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The Effect of Normative Context Variability on Recognition Memory

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According to some theories of recognition memory (e.g., S. Dennis & M. S. Humphreys, 2001), the number of different contexts in which words appear determines how memorable individual occurences of words will be: A word that occurs in a small number of different contexts should be better recognized than a word that appears in a larger number of different contexts. To empirically test this prediction, a normative measure is developed, referred to here as *context variability*, that estimates the number of different contexts in which words appear in everyday life. These findings confirm the prediction that words low in context variability are better recognized (on average) than words that are high in context variability.

In a typical recognition memory experiment, a list of words is studied, and memory is tested subsequently by showing subjects both words that were studied (i.e., *targets*) and words that were not studied (i.e., *foils*). The subject's task is to discriminate the targets from the foils. Of course, subjects have encountered words a large number of times in many different contexts prior to the experiment. Hence, the subject's rather daunting task is to discriminate the most recent encounter with a word from all prior encounters.

Theories of memory usually address this issue by making a distinction between item and context information (e.g., Anderson & Bower, 1972; Dennis & Humphreys, 2001; Humphreys, Bain, & Pike, 1989; Jacoby, 1991; Maddox & Estes, 1997; McGeoch, 1942; Mensink & Raaijmakers, 1988; Raaijmakers & Shiffrin, 1981; Shiffrin & Steyvers, 1997): Item information represents a studied stimulus (e.g., a word), and context information represents the environment in which the stimulus was encountered. According to these theories, when an item is studied, both item and context information are stored in an episodic trace, and when recognition memory is tested, memory is probed with a retrieval cue consisting of both item and context information. The critical role context plays in the retrieval cue is to restrict the probe to the relevant subset of memory traces (as defined by the task). Those episodic traces that contain context information similar to the retrieval cue might become members of the "activated" subset of memory and contribute information to the recognition decision. Hence, the to-be-remembered encounter with a word can, in principle, be isolated from prior encounters according to the similarity between the context used in the retrieval cue and context information stored in memory.

Context has been described in different ways (McGeoch, 1942). For example, context has been described as information that fluctuates randomly over time with respect to different item presentations (e.g., Brown, Preece, & Hulme, 2000; Estes, 1955; Mensink & Raaijmakers, 1988; Shiffrin & Steyvers, 1997), which might be referred to as temporal context (cf. Hintzman & Summers, 1973). Context has also been defined as the physical environment in which an item occurs (e.g., Godden & Baddeley, 1975; Murnane & Phelps, 1993, 1994, 1995; Murnane, Phelps, & Malmberg, 1999; Smith, Glenberg, & Bjork, 1978). Howard and Kahana (2002) described the context associated with a given item as a composite representation of the semantic features of the items that preceded it on a list. Similarly in this article, we propose that context might be defined by the semantic context in which an item is used, and the number of different preexperimental contexts in which an item appears might vary from item to item (Dennis, 1996). For example, consider the words *afternoon* and *tornado. Afternoon* is used in conversations, articles, and television and radio programs about many different aspects of everyday life, whereas *tornado* is used in a relatively small subset of everyday communications (i.e., natural disasters or meteorology). Hence, words might vary in the number of different semantic contexts in which they are used.

For convenience, we refer to the number of different contexts in which a word appears as *context variability.* Words that appear in many different contexts are said to be relatively high in context variability, and words that appear in only a few different contexts are said to be low in context variability.

Of course, *afternoon* is a more common word than *tornado* (Kučera & Francis, 1967), and it is well known that the normative frequency of words has a robust effect on recognition memory: Low-frequency (LF) words are better recognized than high-frequency (HF) words (Schulman, 1967; Shepard, 1967). Perhaps, however, the number of different contexts in which a word is used also affects recognition. For example, Dennis and Humphreys (2001; also see Shiffrin & Steyvers, 1997) described how the number of different contexts in which a word appears might affect recognition memory performance. Hence, we can consider at least two aspects of the usage of words that affect recognition memory: (a) the frequency with which words are used, and (b) the number

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of different contexts in which words are used. In fact, the bind, cue, and decide memory model described by Dennis and Humphreys (2001) predicts that words that are low in context variability will be better recognized than words that are high in context variability. In this article, we derive a normative measure of context variability and empirically assess its effect on recognition memory.

