Change-based Context Effects in Episodic Memory

THESIS

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Abstract

Distinctiveness effects in episodic memory were examined using a novel experimental paradigm. The critical manipulation was context-based change defined by the color feature of words in to-be-remembered study lists. Three experiments brought together the balanced-features design from previous research on isolation effects, different learning conditions reflecting variations on prediction error, and a source monitoring metric. A unique set of data shows a distinctiveness effect in source memory based on context change, but the effect is limited to stable environments with a low frequency of feature change. Conversely, no distinctiveness effect arose in random or frequently changing environments. It is proposed that, during learning, information is modified and associated with context by combining context-updating and prediction-violation mechanisms of cognition. The information provided by this research shows that there is context-sensitive organization critical for memory encoding, and provides a further account for some of the memory variance in effects of distinctiveness.

This work is lovingly dedicated to my three wise womyn: Avantaea Ivy, Rachael Eileen,

and Geraldine Rose.

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Table of Contents

Abstract	ii
Dedication	iii
Acknowledgments	iv
Vita	v
List of Tables	vii
List of Figures	viii
Chapter 1: Introduction	1
Chapter 2: Free Recall	13
2.1 Experiment 1	14
Chapter 3: Source Memory	23
3.1 Experiment 2	25
3.2 Experiment 3	
Chapter 4: General Discussion	41
Chapter 5: Conclusions	47
References	50

List of Tables

Table 1. Fixed effects parameter estimations for Experiment 1	20
Table 2. Experiment 2 parameter estimates for full comparison	
Table 3. Experiment 2 parameter estimates for restricted comparison	

List of Figures

Figure 1.	List design examples for Experiment 1	.16
Figure 2.	Order of task phases for Experiment 1	.17
Figure 3.	Experiment 1 results	.21
Figure 4.	List design examples for Experiment 2	.27
Figure 5.	Order of task phases for Experiment 2 and 3	.28
Figure 6.	Experiment 2 results	.33
Figure 7.	Low List Frequency CRP	.34
Figure 8.	High List Frequency CRP	.34
Figure 9.	Experiment 3 results	.38
Figure 10	Experiment 3 CRP	.39

Chapter 1: Introduction

Cognitive psychological research on episodic memory concerns an act carried out by the brain in which sensory input is stored, then recalled and used at a future point in time. Importantly, human memory performance is noted to have a wide variability in the accuracy of remembered information. Estimating and predicting human memory behavior can have practical and clinical applications. Variance in testable memory performance can be partially explained by the differential processing of distinct contextual information (Mensink & Raaijmakers, 1989; Howard & Kahana, 2002). Context may refer to any item or event information from the learning environment, the internal mental state of the person, or information about other events experienced nearby in time. In this way, context can be viewed as a "fluctuating population of elements reflective of subtle changes in the environment or in the subjects' mental state," (p.269) as it is conceptualized in the Temporal Context Model (TCM) and its variants (Howard, & Kahana, 2002). In the laboratory, context has been shown to have a powerful impact on enhancing memory for target items that differ by some distinct feature such as color, font, or even meaning from study lists in which they are embedded (von Restorff, 1933; for reviews, see Hunt, 2006; Schmidt, 1991; and Wallace, 1965). Researchers have historically attributed the enhanced memory in this paradigm to an effect of distinctiveness or distinctive processing (Murdock, 1960; Neath, 1993; and Hunt, 1995).

The presented research explores ways to understand the cognitive processes that lead to these distinctive representations, and uncovers the role of context-sensitive organization during memory encoding. It will be argued that divergent theoretical and operational conceptualizations of distinctiveness may be reconciled by virtue of their shared inclusion of context as an important factor that drives memory processing.

The problem being explored is that the mechanism for distinctive representations is unknown due to unexplained variance in memory performance. This work seeks to determine if the *amount* of context change is important for creating distinctiveness. If attention, learning, and memory are affected by how much change occurs in a local *micro-sequence* of experience, there may be a testable difference in how people remember information. A mental representation of context can contain information not only about features that change, but also features that *do not* change. If there is a difference in memory for environments with different magnitudes of feature change, or a difference in memory for individual items associated with a change or non-change, no current theory predicts how such a difference will later influence memory. It is proposed that during learning, information is modified and associated with context by combined *context updating* and *prediction* mechanisms.

Synthesizing research on distinctiveness effects has been a complex matter because of different ways that the term has been defined. In a review of the isolation effect – a well-known manifestation of distinctiveness in which perceptually unique study items are remembered better than common items – Schmidt (1991) proposed a definition of distinctiveness based on his "incongruity hypothesis." In this hypothesis, isolation

effects are the result of experimental manipulations that make target items unusual by virtue of being different - or incongruent - from other items in the context of a study list. Thus, an experimental list of to-be-remembered items is itself a level of context that is reflected in the architecture of a person's functional cognitive representation, or schema. The active representation of context explains how isolated events that are incongruent with the prevailing list context can receive increased elaborative or attentional processing during encoding, create less feature overlap with other items, and allow for more selective identification during retrieval (Anderson & Neely, 1996). Schmidt (1991) highlights a difference between Primary Distinctiveness, describing the deviation of items from a list context, and Secondary Distinctiveness, referring to the perception of items as unusual with respect to one's general semantic knowledge. The experiments presented here are specifically concerned with explaining variability within the domain of Primary Distinctiveness. Interpreting distinctiveness in this way, essentially as a manipulable independent variable and its effect on memory, is perhaps the most intuitive use of the term because it indicates a direct cause-and-effect relationship.

However, Hunt (2006) has explicitly argued for a different, more theoretical definition. He contends that distinctiveness is neither a property of experimental material nor even the resulting memory performance, but instead is the outcome of a psychological and relational process that underlies memory performance. Thus, distinctiveness is best defined as a characteristic of the mental representation of an event, not the event itself. In this way, some events stand out in memory because their mental representations are more salient than other items. However, salience itself is not even a

necessary component of the effect (Hunt & Lamb, 2001). Therefore, a dichotomy must be noted between two types of relational processes that directly impact the way salient representations are formed: the processing of differences and the processing of similarities between items. Hunt (2006) defines distinctiveness as "the processing of difference in the context of similarity" (p. 12). Theoretically, memory for a series of items is directly affected when people consider the way that the items are different from each other versus how they are similar. Tversky (1977) has developed a quantitative model of the mechanisms for the computation of similarities and differences between stimuli. Empirically, Hunt and Lamb (2001) have shown that isolation effects can be eliminated when people are asked to describe characteristic differences between items on a study list, but the effect is maintained when describing similarities between items. The implication is that isolation effects derive from the recognition of similar features or categories among the homogeneous, non-isolated items. Again, we have a context-based definition of the psychological phenomenon under study. Although the definition is fundamentally different from Schmidt's (1991) idea that distinctiveness is the result of experimental manipulations, even Schmidt (1991) admits, "We cannot articulate a context-free or subject-free operational definition of the concept of distinctiveness." (p. 525). While the above research has addressed the way distinctiveness effects are defined operationally (Schmidt, 1991) or theoretically (Hunt, 1995), the definitions are divergent and do not fully account for the full spectrum of empirical phenomena.

