Dynamic Decision-Making Processes in Recognition Memory of Images

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For Pooja Reddy, participating in undergraduate research made her textbook education come to life. Meeting other students who were doing research inspired her to achieve excellence in her own project and made her feel more capable and confident. Pooja advises undergraduate students to get involved with research as quickly as possible and to be prepared for the ways in which it will enrich their educational experience. Now that Pooja has graduated from UCI, she is teaching English in Japan and will eventually pursue a Ph.D. in Cognitive and Experimental Psychology. Pooja's fascination with Japanese culture has led her to practice Aikido, a Japanese martial art. Reading is also a favorite hobby.

Key Terms

- Context Effects
- Decision Criteria
- Mirror Effects
- Recognition Memory
- Signal Detection Theory

Abstract

Most models of decision making assume a decision criterion is necessary and that this criterion is static. However, many everyday decisions are made in a dynamic environment. When two decision environments vary in accuracy, with the accurate environment having higher hit rates and lower false alarm rates, a mirror effect is said to occur. Mirror effects are important because they shed light on how people set their decision criteria, but the dynamic course of these effects is not understood. Here we used alternating easy and hard decision environments to induce shifts in decision criteria. A traditional study-test experimental paradigm was employed and the accuracy of recognition memory for pictures was measured. The data indicate that there are slow, systematic changes in decision criteria that lag behind the physical changes in the decision environment. These findings have important implications for models of decision making.

Faculty Mentor

Pooja Reddy's work in our lab investigates the manner in which people search their memory for studied pictures. More specifically, people must use different memory retrieval methods depending on the difficulty of the memorized stimuli. Pooja used cleverly-constructed images to manipulate the difficulty of a memory task. She then used a signal detection analysis to demonstrate that people are able to adjust their behavior to perform more-or-less optimally in different situations. Pooja's work has stimulated a productive research strand in our laboratory that will continue for several years.

Scott D. Brown
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Introduction

Decision-making and recognition memory processes are fundamental and core functions of human cognition and behavior. People make decisions in varying degrees of difficulty and contexts several times a day. In an experimental setting of decision making, participants are presented with perceptual or sensory stimuli and are asked to make certain decisions about the stimuli. Previous studies used tasks such as auditory signal detection (Birdsall, 1956), object recognition (Tulving, 1981), and lexical decision making (Chiarello et al., 1988).

Signal Detection Theory

Almost all conventional theories of decision making agree that to make a decision, an individual must set a decision criterion. This decision criterion is not set in isolation. Several other factors, such as past task experience, internal and external noise, motivation bias, response sets, and strategies, affect the setting of the criterion. This is exemplified by the well-established Signal Detection Theory (SDT) (Birdsall, 1956; Atkinson, 1963; Green and Swets, 1966; Treisman and Williams, 1984).

SDT proposes that participants decide between two classes of items, targets and distracters, by generating an internal magnitude for each stimulus and comparing that magnitude with a decision criterion. For example, in a traditional auditory signal detection experiment, an observer is exposed to auditory signals and is then asked to decide whether the signal is present or absent. This is a difficult decision if the sound is of a low magnitude and is obscured by internal and external noise. By contrast, it is an easy decision if the sound is of a high enough magnitude and internal and external noise levels are negligible.

SDT suggests that an individual makes a decision by gathering quantitative evidence for and against each response, and then evaluates this against some pre-set criterion (Green and Swets, 1966; Treisman and Williams, 1984). Both target and distracter items are assumed to give rise to internal distributions. These distributions overlap because the distracters on the right end have characteristics similar to those of the targets (i.e. a car horn or some machinery outside that sounds like the auditory signal), and the targets on the far left have characteristics similar to those of the distracters (i.e. auditory signals that are so low in magnitude that the participant might mistake them for a sound in their own mind), as shown in Figure 1.