Operationally Defining Context Variability

Our operational definition of the number of different contexts in which a word has appeared prior to an experiment is similar to Dennis's (1996). Our analyses were performed on the Touchstone Applied Science Associates (TASA) corpus (Landauer, Foltz, & Laham, 1998) that contains a large collection of text documents containing information to which 3rd to 12th graders might be exposed (e.g., language and arts, social studies, science, health, business, etc.). Because each document formed a semantically coherent piece of text, we assumed that different documents could be interpreted as different contexts, and because the texts correspond to the type of information to which schoolchildren are exposed, it is likely that adults will have encountered words in similar contexts (Landauer et al., 1998). The TASA corpus contains 10,710,325 words and 37,652 text passages or contexts. As a measure for context variability we simply count the number of different TASA text passages in which a word appears. These counts are referred to here as *context frequency* counts.

The Relationship Between Context Frequency and Word Frequency

As we mentioned earlier, context variability might be correlated with how often a word is encountered in all contexts (i.e., word frequency). Using a different corpus of Australian newspaper articles, Dennis (1996) demonstrated that word frequency is highly correlated with the number of different contexts in which a word appears. Figure 1 shows this relationship as based on the TASA counts: Word frequency is highly correlated with context frequency ($R = .98$). Nevertheless, it is possible to select words from the corpus in such a manner that words associated with a given range of frequency can vary in their context variability.

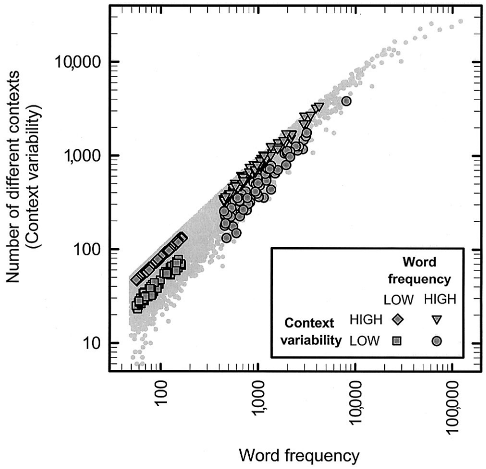

Figure 1. Relationship between word frequency and context frequency (both shown on logarithmic scale). Gray points show relationship for all words in the Touchstone Applied Science Associates corpus.

In Table 1, we show some examples of words listed in terms of their word frequency and context frequency counts. For example, the high-frequency words *atom* and *afternoon* occur about equally often in the TASA corpus. However, the context frequencies for these words show that *atom* occurs in only 354 text samples (low context variability), whereas *afternoon* occurs in 1,025 text samples (high context variability). Similarly, the two low-frequency words *tornado* and *outlook* occur about equally often in the corpus, and also differ in their context frequency count: *Tornado* occurs in fewer text samples than *outlook.* Thus, words with the same word frequency can vary in context variability and vice versa.

Experiment

In this single-item recognition experiment, we tested the hypothesis that context variability affects the recognition of words. To demonstrate that such an effect arises not because of differences in word frequency, we controlled the normative word frequency of the words used in this experiment. We selected words from the TASA corpus that varied in context variability and word frequency, each in two different ranges. These groups of stimuli are shown in Figure 1, which illustrates that the range of context variabilities is greater for LF than for HF words and therefore that context variability might have a greater effect on the recognition of LF words than of HF words. Malmberg, Steyvers, Stephens, and Shiffrin (2002) found that the orthographic distinctiveness of a word significantly affects recognition memory and that this factor is correlated with word frequency. In this experiment we controlled for orthographic distinctiveness to observe the effects of context variability independently of this factor.

Method

Participants. Thirty-one Indiana University, Bloomington students who were enrolled in introductory psychology courses participated in the experiment in exchange for course credit. An additional 110 subjects participated via the Internet. The inclusion of an online group in this study served two purposes. First, it allowed us to test the reliability of the effects across two subject populations. Second, and more important, detailed statistical analyses of effects across items and subjects could be conducted because of the relatively large number of observations. Details of the advantages and disadvantages of online experiments have been discussed elsewhere (e.g., Reips, 2002; Reips & Bosnjak, 2001).