To address the problem, it will be necessary to describe a further contrast between theoretical interpretations of distinctiveness effects found in previous research: encodingbased vs. retrieval-based explanations. The most basic encoding-based theoretical explanations argue that unique events are remembered better because they receive more attention at the time that they are encoded into memory (e.g., Green, 1956). Retrieval-based accounts, on the other hand, argue that memory is determined by selecting the appropriate target information from an interfering set of potential candidates during recall or recognition (Hunt & McDaniel, 1993). Certainly, the facilitative effects of distinctiveness are the result of both encoding and retrieval factors, but theoretical explanations generally rely on one stage or the other. While retrieval-based explanations are supported in a large amount of the empirical literature (e.g., Schmidt, 1985), it can be shown that encoding-based explanations may still uniquely account for some of the variance in distinctiveness effects. The difference between encoding and retrieval explanations is important for the way that context-change is examined in this study.

A central idea from retrieval-based explanations of distinctiveness is that unusual features of items provide discrete identifying information for use in targeting from memory. The basic concept is that we are able to successfully remember things that have different characteristics that somehow set them apart from other competitor items in a set. The identification of items in memory can be described as a process of cue-to-target matching. Self-generated or given cues are used to compare the amount of feature-overlap between cues to targets. The retrieval process is a selection made based on sets of these kinds of comparisons (Hunt & McDaniel, 1993; Capaldi & Neath, 1995; Anderson & Neely, 1996). Thus, "distinct" items make up a mnemonic category containing unique cues. The process can be described mathematically in terms of a simple similarity-based

choice rule that has been used in feature comparison models (e.g, Gillund & Shiffrin, 1984; Nairne, 1990). Feature comparison models demonstrate that successful memory retention is improved by an increase in cue-target match, and is inhibited by informational cue-overload. Cue-target match is when information from a cue uniquely matches specific information from a target. Cue overload is when a particular cue contains information that matches many potential targets. However, because these models implement a combined ratio of cue-target match and cue overload, the two factors by themselves are insufficient to explain successful memory. Furthermore, even when the two factors are combined into a ratio-based model, retrieval-discrimination accounts (e.g., McDaniel, DeLosh & Merritt, 2000) cannot address some of the response biases and memory distortions from encoding manipulations such as highly salient bizarre stimuli (Schmidt, 2002). Given that context manipulations are explicitly implemented during the encoding stage, it is unlikely that an explanation based purely on retrievaldiscrimination can account for the entire pattern of distinctiveness effects.

In contrast, explanatory accounts that rely on differential encoding factors ask how cognitive organization can arise as a direct result of an external experience. Differential encoding suggests that an event may become distinctive as a result of a surprise reflex that generates focused attention and enhanced sensory processing during the initial experience (Jenkins & Postman, 1948; Green 1956; Green 1958a; Green 1958b; Donchin, 1981; Fabiani & Donchin, 1995). This enhanced processing can improve the mental representation of an event, making it easier to subsequently recall or recognize. Computationally, the mental representation of an episodic event is conceptualized as a matrix of associations between all stimulus features and contextual elements made during encoding (e.g., Sederberg, Howard, & Kanaha, 2008). This explanation has particular merit when used to interpret distinctiveness effects for bizarre or arousing stimuli, (Schmidt, 2002). The idea that distinctive processing of context at encoding can be reinstated at retrieval through organizational cues underlies the approach of Hunt and Smith (1996). They showed that unique cue information that is selfgenerated during encoding imparts memory benefits when also used as cues for free recall. Other free recall evidence demonstrating memory variance due to encoding manipulations is provided by Polyn, Norman, and Kahana (2009) who show that mid-list isolation effects can be generated by changing a participant's intentional task during encoding. Additional support for memory effects from events during encoding comes from neurophysiological evidence indicating that neural activity during encoding can predict subsequent memory behavior (Paller & Wagner, 2002). Theta and gamma oscillations detected by intracranial electroencephalography (EEG) during the encoding of lists of words have been shown to predict subsequent free recall performance (Sederberg, Kahana Howard, Donner, & Madsen, 2003). This pattern of activation has also been directly related to hemodynamic response during encoding (Sederberg, et al., 2007). In light of this evidence, it can be argued that retrieval-only explanations involve an unwarranted generalization across experimental paradigms that ignores the diversity of processing activities contributing to variance in memory performance.

Importantly, it must be noted that one of the strongest empirical threats to the differential encoding hypothesis is contained in data from von Restorff's (1933) original

experiments. She was able to demonstrate a memory enhancement for a unique item isolated in the second serial position. She presented a homogeneous list of letter trigrams and compared memory performance with a list of 3-digit numbers that had an isolated letter trigram as the second item. The isolated items were still remembered more than when they were presented in the homogeneous lists. Items in a very early serial position cannot be considered perceptually salient because there have not already been enough common items to make the isolated item seem unique. In fact, in research using the judgment-of-learning task, a self-report measure of how likely a subject was to remember an item, Dunlosky, Hunt, and Clark (2000), show that isolation late in a list still induces salience judgment at encoding, but early list isolation does not, even though both positions receive a memory enhancement. These findings demonstrate that isolation effects can be generated before the establishment of perceptual salience. Again, the implication is that perceptual salience is not necessary for the effects to occur. This is a point emphasized by Hunt (1995; 2006) and is adopted as an *a priori* assumption in the theoretical framework of the current thesis: distinctiveness can be generated by a mechanism of context-change that is not necessarily perceptually salient.

In order to test the hypothesis that the encoding of contextual information can generate distinctiveness effects in memory, however, it is necessary to work within an experimental paradigm that neither relies on perceptual salience, nor allows item features to be discriminated during retrieval. The present research applies a *context change* paradigm inspired by early isolation experiments (Siegel, 1943; Green, 1958a), in which item distinctiveness is determined by local, item-level structural changes in context rather than differences in global, list-level features between items. The difference is important because change is also a local, item-level factor. Local distinctiveness refers to differences in the immediate neighbors of an item along a temporal dimension, whereas global distinctiveness considers all items in a set of similar item-competitors in memory (Neath, Brown, McCormack, Chater, & Freeman, 2006). Any context-change paradigm must eliminate the possibility of applying the global distinctiveness assumption because the assumption relies on retrieval-based selectivity. Critically, the scenario is implemented by controlling the quantity of list features (e.g., color) such that equal amounts of different item features appear within a single study list.

Early findings from this paradigm have gone through a successive evolution of interpretation. Siegel's original (1943) work concluded that the overall structure of a list affects recall, supporting a Gestalt interpretation of isolation effects in terms of a perceptual difference between figure and ground. In this sense, the ground is the overall list structure and the figure is the isolated item. Saul and Osgood (1950) contradicted Siegel (1943) and argued that isolation effects may just be the result of facilitative reminiscence (better memory after a long delay) by showing no effect of list structure when comparing the loss in retention from immediate to delayed recall. However, Postman & Phillips (1954) reconciled the discrepancy by showing that the isolation effect is only due to stimulus features that are relevant to an intentional learning task, and concluded in favor of intraserial interference as a retrieval based interpretation. Perhaps the most relevant direct evaluation of the balanced-features design was implemented when Green (1958a, Experiment 2) used a between-subjects design with a pure change control group, a change isolation group and a standard von Restorff isolation group. His control lists changed the stimulus type (numbers or letters) after every item. The isolation group had a single item of one type isolated in a sequence of items of another type. The change group had alternating micro-sequences of types within the overall list structure. Finding no difference between the experimental groups in free recall probability for a critical item in the fourth serial position, Green (1958a) concluded that the relevant causal manipulation appears to be a structural change in the study list. The implication is that isolation and distinctiveness arise for items that deviate from the sequential structure of a learning set. Follow-up work (Green, 1958b; Swartz, Pronko, & Engstrand, 1958) supported the interpretation of structural change as an exogenous factor that drives attention. While the balanced-features design has not been implemented in any current work on distinctiveness effects, it is revived here as a critical manipulation that allows for a direct assessment of the effects of context-change.