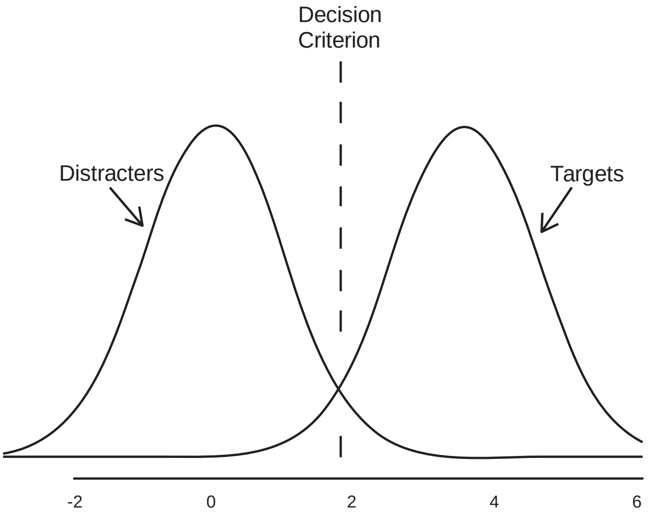

Figure 1
Standard SDT model: Stimuli above the decision criterion are classified as targets; stimuli below are classified as distracters.

In the SDT model, the overlap between the two distributions makes errors inevitable. It is only possible to minimize errors by setting the criterion at an optimal location. Two kinds of errors are possible in the SDT model: misses and false alarms. A miss occurs when a participant fails to identify the presence of a signal. This is due to stimuli from the target distribution falling below the decision criterion. A false alarm is when a participant announces the presence of a signal when none was given. This is due to stimuli in the distracter distribution rising above the criterion. Figure 1 shows the optimal location for the decision criterion to minimize misses and false alarms at the crossover point in the distributions.

Dynamic Signal Detection Theory

Most researchers agree that a decision criterion exists, but much of the research has focused on the static model of decision making (except for Triesman and Williams, 1984; Strayer and Kramer, 1994). The static model assumes that successive decisions are independent. While this simplicity is important from a theoretical standpoint, in the real world this static model poses some difficulties, since our judgments are generally processed in a dynamic environment. From simple everyday tasks, such as driving, to more complex behaviors, such as military aircraft training, human decisions tend to be made in a dynamic environment. For example, when one is driving and it begins to rain, an internal adjustment of some sort must occur to continue the task with efficiency. The same mechanism then applies to the pilot of an aircraft who must decide whether a target is "safe" or "dangerous," when factors such as landscape and visual clarity are continuously fluctuating.

As tasks increase or decrease in difficulty, it is necessary to adjust one's decision criterion to continue to carry out the task with optimal efficiency. Previous research has developed dynamic variants of SDT with a decision criterion that changed from decision to decision, based on the previous stimuli and responses (Colquhoun, 1967; Sanders and TerLinden, 1967; Treisman and Williams, 1984; Vickers and Lee, 1988 and 2000; Strayer and Kramer 1994). Treisman and Williams (1984) applied their model to data from stationary decision-making experiments, whereas the present study addresses the criterion-setting problem as it applies to dynamic decision-making environments. Changes occur in a static environment, even though no changes need to be made. This dynamic model is advantageous because induced shifts in stimuli force participants to make a change.

For example, in the experiment involving sound detection, suppose the magnitude of the sound is increased. For participants to continue responding with optimal accuracy, they must shift their decision criterion. They have to raise the level at which they will consider a sound a signal, to reduce chances of making false alarms. Figure 2 portrays how this shift in criterion is likely to occur in contexts with variable difficulty levels.

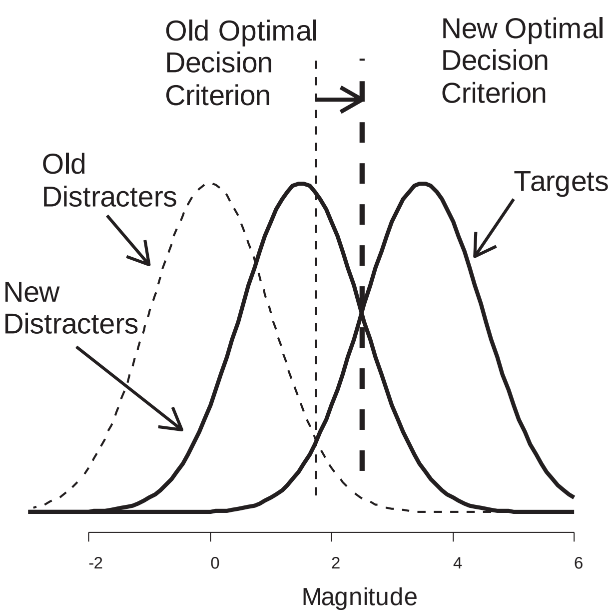

Figure 2
SDT in a dynamic environment: The optimal decision criterion changes to keep up with changes in properties of distracters.