Design and materials. Normative word frequency and context variability were varied as within-subject variables in a 2 × 2 factorial design. The dependent variables were *hit rates (HRs), false-alarm rates (FARs),* and d_a (Macmillan & Creelman, 1991).

We selected 288 words from the TASA corpus (see the Appendix). Our analyses showed that nouns, verbs, and adverbs differ greatly in their context variability. Therefore, we included only nouns in our word selection to facilitate the problem of balancing for context variability. The nouns were organized into four groups (each group containing 72 items) according to context variability and normative word frequency: (a) low context variability/low word frequency, (b) high context variability/low word frequency, (c) low context variability/high word frequency, and (d) high context variability/high word frequency. The word groups were also controlled for orthographic distinctiveness (Malmberg et al., 2002) so that the average letter frequency of the words in the four groups was approximately

Table 1

Examples of Words With Corresponding Touchstone Applied Science Associates Frequency Count (f) and Context Frequency Count (d)

Word	*f*	*d*
Atom	1,140	354
Afternoon	1,132	1,025
Tornado	88	28
Outlook	83	76

the same. Table 2 shows the means and standard deviations of the word frequencies, context frequencies, and orthographic distinctiveness scores for words in these conditions.

We constructed two study lists and two test lists randomly for each subject. Each study list consisted of 130 words: 24 words from each of the four conditions and 34 filler items. Each test list consisted of 96 items containing half targets and half distractors, with words chosen equally from each condition.

Procedure. An experimental session consisted of two study–test cycles. Participants were instructed prior to each study–test cycle to remember the words on the study list for a later memory test. Each word was displayed in uppercase form in the center of a PC screen for 1.3 s of study. Test items were presented one at a time, and subjects were instructed to rate how confident they were that a test item was studied by utilizing a 6-point scale ranging from 1 (*high confidence that an item had not been studied*) to 6 (*high confidence that an item had been studied*). Responses were made by using a mouse to click the appropriate button in the computer display. Each response was followed immediately by the presentation of a new item. At the end of the experiment, subjects were given feedback concerning their performance on the task.

Results

To obtain *HR*s and *FAR*s, (we converted) the 6-point confidence ratings to “old” and “new” responses by choosing a criterion and marking ratings higher or equal to the criterion as old responses and ratings lower than the criterion as new responses. For each subject, a criterion was chosen to equalize the overall number of old and new responses as best as possible.[1] The confidence ratings were used to construct ratings *z*-ROC curves for each subject for each condition in order to compute sensitivity, d_a (Macmillan & Creelman, 1991). Table 3 lists the d_a and *z*-ROC slope statistics as a function of context variability and word frequency for both the lab and online participants. An alpha of .05 was the standard of significance for all statistical analyses. Figure 2 plots average d_a and the *HR*s and *FAR*s as a function of context variability and word frequency for both groups.

Table 2

Means and Standard Deviations of the Word Frequencies, Context Frequencies, and Orthographic Distinctiveness Scores

	Context variability			
	Low		High	
Measure and word frequency	*M*	*SD*	*M*	*SD*
Word frequency				
Low	95	32	95	32
High	1,224	1,095	1,160	836
Context frequency				
Low	44	15	78	26
High	591	544	923	673
Orthographic distinctiveness[a]				
Low	.07	.02	.07	.01
High	.07	.01	.08	.01

[a] Orthographic distinctiveness was computed by averaging letter probabilities computed separately for first, middle, and last positions of the word. Higher scores are associated with lower orthographic distinctiveness (see Malmberg et al., 2002, for details).