The structural-change hypothesis, stating that isolation effects result from increased attention to items that introduce a change to the structure of a list, has been criticized (Erickson, 1963) on the grounds that it does not explain why increased attention should produce more learning. Regardless of whether surprise or attention mechanisms underlie encoding processes, more recent work with event-related brain potentials (ERPs) in scalp EEG indicates that the online, real-time processing of novel, unexpected, or rare information during encoding has a direct impact on memory organization and subsequent performance (Donchin, 1981). Amplitude of the P300 component of ERP, a large positive-moving waveform that peaks approximately 300ms after a stimulus presentation, has been shown to have a direct relationship to subsequent recall (Karis, Fabiani, & Donchin, 1984), and indicates that incongruity in a study list leads to increased attention to stimuli, which in turn can trigger an *update* to the current mental representation of context (e.g., Hupbach, Hardt, Gomez, & Nadel, 2008). Related to this surprise/attention hypothesis is the expectation-violation view (Hirshman, Whelley, & Palij, 1989), which proposes that distinctive items violate expectations about the quality of to-be-encountered stimuli and engender more extensive and elaborate processing of the general context associated with an item or event. The expectation-violation view will be a critical component in describing the results of the following experiments and will be addressed in further in detail in the General Discussion.

It can be shown that the divergent theoretical and operational conceptualizations of distinctiveness may be reconciled by virtue of their shared inclusion of context as an important factor that drives memory processing. Specifically, the following experiments are intended to show that the processing of *context change* is a critical element supporting an encoding-based explanation that can uniquely account for some of the variance in distinctiveness effects. Implementation of a context-based account of the variance may provide the link between theoretical and operational definitions of distinctiveness. A more complete examination of the underlying processing mechanism for context-change is relevant both to a theoretical understanding of episodic memory and to the way humans learn and remember information. To study context-change it is necessary to eliminate global feature distinctiveness, and isolate any causal manipulation to an encoding factor that does not rely on perceptual salience. These restrictions are met by the employment of the balanced-features design.

Chapter 2: Free Recall

Perhaps the most basic measure of memory is the free recall task. Free recall is when a subject is asked to study a list of stimulus items and then to recall as many as possible in any order. Responses can be either written, verbal, or keyed entry. The starting point for this research is within the free recall paradigm primarily because the theoretical basis for the operational definition of context used in this work is based on a model of free recall (Sederberg, Howard, & Kahana, 2008). Also, free recall is the traditional testing method employed in the large majority of the research on distinctiveness effects (Wallace, 1965; Schmidt, 1991) and has been specifically used in the balanced-features design (Siegel, 1943; Green, 1958a). The quality of free recall data is typically demonstrated by the well-known U-shaped serial-position curve, which shows that people remember items better when they are presented at the beginning or end of a study list. Data from a number of relevant papers on isolation effects and encoding manipulations have been represented as some deviation from the serial position curve in recall (Green, 1956; Green, 1958a; Karis, Fabiani, & Donchin, 1984; Polyn, Norman, & Kahana, 2009) including the prototypical von Restorff (1933) effect.

The research presented here is less concerned with primacy and recency effects than with modulations of memory performance for other items in the study list. Therefore, the following free recall experiment combines a type of free recall known as delayed free recall, with the use of primacy and recency buffer items. In delayed free recall, there is a distractor task between study and test phases to minimize rehearsal and recency effects (Postman & Phillips, 1965). While primacy cannot be directly eliminated in delayed free recall, there is a critical design component that effectively removes the effect: the length of study lists can be extended to include buffer items that are excluded from analysis. Thus, the experiments presented here will only be considering list items not affected by primacy or recency, and that differ from normal recall probability only if there is an effect of distinctiveness due to the manipulation of context change.

Furthermore, to enhance the potential for a distinctiveness effect based on context-change, a simple color-detection task was implemented during the study phase of all experiments in this research. The justification for this task implementation is that the changing feature must be directly attended to in an intentional learning paradigm. The hypothesis that changes in context can modify attention to item features is based on intentionally processing context information.

2.1 Experiment 1

The rationale of Experiment 1 is that mental states can be affected by context and that context can inform expectancies or predictions about upcoming events. Predictions can then be violated or reinforced in different ways depending on the amount of change that is occurring in the environment (Frank, Woroch, & Curran, 2005; Bubic, von Cramon, Jacobsen, Schröger, & Schubotz, 2008). Based on the idea of prediction violation (Mumford, 1992; Rao & Ballard, 1999), the purpose of this experiment was to manipulate the frequency of changing features within a study list so that the list structure induces a mental state critical for memory-related prediction error. In conditions where

context could be anticipated and violated, there may be a qualitative difference in the binary direction of prediction error generated by change. It is proposed that a type of distinctiveness effect can arise by violating active schemas in working memory. If the schemas are defined in terms of the amount of change occurring in a learning environment, then an item-level feature that deviates from the pattern of features in a sequence of stimuli should be recalled with higher probability than other items in the list.

2.1.1 Design

Eighteen study lists of words randomly drawn from the University of South Florida Word Association Norms (Nelson, McEvoy, & Shriber, 1998) were generated for each subject. Each list had 21 words of 4-7 letters. Words were presented one at a time in either blue or red font on a white computer screen. Importantly, each list had an equal number of blue and red words. Event Type was a critical factor indicating whether or not the color feature of a word changed from the color of the previous word and comprised 2 levels (change vs. non-change). The lists were divided into two conditions based on the frequency of Event Types within a list. Thus, high-frequency lists contained 2-4 common (~80%) *change* Event Types interrupted by rare (~20%) *non-change* Event Types. Conversely, low-frequency lists contained sequences of common non-change Event Types interrupted by rare change Event Types. In this way, List Frequency reflected the nature of sequences of common events interrupted by rare events. The result is an overall 2 (Event Type: change or non-change) X 2 (List Frequency: high or low) design. See Figure 1 for examples of the list designs.



Figure 1. List design examples for Experiment 1. Items in bold rectangles represent rare Event Types that deviate from the List Frequency.

2.1.2 Method

Participants. Thirty-six volunteers (ages 18-20) recruited from Introductory Psychology classes at The Ohio State University participated in Experiment 1. All participants gave written informed consent prior to the procedure and were given partial course credit for their time. The experiment was approved by the OSU Institutional Review Board.

Procedure. Participants were seated at computer consoles for all experiments.