In this dynamic environment, where signal strength is changing, past task experience becomes influential because individuals have to watch for varying properties of the stimuli to change their decision-making criterion. Participants who change their criterion too quickly or too slowly are likely to have poor response accuracy, that is, they will fail to minimize the possibility of making false alarms and misses.

Dynamic Recognition Memory and Context Effects

The current experiment investigates the effects of changing environments on decision-making processes in recognition memory of images. Recognition memory refers to the process of identifying an object as having been seen before (Strong, 1912). Recognition memory has been measured in different ways in the past. Words are the most commonly used stimuli in recognition testing (Greene and Tussing, 2001). The present study employs images, rather than words, as stimuli because it is easier to parametrically adjust the similarity of image stimuli. In addition, images are encoded and processed differently than words. For example, the double encoding theory suggests that pictures help people understand imagery memory and conceptual memory (Joseph et al., 1984), unlike words, which are processed primarily in semantic memory. Another example is the picture superiority effect, which suggests that pictures also trigger vision (Dewhurst and Conway, 1994; Mintzer and Snodgrass, 1999). These findings suggest that pictures help produce a more comprehensive understanding of memory.

In the experimental paradigm implemented in this study, a participant is shown a series of pictures (study set) and is asked to study them. The participant is then shown more pictures (test set), of which half of the pictures are from the study set and the other half are new pictures that they have never seen before. Then the participants are required to do a recognition memory task by deciding if the test pictures are old or new. In this experimental setting, there are two classes of stimuli: "targets" and "distracters." We define two different decision environments by the properties of their distracters. In one environment, the distracters may be relatively dissimilar from the targets, making decisions relatively easy. In the other, the two types may be much more alike, resulting in relatively hard decisions. The degree of difficulty was changed mid-block in the test set, and the participants' responses were measured in terms of their hit rates (HR) and false alarm rates (FAR).

These types of alternating decision contexts are often used in cognitive psychology experiments to show context effects. A context effect occurs when behavior associated with an experimental condition is different at different times, even though the condition itself is unchanged, because the context of the condition has changed (Brown and Steyvers, 2004). We propose that context effects become stronger with time. An example of a relevant context effect is the mirror effect. The mirror effect has been reliably observed in SDT experiments (Stretch and Wixted, 1998). A mirror effect occurs when there are differences in accuracy between HR and FAR in two conditions that differ in decision accuracy. In particular, a mirror effect occurs when the condition with higher accuracy has higher HR and lower FAR than the condition with lower accuracy (Glanzer et al., 1993). This effect is important because it reflects a change in the participants' cognitive processing rather than changes in the stimulus. Changes in distracters usually lead to a mirror effect. Stimulus changes can explain the changes in FAR, but not HR (as target items are never changed in these experiments). Hence, we hypothesize that changes in HR must then reflect a change in the cognitive strategy being employed. Participants tend to alter their criterion based on stimuli that have already been presented and previous decisions they have made, among other factors. To set an optimal criterion in response to changing levels of difficulty, participants must maintain some past knowledge of the stimuli, so that they can estimate the changing properties. When participants make their first decision they have a pre-set criterion, but as soon as the task difficulty changes, participants will have to change their criterion.

Initial Studies

Preliminary experiments by Brown and Steyvers (2004) used the experimental paradigm of lexical decision-making tasks in a changing setting. Participants were asked to quickly identify a string of letters as a word ("surf") or as a non-word ("sudf"). The "wordiness" of non-words was manipulated. This task was accomplished by increasing or decreasing levels of difficulty of identification of a string of letters as a non-word. For instance, "XFHQ" is easy to classify as a non-word because it breaks the rules of English word construction. However, "HARB" is difficult to classify as a non-word because it conforms to all the rules of the English language and can be classified as a non-word only on the basis of the difficulty in identifying it as part of the lexicon. The effect of changing these stimulus properties was measured, with the words being kept constant and the non-words varying in difficulty level. This experiment was conducted on over 100 participants. Stimulus properties were changed midway through the blocks. Figure 3 shows a model that represents the data collected.