Table 3

z-ROC d_a and Slope Statistics Across Context Variability and Normative Word Frequency

	d_a		Slope	
Word frequency and context variability	*M*	*SD*	*M*	*SD*
Lab				
Low frequency				
Low context	1.58	0.46	0.55	0.21
High context	1.09	0.43	0.71	0.19
High frequency				
Low context	0.98	0.51	0.75	0.23
High context	0.76	0.39	0.81	0.17
Online				
Low frequency				
Low context	1.54	0.61	0.52	0.23
High context	1.07	0.58	0.66	0.23
High frequency				
Low context	1.02	0.57	0.67	0.22
High context	0.72	0.57	0.77	0.22

Word frequency effects. A typical word frequency effect was observed. Mean d_a was greater for LF than for HF words in both the lab and online conditions: $F(1, 30) = 56.5$, $MSE = 6.73$, and $F(1, 109) = 137.1$, $MSE = 22.0$, respectively. The *HR*s were greater for LF words than for HF words in both the lab and online conditions, $F(1, 30) = 16.5$, $MSE = 0.23$, and $F(1,109) = 65.5$, $MSE = 0.66$, respectively. The *FAR*s were lower for LF words than for HF words in both the lab and online conditions, $F(1, 30) = 31.2$, $MSE = 0.26$; and $F(1, 109) = 65.8$, $MSE = 0.69$, respectively. These results replicate the well-known mirror effect for word frequency in recognition memory (Glanzer & Adams 1985; Schulman, 1967; Shepard, 1967).

Context variability effects. Figure 2 shows that context variability produced a mirror effect (Glanzer & Adams, 1985): *HR*s were significantly higher in both the lab and online conditions: $F(1, 30) = 4.54$, $MSE = 0.05$, and $F(1, 109) = 25.9$, $MSE = 0.304$, respectively. *FAR*s were significantly lower for

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[1] An alternative procedure is to use one criterion for all subjects such as the criterion between the first three and last three confidence ratings. With this alternative procedure, all statistical results remain qualitatively the same. We chose the procedure of selecting criteria separately for each subject for two different reasons. First, this procedure corrects for idiosyncratic use of the confidence scale (i.e., some subjects use one end of the scale more than other subjects). Second, a subject-specific criterion leads to smaller standard errors in d_a, *HRs*, and *FARs* than does a universal criterion.

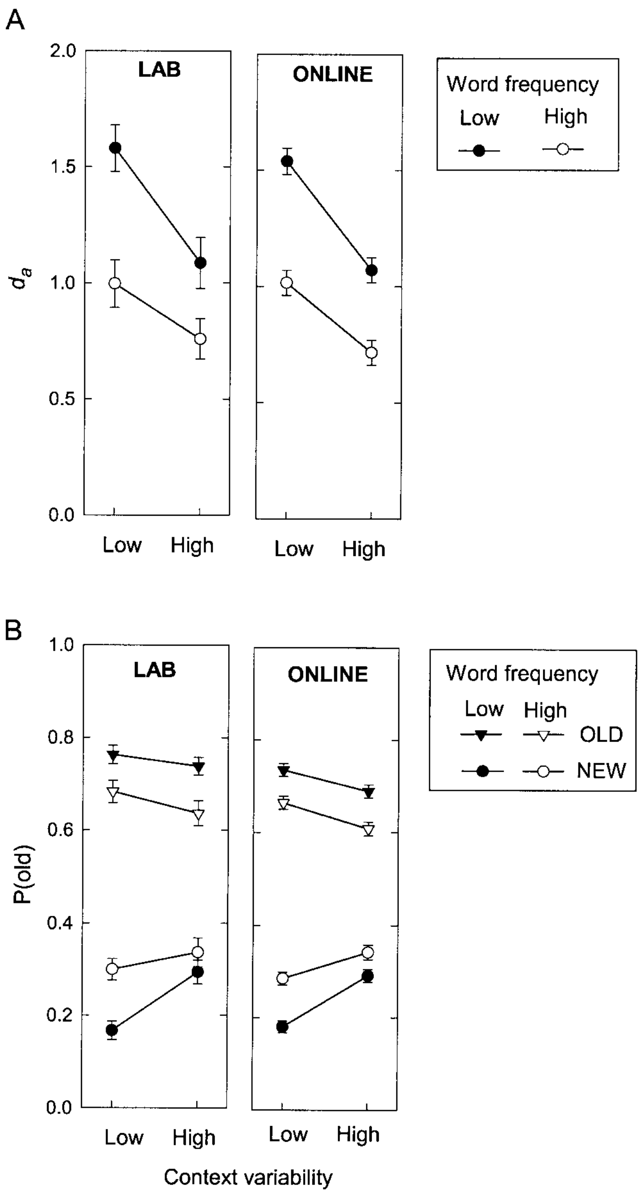

Figure 2. The results of the experiment for lab and online subjects. A: Sensitivity results d_a. B: Hit and false-alarm rates. P(old) = probability of responding "old."

words with low context variability than for words with high context variability in both the lab and online conditions: $F(1, 30) = 18.3$, $MSE = 0.17$, and $F(1, 109) = 106.5$, $MSE = 0.80$, respectively. Hence, words with low context variability were better recognized than words with high context variability.