After participants completed a brief demographic survey, an experimenter read aloud the

instructions for each phase of a practice block of experiment tasks, which simultaneously appeared on the computer screen. All tasks were performed on a computer keyboard and all stimuli were presented on a 17-inch monitor. Each experimental session took approximately 50-55 minutes.

The practice block preceded 18 self-initiated experimental blocks consisting of three task phases each (Figure 2). Each block began with a fixation cross at the center of



Figure 2. Order of tasks in each block of Experiment 1.

a white screen for 1000ms indicating the beginning of a study phase. Study items were then presented at a rate of 2200ms per item with a 500-800ms jittered inter-stimulus interval (ISI) consisting of a blank white screen before the onset of the next item. As instructed, participants pressed "J" with the right index finger to indicate a word in red font, or "K" with the right middle finger to indicate a word in blue font. Participants were instructed to respond as quickly and as accurately as possible, and were told that they would only have about 2 seconds to respond before the word would be removed from the screen. Also, participants were specifically told, "you should study that word and try to remember it for a later recall test. When studying the words, please try to avoid thinking back to previous words on the list; just focus on studying the word that is on the screen."

Study phase was followed immediately by a 30-second distractor phase. Simple math equations were presented in the form $A \pm B \pm C = D$, where A, B, and C were randomly chosen positive integers from the set one through nine. Participants indicated whether each equation was correct via key press. Participants had 4 seconds per equation to respond, with feedback, until time expired.

Immediately following the 30-second distractor phase, the recall phase began with a row of seven question marks in black font on a white background. This was the prompt for participants to begin entering typed recall responses, one at a time, until 45 seconds had elapsed. Typed characters replaced the question marks, which re-appeared when the enter key was pressed. As instructed, participants were to type any word that they recalled from the most recent list, in any order. At the end of each recall phase, a prompt appeared asking the participants to press a key to self-initiate the next study phase. The experiment was designed and run using the pyEPL experimental library (Geller, Schleifer, Sederberg, Jacobs, & Kahana, 2007).

Analysis. A binomial distribution test indicating at- or below-chance performance on the math distractor test was used to identify any participants who appear to have failed to follow instructions. Data from nine participants was identified and removed in this way. Memory performance for the remaining N = 27 participants was evaluated using a generalized linear mixed model (GLMM; McCulloch & Neuhaus, 2013) from the lme4 package in the R environment (R Development Core Team, 2007), which allows statistical control for unequal numbers of trials in each condition for each participant and for random variability in participants, colors, and words. Using the GLMER function, Event Type and List Frequency were treated as predictors of correct recall. Correct recall was modeled with Event Type, List Frequency, and Task Block (1-18), as fixed factors, and with participant, word, and color as random effects. Following the procedure recommended by Baayen, Davidson, and Bates (2008), likelihood ratio tests were used to compare reduced models in which non-significant factors were systematically eliminated. Factors and interactions were only removed if the χ^2 (ANOVA) likelihood ratio exceeded a significance of p = 0.05. Results of the final model with the best fit for the data are reported.

2.1.3 Results

Overall free recall performance was low (M = 0.25, SD = 0.43), indicating that the task was generally difficult. The final model for Experiment 1 is represented by the equation:

P|Recall ~ Event Type + List Frequency + Task Block + (1|subject) + (1|word) (1) The equation states that the probability of recalling an item can be described as a function of the fixed factors Event Type, List Frequency, and Task Block as well as random effects of variability in participants and words. As shown in Table 1, there were no significant main effects of Event Type or List Frequency. There was a significant main effect of Task Block indicating the common effects of practice, which was verified with

	Param. Estimate	Std. Error	z-value	Pr(> z)
(Intercept)	-1.495977	0.125565	-11.914	<2e-16 ***
Event Type	0.001792	0.060948	0.029	0.977
List Frequency	0.071893	0.061019	1.178	0.239
	0.02(525	0.004717	5 (2)	1.05.00 ****
Task Block	0.026535	0.004717	5.626	1.85e-08 ***

Table 1: Fixed effects parameter estimates for Experiment 1. Significance level is indicated by '***' for p < 0.001, '**' for p < 0.01, '*' for p < 0.05, and '.' For p < 0.1.

an additional regression on the Task Block factor alone ($\beta = 0.03$, se < 0.01, z = 5.67, pr(>|z|) < 0.01). Importantly though, the Task Block factor did not have an interaction with any of the other factors, and all interaction factors were successfully removed from the final model. The overall pattern of results for Experiment 1 is shown in Figure 3.

2.1.4 Discussion

Contrary to the original hypothesis, change Event Types in the low List Frequency condition did not show better recall, nor did non-change Event Types in the high List Frequency condition. With no significant differences in free recall performance for context-change events in either condition, a theoretical justification for different mental states required for memory-related expectation violation is not yet supported. It must be concluded that the change in color during study was not sufficient to elicit distinctive processing, at least in Experiment 1. Isarida and Isarida (2007) did find



Figure 3. Experiment 1 results. Percent correct free recall as a function of Event Type (change vs. non-change) and List Frequency (high vs. low). Bars indicate \pm 95% C.I.

improved cued recall from distinct color cues, but showed no effect when one common background color was presented for a number of successive items. While this finding is contradictory to the effect shown in Green's (1958a) design, the discrepancy may be due to the overall difficulty of the task design. Green's (1958a) list length was only 12 items long, and he did not include an additional task during study phase. Also, his critical item was the same in all lists ('CZ'). Experiment 1 had a list length of 21 items. Furthermore, the color discrimination task that was implemented during the study phase may have contributed an additional cognitive demand that was not directly related to free recall performance. This null result implies that passively attending to the item features alone was not a relevant factor in producing an association that would be meaningful or helpful to subsequent memory. This is in line with the finding of Postman and Phillips (1954) showing isolation-type effects only for features that are relevant to intentional learning tasks. Due to these design shortcomings, another measure of memory performance is considered in which information from an attentional processing task during study is directly relevant to subsequent responses at test.

Chapter 3: Source Memory

A valuable experimental framework that examines the direct memory relationship between the conditions during encoding and those during retrieval is the source monitoring, or source memory, framework described by Johnson, Hashtroudi, and Lindsay (1993). The idea of source memory refers to memory for characteristics that specify the conditions under which a memory is encoded. These conditions include spatial, temporal, and social contexts, as well as the surface features of items, types of media, sensory modalities, and environments. Within the source memory framework, the paradigm of *external source monitoring* refers to discriminating between externally derived sources of information. In this paradigm, participants receive information from different sources during a study phase. During a subsequent test, participants' ability to identify the source of the information is examined. A typical example is to have participants listen to words spoken by two different people or voices, and to subsequently cue them with the words and ask them to indicate which person or voice originally spoke the word (Hashtroudi, Johnson, & Crosniak, 1989). Unlike any previous work in the isolation paradigm, the following experiments will examine source memory for the background color (a surface feature) of study words by presenting the word as a cue and testing for memory of the background color.

The source memory procedure is both particularly useful and theoretically relevant for the present research because it directly examines memory for context.