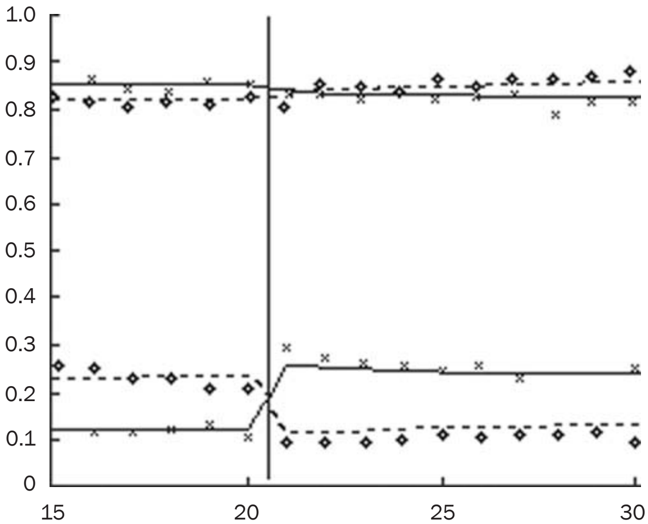

Figure 3
Induced criterion shifts: The top lines represent HR and the bottom lines represent FAR. Open symbols (o) represent blocks that went from hard to easy and solid symbols (x) represent blocks that went from easy to hard.

Some important findings are portrayed in this model. As expected, the probability of responding "word" for words is much higher than for non-words. Also, as expected, the switch point caused greater and more rapid changes for non-words than for words, because these non-words were manipulated. However, the importance of this model is that it shows that data from the word stimuli exhibit a crossover. This crossover suggests that a shift in decision criterion is occurring, because the properties of the words remained constant. Also, this model indicates that the change for the word stimuli is slower than the stimulus change. This suggests shifts in criterion lag behind shifts in context, underlining the importance of accumulation of stimulus history.

Materials and Methods

Participants

Participants were 135 self-selected undergraduates from the University of California, Irvine, who were recruited from the Social Sciences Human Subject Pool. All participants received course credit for participating. Data from subjects with a d', or discriminability index, of less than 0.25 were discarded. This resulted in the loss of data from 13 participants. The participants were randomly assigned to a condition that either began with hard stimuli and switched over mid-block to easy stimuli, or to a condition that began with easy stimuli and switched over mid-block to hard stimuli.

Participants were not informed of the changes between stimulus types, or even that there were different classes of stimuli.

Stimuli

All stimuli were images that were collected from a large database. Images ranged from sceneries (coastlines, landscapes) to buildings (skyscrapers, cottages, farms) to people and animals. There were no images presenting just a human face; images of people and animals were always embedded in a larger scenery or background.

Difficulty was manipulated by varying the degree of similarity between the test picture distracters and the study pictures. Therefore, if a distracter picture in the test set looked similar to a picture in the study set, it was classified as the hard condition, assuming it would be difficult to identify it as a "new" picture, due to the similarity of its properties. Whereas, if a distracter picture in the test set looked quite different from a picture in the study set, it was classified as the easy condition, assuming it would be easy to identify it as a "new" picture, due to the lack of similarity in its properties.

Design and Procedure

All stimuli were presented on a computer screen. The stimuli were developed by SuperLab software (Cedrus Corporation). Stimuli were presented in study set blocks and test set blocks. There were 12 blocks total. Participants were shown a series of 32 pictures and were asked to study them, out of which only 24 were relevant study items (the first four and the last four were filler pictures). Each study picture was shown for one second in the middle of the computer screen. Participants were then shown a series of 24 test pictures, out of which 12 were new and 12 were old. Recognition memory was tested by having participants decide whether the pictures in the test set were old or new. This was indicated by clicking on the appropriate key on the keyboard (stickers marked which key to press for "old" and which one to press for "new"). Their response accuracy rate was measured in terms of HR (saying "old" when a test picture is old, and "new" when a test picture is new) and FAR (saying "old" when a picture is new or saying "new" when a picture is old).

For ease of interpretation, Figure 4 shows how the stimuli were developed. Each image was cropped into six overlapping segments. The images were cropped in horizontal, diagonal, or vertical sequences. There was an equal number of each sequence type represented in the study. Individual segments were presented in the experiments. There is a 70% overlap between each adjacent picture. For example, segment A is shown as a study item. In a hard condition, the neighboring segment B is shown as a distracter in the test set, and in an easy condition, E is shown as a distracter in the test set (the fourth segment from the study item). They are both new pictures but the degree of overlap determines the ease of being able to recognize them as new pictures. Only two conditions were implemented: easy, when the study item and the test item were four pictures apart, and hard, when the study item and the test item were adjacent to each other. The segment that was chosen as the study item was randomly selected from the sequence, although the hard distracter was always the neighboring segment and the easy distracter was always the fourth segment from the study item.