Mean d_a was greater for low than for high context variability words in both the lab and online conditions: $F(1, 30) = 47.4$, $MSE = 3.94$, and $F(1, 109) = 105.7$, $MSE = 16.9$, respectively. The interaction between word frequency and context variability was significant in both the lab and online conditions: $F(1, 30) = 9.54$, $MSE = 0.58$, and $F(1, 109) = 6.24$, $MSE = 0.80$, respectively. The context variability effect was larger for LF words than for HF words, as expected when the range of context variabilities is greater for LF than for HF words (as is the case in the TASA corpus).

z-ROC slope effects. Table 3 lists the *z*-ROC slopes for the four conditions. Mean slopes are higher for HF words than LF words in both the lab and online conditions: $F(1, 30) = 51.8$, $MSE = 0.70$, and $F(1, 109) = 87.8$, $MSE = 2.0$, respectively, replicating previous findings (e.g., Glanzer, Kim, Hilford, & Adams, 1999). Context variability also had a significant effect on *z*-ROC slopes. Mean slopes were higher for high than for low context variability words in both the lab and online conditions: $F(1, 30) = 23.3$, $MSE = 0.38$, and $F(1, 109) = 72.9$, $MSE = 1.64$, respectively.

Generalizability across subjects. Figure 2 shows how the lab and online participants show similar effects for context variability and word frequency. Statistical analyses revealed no significant differences in d_a, *HR*s, and *FAR*s between the two groups. The large number of online participants also allowed us to take a closer look at subject differences within this group. Figure 3 plots distributions of *HR*s and *FAR*s, where each observation is a subject from the online group, averaged across items. The distributions are plotted for each of the four conditions separately. Figure 3 shows the typical mirror pattern: *HR* and *FAR* distributions coverage with increases in context variability and word frequency. It also shows that these changes are not due to a few atypical subjects. Therefore, the mirror effects associated with context variability and word frequency seem to generalize to a large population of subjects.

Generalizability across words. The words in the experiment were drawn from a relatively small pool of words, thus raising the question of whether the effects generalize to a larger population of items (cf. Clark, 1973). We performed word (F_2) analyses on the *HR*s and *FAR*s, in which each word is taken as an observation, averaged across subjects. Except for a marginal effect of context variability on *HR*s for the lab group, $F(1, 287) = 3.15$, $MSE = 0.09$, $p < .08$, all context variability and word frequency effects were significant for both the lab and online subjects. However, neither these F_2 analyses nor combinations of F_1 and F_2 analyses demonstrate that the effects generalize to all items (Raaijmakers, Schrijnemakers, & Gremmen, 1999). Instead, to verify that the effects are not dependent on a few atypical stimuli, Figure 3B shows the *HR* and *FAR* distributions for words, averaged across subjects. As can be observed, the mirror pattern for context variability and word frequency is not associated with changes in only the tails of the distributions. Instead, the histograms show that the majority of words contribute to the context variability and word frequency effects.

