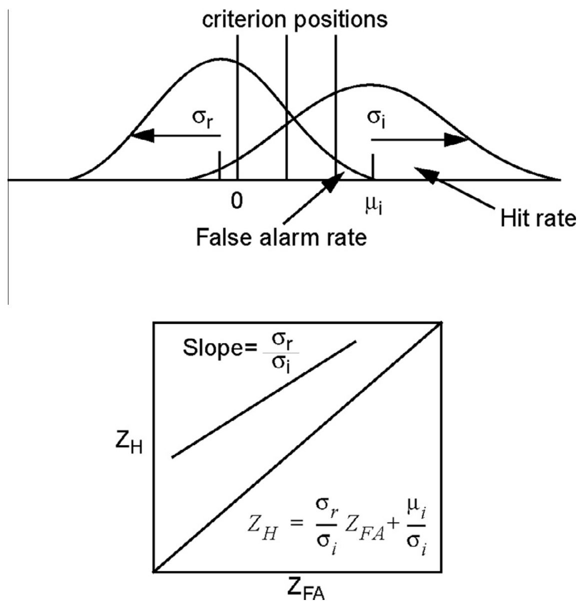

Fig. 1. The standard Signal Detection model with one normal distribution each for the intact and rearranged items respectively, four response regions created by three confidence criteria, the z-ROC obtained from the two distributions, and the equation relating the z-transformed hit and false alarm rates.

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