23

Context has been defined here as a mental representation of the running average of recent experience (e.g., Sederberg, Howard, & Kahana, 2008), and is explicitly congruent with source information. This approach demonstrates a theoretical fluidity between the ideas of item and context and represents a novel method for quantitatively examining context distinctiveness effects in memory. Using the source memory procedure, context information can be attended to during an encoding task and also directly tested for at retrieval, thus addressing a potential reason for the failure of Experiment 1 to find a change-based distinctiveness effect in free recall. Furthermore, a distinctiveness effect such as change-based context-dependent memory may actually be predicated on a scenario in which the test context matches the learning context. This precise scenario is accomplished with the following source memory experimental design.

The source memory analog to correct recall is the correct identification of source when given an informational cue. Source memory accuracy provides a measure of the ability to recollect qualitative information about studied events (Johnson, Hashtroudi, & Lindsay, 1993). Thus, the following experiments will examine differences in correct source identification for different event types (change or non-change) within different conditions of change frequency. If the frequency of feature change in an external stimulus can directly impact our mental representation of context, and if the mental representation of context includes predictions about upcoming events, then events that do not conform to those predictions may be remembered better.

3.1 Experiment 2

In this experiment, the Event Type factor was implemented just as in Experiment 1 with change and non-change Event Types. Experiment 2 includes the high and low List Frequency conditions that reflect environments with high and low amounts of change. As in Experiment 1, these environments are intended to induce different mental states that inform predictions about upcoming stimuli and what kind of event determines a violation of that prediction. Additionally, a random List Frequency condition was added that contained no patterns or micro-sequences of change and non-change Event Types, although the balanced-feature constraint of equal color elements was retained. Random lists were used both as a control to compare the high and low List Frequency conditions to non-prediction based behavior, and as an additional exclusion criterion to identify participants who may not have been fully attending to the experiment. It is assumed that in a random environment, predictions about upcoming stimuli cannot be made, and there is no context factor that can give rise to a distinctiveness effect. As noted in the analysis for Experiment 2, the change factor should only show a difference when the environment is not random. Therefore, a direct comparison will be made between the non-random environments of high and low List Frequency.

Different colors were used in this experiment as well. Colors themselves can give rise to distortions in memory when hue and luminance are perceivably different (Isarida & Isarida, 2007). Because the following experiments used stimuli with a larger color area than only the font, blue and green colors were equated for hue and luminance as much as

possible within the software. The variable of interest is again change, represented as the occurrence of an inter-item switch in blue and green blocks of background color.

3.1.1 Design

Twelve study lists of words were generated for each subject as in Experiment 1. Each list had 30 words of 4-7 letters. Three "buffer items" at the beginning and end of each list shared the same context as the beginning and ending sequences. The buffer items were excluded from analyses because these items are assumed to undergo normal effects of primacy and recency. Words were presented sequentially in black font over a block of blue or green color. Each list had an equal number of blue and green color blocks. The Event Type factor was the same as in Experiment 1, indicating whether or not the color feature changed from that of the previous item and again comprised two levels (change vs. non-change). The lists were divided into three conditions based on the frequency of Event Types within a list. Thus, high-frequency lists contained sequences of 3-6 common change Event Types interrupted by five rare non-change Event Types. Conversely, low-frequency lists contained sequences of 3-6 common non-change Event Types interrupted by five rare change Event Types. The random List Frequency lists also had equal quantities of item colors, but change Event Types occurred randomly. The design of the stimuli is presented in Figure 4. Source memory accuracy can be compared across Event Type (change or non-change) and List Frequency (high, low, and random) as within-subject factors yielding an overall 2 (Event Type) X 3 (List Frequency) design. However, because Event Types in the random lists cannot deviate from a random frequency, a separate comparison of List Frequency was planned to determine if there is a

Low List Frequency	High List Frequency	Random List Frequency
LECTURE	RATTLE	JEWEL
MEETING	REPORT	STADIUM
COMFORT	SACK	PALM
PEARL	ICEBERG	AMOUNT
TYPIST	EFFORT	BEAST
APPLE	LEADER	SUIT
SENATE	FATHER	YARD
GLOBE	HEAVEN	MORAL
FIGURE	CUSHION	BOSS
BENCH	KITTEN	COTTAGE
DOLLAR	PROGRAM	ACORN
RAGE	SESSION	JACKET
MOVIE	SHRIMP	CHALK
SALT	MEADOW	FEMALE
DETAIL	DELIGHT	TUNNEL
CAMP	TULIP	TALENT 3
LEGEND	RECORD	SARDINE
HARVEST	POET	CHAIN
GOSSIP	DRIVER	WEDDING
PEANUT	HYGIENE	GRASS
EARTH	RING	PYRAMID
TRIAL	DIAL	WORKER
CITY	BILL	RUBBER
SEAT	DANCE	SKIRT
LOVER	WALL	STREET
CAKE	SINGLE	OMLET
ROMANCE	DOVE	CREW
HERB	CUSTARD	FUEL
POND	THEORY	VILLAGE
PEBBLE	WITNESS	REMARK

Figure 4. List design examples for Experiment 2. Items in bold rectangles represent isolated Event Types that deviate from the list context. There are no such isolated items in the random List Frequency condition.

qualitative difference in the direction of prediction error generated by change. The full statistical model was then calculated only on high and low List Frequency giving a final 2 X 2 design similar to Experiment 1.

3.1.2 Method

Participants. Ninety-nine volunteers (ages 18-47) recruited from Introductory

Psychology classes at The Ohio State University participated in Experiment 2. All

participants gave written informed consent prior to the procedure and were given partial

course credit for their time. The experiment was approved by the OSU Institutional Review Board.

Procedure. All equipment, software, experimenter procedures, and experiment duration were the same as Experiment 1 except for the design of the stimuli and the memory task. The practice block preceded 12 self-initiated experimental blocks consisting of three task phases each (Figure 5). Each block began with a fixation cross at



Figure 5. Order of tasks in each block of Experiment 2 and 3.

the center of a white screen for 1000ms indicating the beginning of a study phase. Study items were then presented at a rate of 1800ms per item with a 600-900ms jittered ISI consisting of a blank white screen before the onset of the next item. As instructed, participants pressed "J" with the right index finger to indicate a word on a blue rectangle, or "K" with the right middle finger to indicate a word on a green rectangle. Participants were instructed to respond as quickly and as accurately as possible, and were told that they would only have about two seconds to respond before the word would be removed from the screen. Participants were also told, "You should study that word and try to remember it for a later recall test. When studying the words, please try to avoid thinking back to previous words on the list; just focus on studying the word that is on the screen."

Study phase was followed immediately by the same math distractor task used in Experiment 1. The source memory task began immediately after the 30-second distractor phase. In this task, the most recent study list was randomized and presented without colors. Test stimulus duration was 2000ms with a 200ms ISI. The participants indicated which color they thought the word was originally presented on by key press. Key-mapped instructions at the bottom of the screen disappeared upon response for both study and test phases. At the end of each test phase, a prompt appeared asking the participants to press a key to self-initiate the next study phase.