Generalizability across word frequency norms. To determine whether the context variability effect holds for a different measure of normative frequency, we performed post hoc statistical analyses on the data from a subset of the stimuli selected to balance normative word frequency according to Kučera and Francis (1967). Mean normative word frequencies were 9.3 (LF) and 79 (HF) for the low context variability groups and 10.4 (LF) and 88 (HF) for the high context variability groups. For this subset of data, low context variability words were better recognized than high context variability words. All statistical (F_1) analyses on d_a, false-alarm rates, and hit rates revealed the same significant differences as reported above except for a marginal effect of context variability on the hit rates for the lab participants, $F(1, 30) = 2.92$, $MSE =$

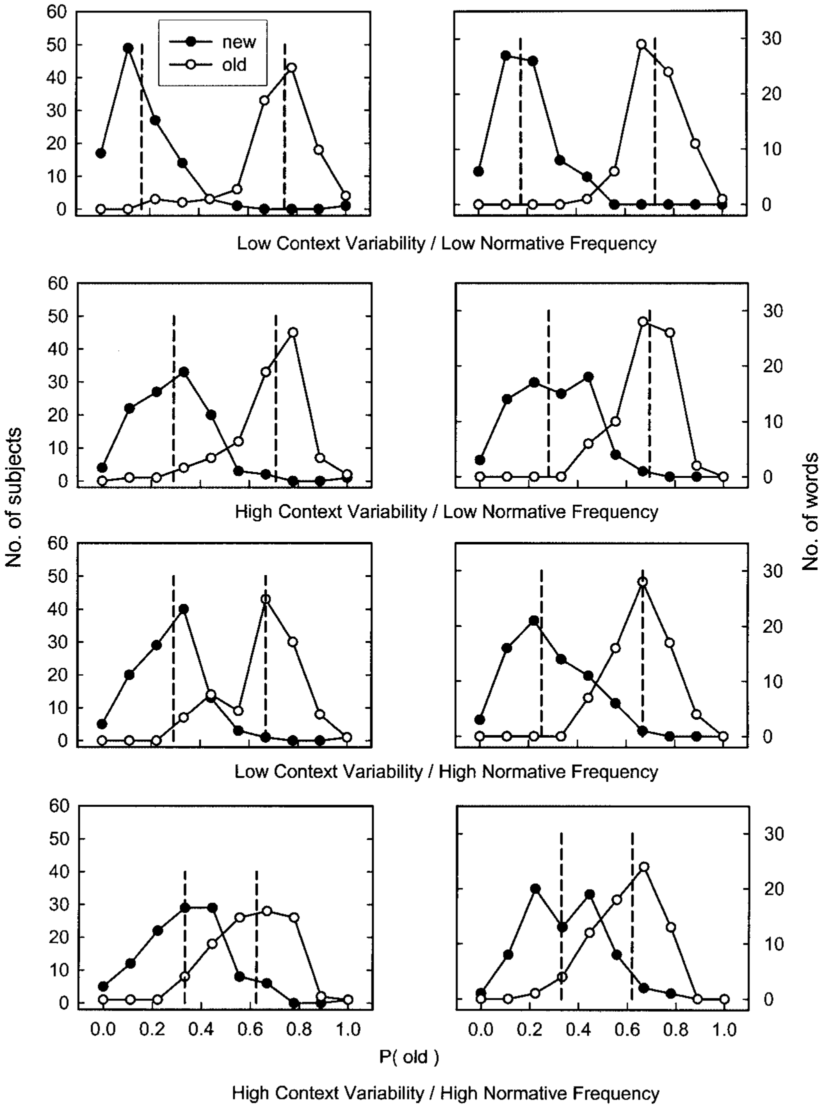

Figure 3. Histograms of hit and false-alarm rates across the four conditions. Left panels show the number of subjects, averaged across words. Right panels show the number of words, averaged across subjects. Dashed lines indicate the median of the distributions. All histograms were calculated for the group of online participants only. P(old) = probability of responding "old."

0.04, $p < .10$. This effect was significant, however, for the online participants, $F(1, 109) = 25.7$, $MSE = 0.35$, $p < .01$, suggesting that the marginal effect of context variability on *HR*s for lab subjects was due to the relatively small number of observations.

Discussion

Estes (1955) suggested shifting "the burden of explanation from hypothesized processes in the organism to statistical properties of environmental events" (p. 145). In this research, a statistical property of the environment (context variability) was identified and normatively quantified and was shown to affect recognition memory. Words that occur in many contexts are more difficult to recognize than words that occur in fewer contexts, confirming the prediction of the bind, cue, and decide memory model described by Dennis and Humphreys (2001).