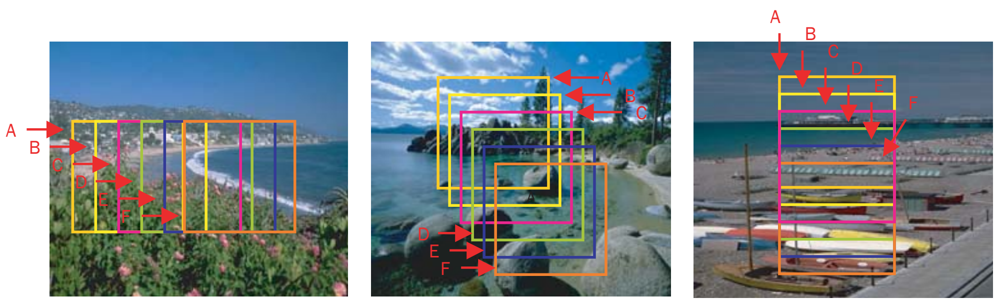

Figure 4
Stimuli development procedures

There were several constraints implemented. First, there were no four consecutive "old" or "new" items, to make sure participants did not detect a pattern or develop any kind of response bias. Second, the transitions between easy and hard always took place after 12 test items, to control for factors such as fatigue, and to attribute the changes in decision criterion to the switch point and not to any other extraneous variables. This change in difficulty was counterbalanced throughout the experiment, with some participants randomly assigned to a sequence that started with a hard subset, and some randomly assigned to a sequence that started with an easy subset. Third, the shift between easy and hard conditions always occurred mid-block. That is, if one block ended with hard, the next one began with hard, and likewise with easy blocks. Also, after each test set a "Where's Waldo" picture was inserted as a distracter task.

Results

The data collected from the 122 participants are shown in Figure 5.

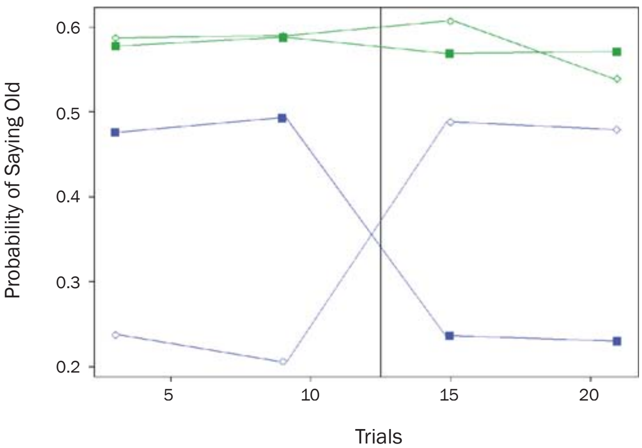

Figure 5
Line graph of HR and FAR: blue dashed lines represent FAR and green solid lines represent HR. Open symbols (diamonds) represent blocks that went from easy to hard; solid symbols (rectangles) represent blocks that went from hard to easy.

HR and FAR were analyzed across trials and within blocks. Figure 5 shows these HR and FAR averaged across participants in averaging windows of six trials. As can be seen, the manipulation of difficulty of stimuli produced the expected effect. This is clearly demonstrated in the crossover in the FAR, which reflects a mirror effect. Thus when the decision context was easy, the probability of incorrectly identifying an object as "new" when it was old was low. When the decision context was difficult, the probability of incorrectly identifying an object as "new" when it was old undoubtedly increased. Not surprisingly, this crossover is due to changes in the stimuli: distracters that were similar to targets were more often confused for targets, which was reflected by a higher FAR.

A crossover in the hit rates can also be observed, but, interestingly, the decision context was made difficult only by changing the properties of the distracter stimuli. Therefore, new items were different, and old items were never changed. After the distracters were made more difficult (the context was manipulated to a higher level of difficulty), the HR steadily declined. The opposite occurred when distracters were made easier by manipulating the context to a lower level of difficulty.