Analysis. A binomial distribution test indicating at- or below-chance performance on the math distractor test as well as on the random list condition identified participants who failed to follow instructions. Data from 26 participants was identified and removed in this way. Memory performance for the remaining N = 73 participants was evaluated using the same generalized linear mixed model (GLMM; McCulloch & Neuhaus, 2013) from the lme4 package in the R environment (R Development Core Team, 2007) as in Experiment 1. Using two separate modeling procedures, the analysis first compared source memory performance across all conditions and levels of List Frequency. Then, a second procedure examined only the List Frequency conditions where non-random context could be anticipated and violated by rare Event Types. Correct source memory was modeled with Event Type, List Frequency, and Task Block (1-12), as fixed factors, and with participants, words, and colors as random effects. Following the same procedure as Experiment 1 (Baayen, Davidson, and Bates 2008), likelihood ratio tests were used to compare reduced models in which non-significant factors were systematically eliminated. Results of the final best-fit models for the data are reported.

3.1.3 Results

The overall mean source memory performance was 69% correct (M = 0.69, SD = 0.49). The full-model comparison was reduced to the equation:

P|Source Memory ~

Event Type + List Frequency + Task Block + (LF X TB) + (1|subj) + (1|color) (2) The equation states that correct Source Memory can be predicted by the fixed effects of Event Type, List Frequency, Task Block, the random effects of variability in subjects and words, as well as an interaction between Task Block and List Frequency. Estimates of the final model are shown in Table 2. The interaction was shown to only occur with the random lists as a reference and only indicates normal practice effects over all conditions. The main effect of Event Type was analyzed further and found not to be significant (p =0.126). However, the overall main effect of List Frequency remained and was strongest with random lists as condition referents ($\beta = 0.13$, se < 0.04, z = 3.53, pr(>|z|) < 0.001). High List Frequency conditions had lower Source Memory performance (M = 0.68, SD = 0.47) than either low (M = 0.70, SD = 0.46) or random (M = 0.70, SD = 0.46) List Frequency.

A second modeling procedure examined the effect of context change in the conditions where the rare, isolated Event Types could be compared to the common Event

	Param. Estimate	Std. Error	z-value	Pr(> z)
(Intercept)	0.640657	0.099374	6.447	1.14e-10 ***
Event Type	0.109616	0.034952	3.316	0.00171 **
List Frequency (Re: low)	0.219933	0.084925	2.590	0.00960 **
List Frequency (Re: random)	0.404098	0.085973	4.700	2.60e-06 ***
Task Block	0.009448	0.008233	1.148	0.25117
LF(low) X Task Block	-0.008724	0.011355	-0.768	0.44233
LF(random) X Task Block	-0.36349	0.011595	-3.135	0.00172 ***

Table 2. Experiment 2 fixed effect estimates for full comparison of all factors.Significance level is indicated by '***' for p < 0.001, '**' for p < 0.01, '*' for p < 0.05,and '.' For p < 0.1.

Types within a list. List Frequency was restricted to the high and low levels, ignoring any effect of behavior in random environments. The final reduced model from this procedure is represented by the equation:

P|Source Memory ~ Event Type + List Frequency + (ET X LF) + (1|subj) (3) Equation 3 states that correct Source Memory can be described as a function of the fixed factors Event Type, List Frequency, their interaction, and random participant variability. As shown in Table 3, the model indicated a significant interaction effect between Event Type and List Frequency ($\beta = 0.33$, se =0.09, z = 3.58, pr(>|z|) < 0.001). The marginal main effect of Event Type was probed with a separate regression and found to be not significant (p = 0.382) when collapsed across condition. However, when probing the

	Param. Estimate	Std. Error	z-value	Pr(> z)
(Intercept)	0.81380	0.06767	12.025	< 2e-16 ***
Event Type	-0.11983	0.06385	-1.877	0.060558.
List Frequency	0.03002	0.04192	0.716	0.47939
(ET X LF)	0.33171	0.09274	3.577	0.000348 ***

Table 3. Experiment 2 fixed effect parameter estimates for restricted comparison. Significance level is indicated by '***' for p < 0.001, '**' for p < 0.01, '*' for p < 0.05, and '.' For p < 0.1.

interaction by regressing within separate levels of List Frequency, change Event Types elicited significantly higher source memory (M = 0.73, SD = 0.44) than the non-change Event Types (M = 0.69, SD = 0.46) in the low List Frequency condition Frequency ($\beta =$ 0.21, se = 0.07, z = 3.16, pr(>|z|) < 0.01). A marginal effect of Event Type in the high List Frequency condition ($\beta = -0.12$, se =0.06, z = -1.90, pr(>|z|) < 0.058) showed slightly better memory for the common change Event Types (M = 0.68, SD = 0.47) than the rare non-change Event Types (M = 0.65, SD = 0.47). The overall pattern of results can be seen in Figure 6. A more detailed example of the Event Type effect can be shown by plotting the conditional response probability (CRP) of source memory as a function of temporal distance between rare, isolated items that deviate from the List Frequency context by having an Event Type that represents a violation of context. Temporal distance in these experiments is defined in terms of positional lag and is the nearest equivalent to a serial position curve when comparing different lists. In Figures 7 and 8, the rare events are plotted as lag-position 0 and common events that both precede and follow the rare events are shown. The Event Type effect is seen in Figure 7 for the low List Frequency condition showing better source memory for change Event Types. The null marginal effect of Event Type in the high List Frequency condition is plotted in Figure 8.



Figure 6. Experiment 2 results. Correct source memory as a function of Event Type (change vs. non-change) and List Frequency (random vs. low vs. high). Bars indicate \pm 95% C.I.



Figure 7. Low List Frequency CRP of source memory as a function of lag position centered on change Event Types. Bars indicate \pm 95% C.I.



Figure 8. High List Frequency CRP of source memory as a function of lag position centered on non-change Event Types. Bars indicate \pm 95% C.I.

3.14 Discussion

As shown in Figure 6, the effect of context change gave rise to a difference in source memory performance in the low List Frequency condition. Change Event Types were remembered better than non-change Event Types. While the effect was marginal in the high List Frequency condition, it was neither significant nor in the expected direction and can be considered a null effect. The pattern of data may reflect a specific case where a low amount of change focuses attention on unpredicted events. In fact, there is no known research that compares memory performance in environments with low levels of change with memory in highly changing environments. If the result of Experiment 2 is interpreted in terms of expectation violation and prediction error as a way to compare current and expected stimuli (e.g., Schütz-Bosbach & Prinz, 2007), it indicates a difference in the way prediction errors can occur. Change based events appear to violate prediction differently than non-change based events. The difference may reflect a behavioral adaptation in terms of negative and positive rewards for prediction error as indicated in a recent model of neural learning by Cavanagh, Frank, Klein, and Allen (2010).

The data clearly demonstrate that context related events during encoding can affect subsequent memory performance. Importantly, the balanced-features design restricts interpretation of the change-based distinctiveness effect to local changes in context when none of the stimuli stand out due to their global features. To replicate the Event Type effect from Experiment 2, a further experiment was conducted using only the low List Frequency condition.

3.2 Experiment 3

The main purpose of Experiment 3 was to provide a replication of the context change effect from the Low List Frequency condition of Experiment 2. Experiment 3 also included very slight design alterations for the purpose of magnifying the effect size and to increase the number of data points for analysis. The critical balanced-features restriction was maintained to eliminate global feature distinctiveness and thereby confine interpretation to the local, item-level effects of context change. Continuing with the idea that active schemas reflect the amount of change in a learning environment, it is hypothesized that distinctiveness can arise by violating expectations established by the pattern of feature change in a sequence of stimuli. If an item-level feature deviates from the context of a schema, then information associated with that item should be remembered better than information that conforms to the context.

3.2.1 Design

Only the low List Frequency list condition was used in this experiment. To increase the number of data points, the list length was increased to 32 items, and the primacy and recency buffers were reduced to two items. Also, the study phase ISI jitter was reduced to 420-580ms. The test phase stimulus duration was 1800ms with a 160ms ISI. The sequence length of non-change items was increased to a range of 3-8 items so that enough items were present to ensure a stable context. All other design parameters were the same as in Experiment 2. See the low List Frequency condition in Figure 4.

3.2.2 Method

Participants. Eighty-eight volunteers (ages 18-29) recruited from Introductory

Psychology classes at The Ohio State University participated in Experiment 3. All participants gave written informed consent prior to the procedure and were given partial course credit for their time. The experiment was approved by the OSU Institutional Review Board.

Procedure. Except for changes noted in the Design, all procedures were the same as in Experiment 2. See Figure 5 for an example of a task block.

Analysis. A binomial distribution test indicating at- or below-chance performance on the math distractor test identified participants who failed to follow instructions. Data from 16 participants was identified and removed in this way. Memory performance for the remaining N = 72 participants was evaluated using the same generalized linear mixed model (GLMM; McCulloch & Neuhaus, 2013) from the lme4 package in the R environment (R Development Core Team, 2007) as in Experiments 1 and 2. Correct source memory was modeled with Event Type, List Frequency, and Task Block as fixed factors, and with participants, words, and colors as random effects. Following the same procedure as Experiments 1 and 2 (Baayen, Davidson, and Bates 2008), likelihood ratio tests were used to compare reduced models in which non-significant factors were systematically eliminated. Results of the final best fit model for the data are reported.

3.2.3 Results

The overall mean source memory performance was 64% correct (M = 0.64, SD = 0.48). The final model for Experiment 3 is represented by the equation:

 $P|Source Memory \sim Event Type + Task Block + (1|subj) + (1|color)$ (4) The equation states that correct Source Memory can be predicted by the fixed effects of Event Type, Task Block, and the random effects of variability in subjects and colors. The main effect of task block ($\beta = -0.01$, se < 0.01, z = -3.11, pr(>|z|) < 0.01) merely indicated the common effects of practice and fatigue showing that performance improved over the first few blocks and then deteriorated back to baseline. As shown in Figure 9,



Figure 9. Experiment 3 results. Correct source memory as a function of Event Type (change vs. non-change). Bars indicate ± 95% C.I.

there was a significant main effect of Event Type ($\beta = 0.17$, se = 0.04, z = 4.64, pr(>|z|)< 0.001) showing higher source memory performance for the change Event Types (M = 0.67, SD = 0.47) than the non-change Event Types (M = 0.63, SD = 0.47). The Task Block factor did not interact with the Event Type factor indicating that the main effect of Event Type is independent of the length of the test and the number of blocks. Again, a more detailed example of the Event Type effect can be shown by plotting the CRP of source memory as a function of temporal distance between rare, isolated items that deviate from the List Frequency context by having an Event Type that represents a violation of context. In Figure 10, the change Event Types are plotted as lag-position 0 and non-change Event Types that both precede and follow them are shown.



Figure 10. Experiment 3 CRP of source memory as a function of lag position centered on change Event Types. Bars indicate \pm 95% C.I.

3.2.4 Discussion

The replication in Experiment 3 demonstrates that context related events during encoding are able to generate distinctiveness effects for memory. The finding is most closely aligned with Green's (1958a, Experiment 2) change group that showed isolation effects when micro-sequences of feature types alternated within an overall list structure.

By implementing a balanced-feature design, these experiments support the hypothesis that distinctiveness arises for items that violate expectancies from the sequential structure of a learning set. This finding runs contrary to the assumption underlying retrieval-based interpretations of global feature distinctiveness because unique item characteristics cannot be later recruited by memory to identify unique features of events. The basic interpretation of the effect shown in Experiment 3 is that context-based structural change is an exogenous factor that drives attention during memory encoding.

This effect occurs when sequential structures that represent context are stable and do not contain frequent changes. Under this constraint, a mental schema of context can be developed to derive expectancies about upcoming stimuli. Changes in context cues act as violations of expectancy (Hirshman, Whelley, & Palij, 1989) and can be framed in terms of prediction errors. Prediction error, as described by Karl Friston (2012), is essentially the difference between encoded representations of stimuli and internal predictions generated by the brain. When prediction error is large enough, as when generated by change Event Types in the low List Frequency conditions, attention can be shown to exhibit a bias toward processing specific features of an event (Fabiani & Donchin, 1995). In the end, the manipulations used in these experiments are assumed to engage attentional bias as a mechanism for episodic memory encoding.

Chapter 4: General Discussion

The pattern of data from these experiments provides an interesting set of constraints for interpretation. The overall result indicates a distinctiveness effect in source memory based on context change, but only when the local context environment (list structure) contains a relatively low frequency of changes. Conversely, when the environment is random or contains frequent changes, there is no distinctiveness effect that arises. This unique set of results has been brought about by a novel combination of theoretically motivated design features. Specifically, the balanced-features design from research on isolation effects (Siegel, 1943; Saul & Osgood, 1950; Postman & Phillips, 1954; Green, 1956; Green, 1958a) was combined with different list types reflecting variations on prediction error (Frank, Woroch, & Curran, 2005; Cavanagh, Frank, Klein, & Allen, 2010), and a source memory metric (Johnson, Hashtroudi, & Lindsay, 1993). The information provided by this data shows that context sensitive organization is critical for memory encoding, and provides a further account for some of the memory variance in distinctiveness effects. No known published work has derived the specific set of results found in this research.

The failure to find a context-change-based distinctiveness effect in the free recall paradigm in Experiment 1 was surprising in light of the previous work by Green (1958a) and Wright (1976). They were able to show modulations in the serial position curve of free recall by context manipulations. Previous work with color stimuli has shown that an item-by-item change in background color may attract attention even if the change is simply between 2 colors (Isarida & Isarida, 2007). Furthermore, Karis, Fabiani, and Donchin (1984) showed isolation effects on free recall related to the P300 ERP component (an EEG analog of attentional processing) in the classic oddball paradigm, although the effect was weakened when their subjects employed elaborative rehearsal strategies. The Experiment 1 null effect may have been due to various intricacies of experimental design. Foremost among these is the fact that the context features that were attended to during the study phase were not directly relevant to the demands of the memory task. Attention to item features alone does not appear to be relevant for producing meaningful associations helpful to memory. For this reason, the use of the source monitoring procedure as a valid measure of memory is supported for use in examining context-based variance in distinctiveness effects.