The data also show that changes in FAR occur suddenly and significantly when stimulus properties are changed. However, changes in HR occur more slowly and steadily. These changes in HR lag behind the changes in context as is seen with the slower shift in HR than in FAR. After the contexts were changed, it took approximately six trials to visualize the effect. Indeed, immediately after the stimulus properties changed, the mirror effect was not seen, but with time, a crossover occurred and the mirror effect was restored.

Before the stimulus switch point, differences in HR were significant for the trial window 1-6 $t(106) = 1.76, p < .05$ and not significant for the trial window 7-12 $t(106) = 1.3, p > .05$. However, after the switch point a significant difference was found between the HR. In the trial window 13-18, the HR were significantly higher for the easy blocks than the hard blocks $t(106) = 3.1, p < .001$. For the trial window 19-24, HR were significantly higher for the easy blocks than the hard blocks $t(106) = 1.7, p < .05$.

Discussion

The data are consistent with the idea that there is a dynamic build-up of mirror effects over time. As hypothesized, the crossover in the hit rates shown in Figure 5 reveals a criterion shift that is taking place in the cognitive processes of the participants. This is evident because old items were never altered; only distracters were changed. Therefore, the crossover in HR must be accounted for by a criterion shift. It is also apparent that this mirror effect did not occur as soon as the stimulus change occurred. Rather, the observed HR pattern showed that the decision criterion changes lag behind changes in stimulus properties. Analyses with a dynamic SDT model showed that it took participants six trials, on average, to adjust to the new environment. Perhaps in that lag period the data from hard environments still diffused into data from the easy environments and vice versa. Past studies (Treisman and Williams, 1984) do not account for this accumulation of past task history in a dynamic model of decision-making. In addition, studies of hard versus easy conditions in many decision-making paradigms typically assume that carry-over effects are unimportant. The current study calls this assumption into question. The results presented here show that when participants are forced to make decisions in shifting contexts, they will adjust their criterion to the changed context. However, this change is slower than the change in the decision context.

This study is important because dynamic models of decision making in the domain of recognition memory have not been studied in this way before. However, the results are limited in that all of the participants were undergraduate psychology students from UCI. This study, then, may or may not be generalizable. Some fatigue effects also occurred between and within blocks. When data were examined for each block separately, there was a subtle decline in HR through the block due to fatigue rather than to shifts in context. This effect can be seen in Figure 5, with a slow convergence between HR and FAR across trials. A similar effect was also observed across the entire 12 blocks. It is important to keep these factors in mind while interpreting the data. A follow-up study could run a version of this experiment without making any changes to decision difficulty. This would examine how d' changes in a static experiment. These results may be used to titrate the effects of d' change from the current data.

Future experiments could also be conducted on various psychophysiological domains to test the generalizability of the model. Steyvers and Brown (2004) have conducted experiments employing dynamic lexical decision-making tasks and numerosity judgment tasks. Any environment in which the level of difficulty can be manipulated can be further examined, such as spatial judgment tasks, visual or auditory discrimination tasks, or tasks that mimic real-world situations. For example, to simulate a military decision-making task, an experiment could be created in which participants try to kill the "bad guys." In certain situations, it is difficult to distinguish friends from foes, thereby forcing changes in the criterion.

The implications of such a study are far-reaching. In military decision-making, for example, many decisions are made in a dynamic context, and quick responses are required. It is important to understand how people shift between contexts to optimize making "correct" decisions. In eyewitness testimony, this dynamic model of decision-making can help researchers understand, in retrospect, how a decision was made in a "varying situation" context. Consumer decision making is another realm of human activity that can be characterized by this type of decision-making. One could study how people make consumer choices in a hard context (many tempting options) versus in an easy context (few tempting options). Additionally, potentially life-threatening decisions made by health professionals occur in a highly dynamic context in which factors such as patient condition, patient population, and symptomology are shifting. The scope of decision-making processes in a dynamic environment is extensive. Gaining a better understanding of the underlying mechanisms involved in the process is fundamentally important.

Acknowledgments

I would like to thank Dr. Scott Brown for his support, encouragement, and his productive criticisms from the inception to the completion of this project. I would also like to thank Dr. Mark Steyvers for all his assistance and comments. Thank you to Dr. Virginia Mann for her comments on an earlier draft and to Dr. Carol Cicerone for helping complete the project.

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