In Experiments 2 and 3, the implementation of source monitoring permitted the discovery of a unique distinctiveness effect based on context change. In the low List Frequency condition of Experiment 2, replicated in Experiment 3, rare isolated change events elicited significantly higher source memory performance than common non-changing events. Better memory performance for change-based events can be driven by a cognitive mechanism that "updates" a mental representation of current events in working memory whenever new information is provided (Donchin, 1981). The process of updating context has been directly linked to physiological signatures of attention (Karis, Fabiani, & Donchin, 1984; Lenartowicz., Escobedo-Quiroz, & Cohen, 2010), and has been shown to mediate the assimilation of new information into memory (Hupbach, Hardt, Gomez, & Nadel, 2008). The change-based distinctiveness found in this research

can be explained as a function of context updating that occurs when the mental representation of elements in a study list is confronted with new information in the form of a new color feature. When the new feature is encountered, attention is re-oriented to the event, and working memory is modified – or updated – by encoding an association between the contextual elements of that event. This explanation makes sense for more stable environments like the low List Frequency condition.

What if context change is *not* a rare event? For example, unstable environments may be composed of context features that change rapidly or frequently, and features that do not change could be isolated in such a context. The high List Frequency condition of Experiment 2 was designed to address this scenario. If the requisite causal manipulation for distinctiveness is to isolate items from the sequential structure of a learning set by virtue of structural change (Green, 1958b; Swartz, Pronko, & Engstrand, 1958), then it is possible that attention could be affected by a stimulus sequence that includes high amounts of change. This idea provides the theoretical rationale for the high List Frequency condition and it was hypothesized that isolated non-change events would be remembered better than the sequences of change events. Because the data did not support that hypothesis, it is necessary to explain why the change and non-change Event Types had different effects on source memory.

It is possible that the high List Frequency condition was perceived as random, or perhaps the entropic nature of the environment created too much of a sensory processing load. In research on the claim that the perception of sequence depends upon people's actual experiences with particular sequence types, Matthews (2013) showed that subjects who evaluated sequences with rapid alternations between stimuli were more likely to have judged them as having been produced by a random mechanical process. It is possible that the participants in the current research perceived the changes in the high List Frequency condition to be random, and therefore did not establish a mental context schema for the sequences of change Event Types. A similar possibility is that the rapid switching of stimulus features creates a cost in sensory processing that is reflected in a cognitive inertia for encoding new information into working memory. The processing cost is indicated in previous work demonstrating cognitive difficulty in terms of a reaction time decrement in a memory task when subjects switched from image to word stimuli (Kavcic, Krar, and Doty, 1999). The reaction time cost was unavoidable even if switching was explicitly predicted, meaning that the cost was automatically driven by the stimuli, and not by expectation or processing of change. The researchers argued that a major component of the reaction time cost was the rapid termination of the previous mode of processing (context). This may explain why the high List Frequency performance was lower and no distinctiveness effect happened: rapid item-by-item context changes forced a processing load on the visual system that hindered memory encoding.

However, the idea of encoding-based organization of context provides access to a more nuanced explanation for the different patterns in the data that were found. If encoding-based organization of context serves to orient attention to deviations from expected features and assist learning (Hirshman, Whelley, & Palij, 1989), then interpreting the difference between change or non-change context deviations can be accomplished in terms of a theory of predictive coding. Predictive coding refers to a set of mathematical models first developed in perception research on the cortical pathways of the visual system (Mumford, 1992; Rao & Ballard, 1999) and developed through Friston's "free-energy" principle of perception and cognitive processing (Friston & Keibel, 2009). In predictive coding, sensory input is sent through a feedback loop that simultaneously monitors incoming information and makes inferences about future events based on past information. In this way, the brain is seen as an information-processing instrument that integrates top-down expectations and bottom-up stimulus information occurring across multiple sensory levels and pathways (Bubic, von Cramon, & Schubotz, 2010). A prediction violation, or error, occurs when new information conflicts with an expected future trajectory. The difference between the mental trajectory, or context structure, and new information is itself used as new information. In terms of memory, these models would posit that new predictions are established with context information from each new event.

A key point to highlight is the difference between positive prediction error (when an unpredicted event *happens*), and negative prediction error (when a predicted event *does not happen*). The distinction arises from literature on probabilistic reinforcement learning where reward expectancy affects the degree of negative or positive prediction error for different behavioral adaptations (Cavanagh, Frank, Klein, & Allen, 2010). The experimental design in the current research contains events that parallel both types of prediction error. Change-events in the low List Frequency condition represent positive prediction represent positive negative prediction error. The comparison made between these conditions was intended to examine the potential qualitative differences between the possible types of prediction error in terms of a binary direction generated by change.

When viewed through the lens of binary prediction error values, the results of Experiment 2 can be more fully understood. In the low List Frequency condition, sequences of non-change events signal predictions for more of the same type of stimulus. Change becomes an unpredicted event, and when it does occur, the expected future trajectory comes into conflict with new information from the stimulus. The result is a positive prediction error that drives attentional processing to bind feature associations into working memory by updating context representations. Conversely, the high List Frequency condition should establish an expected trajectory reflecting item-by-item change. Within a sequence, the expectancy of continually changing information adapts the mental representation template to conserve cognitive resources by habituation to the changing features (Friston & Keibel, 2009). When anticipated information suddenly does not change, a negative prediction error occurs that is not sufficient to overcome the habituation that has built up over the course of the sequence. Additional attention resources are not required to process the absence of change, so there is no trigger for a context update to occur as in the opposite scenario.

46

Chapter 5: Conclusions

The purpose of this research was to evaluate the cognitive processes that lead to distinctive memory representations and their effects. In these experiments, it has been shown that an item-level feature change can enhance memory for context by a process that occurs during encoding. The principle contributor to the data pattern appears to be a violation of stable context representation. The novel results provided by the data support the conclusion that distinctiveness in memory can be generated by context change, accounting for some of the unexplained variance in memory performance. The result also points to a context based interpretation of distinctiveness that can reconcile divergent theoretical and operational definitions of distinctiveness. The experience of context informs subsequent cognitive predictive coding (Mumford, 1992; Rao & Ballard, 1999). However, it also possible that contextually distinct items update our active cognitive representations by involuntarily engaging attention to modulate and enhance them, allowing for better memories.

It is proposed that the learning of episodic information happens through a computational mechanism that combines context updating and positive prediction error. The combination provides a unique bridge between divergent concepts of distinctiveness effects by accounting for the role of context change in memory formation. Memory is an

evolving mental representation of context that generates predictions about upcoming experiences. Information from experience that deviates from prediction generates an error signal that can trigger attention orientation during encoding. When this occurs, a context update modifies existing representations and binds them to new information.

Limitations of the present work include the possibility that subjects do not need to associate color to word information for the free recall task, even if they are explicitly attending to color during study. Also, the length of the list in the source memory experiments provided a limited set of data points that may have decreased the size of the effect found in the low List Frequency condition. Furthermore, the size of the change based distinctiveness effect was small and will be difficult to correlate with online physiological indices of context processing that will be important in fully understanding distinctive memories.

Future work should focus on developing the mathematical framework for the context updating/positive prediction error combination. The foundation of the theoretical framework described here lies on the assumption of some form of attention processing, and this component should be included in any potential model of the effect described in this work. Additionally, future work should examine the psychophysiological signatures of attention that respond to context change and contribute to the formation of episodic memory. This may include neural signatures of context encoding, pupillometry response, or eye fixation. The requisite empirical design for examining context change should include some measure of subsequent memory that indicates when information has been successfully encoded. By examining how memory is encoded and by accounting for

variance in human memory performance, cognitive science can begin to understand and improve the ways that humans can learn new information.

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