In our experiment, context variability was operationally defined as an extra-list variable by analyzing word usage in a large corpus of text. Unlike other theories of episodic context (Estes, 1955; Mensink & Raaijmakers, 1988; Murnane et al., 1999), this conceptualization of the context used to perform episodic memory tasks assumes that item and context information are not independent; this proposal is consistent with the formal model described by Howard and Kahana (2002). According to our view, context is partly determined by the kind of words encountered in a situation, which in turn might lead to expectations for other words to occur in that context (see also Griffiths & Steyvers, in press); that is, context and item information are not independent sources of information. This characterization of context is not necessarily incompatible with other forms of possible contexts (cf. McGeoch, 1942), such as temporal, environmental, or physiological contexts, that are independent of the items encountered within them. Although additional research is required to identify the different dimensions on which context might vary and to tease apart their contributions to episodic memory, the present experiment suggests that low context variability words are better recognized than high context variability words.

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(*Appendix follows*)

Appendix

Words in the Four Conditions

Low Context Variability/Low Word Frequency

ABBOT
ALLIGATOR
BALLET
CACAO
CAESAR
CAMEL
CAPSULE
CARBURETOR
CARNIVAL
CARTILAGE
CASHIER
CHICK
COLT
CORTEX
CREDITOR
CROCODILE
DICTATION
DINOSAUR
ELECTROMAGNET
EMBRYO
EPIDERMIS
EQUITY
ESKIMO
FERMENTATION
FLASK
GLACIER
GUITAR
HABITAT
HEROIN
IMMUNITY
INCA
INTAKE
IODINE
ION
IRIS
MATRIX
MEMORANDUM
MOLE
MOOSE
MOTH
MUCUS
NICOTINE
OXIDATION
PENICILLIN
PHARAOH
PLASMA
POLO
POPCORN
PRISM
PROTON
PUDDING
PULLEY
PUPPET
QUANTUM
QUOTATION
RADIATOR
RECIPE
REHEARSAL
RETINA
SATURN
SEDIMENT
SHERIFF
SHOEMAKER
SOCCER
TAILOR
TORQUE
TUBING
TUNDRA
TURBINE
URINE
VALENCE
VECTOR

High Context Variability/Low Word Frequency

ABDOMEN
AGONY
AISLE
APRON
ATTACHMENT
ATTORNEY
BURIAL
CAFETERIA
CHAOS
CONJUNCTION
CONSPIRACY
CONSTRUCT
CONVENIENCE
CORRIDOR
CUPBOARD
DEALER
DIAGNOSIS
DISABILITY
DISPOSAL
DOMINANCE
DRIVEWAY
EMOTION
FACULTY
FARMLAND
FLEXIBILITY
GUIDANCE
GYM
HEARTH
HOBBY
ILLUSION
INDUSTRIALIZATION
INQUIRY
INTEGRATION
INVASION
INVITATION
MANIPULATION
MIRACLE
MONUMENT
NAVIGATION
NEUTRALITY
NOBILITY
NUISANCE
OBLIGATION
ODOR
ORCHARD
PARLOR
PERSUASION
PHILOSOPHER
PICKUP
POTTERY
PRAYER
PRESENTATION
PRESERVATION
PRIORITY
PUBLICATION
PUBLICITY
REALM
REBELLION
RELAXATION
RESTORATION
SENSATION
STRATEGY
SUMMIT
SURGEON
TALENT
TAVERN
TRADER
TRAGEDY
TRANSITION
UNDERSIDE
VIOLATION
WRIST

Low Context Variability/High Word Frequency

ALCOHOL
ATMOSPHERE
ATOM
BEHAVIOR
BIRD
BLOOD
CAR
CHILD
CHINA
CHRISTMAS
CLAY
CLIMATE
COLONY
COLUMN
COMMITTEE
COMPUTER
CONGRESS
CONSTITUTION
CUSTOMER
DAD
EDUCATION
ELECTRICITY
ELECTRON
ELEMENT
EMPEROR
EMPIRE
EMPLOYEE
EMPLOYER
ENTRY
ENVIRONMENT
EQUATOR
FIG
FOOD
FROG
GRANDFATHER
GRAVITY
HEALTH
HYDROGEN
INCOME
INSURANCE
JOURNAL
KING
LATIN
LEDGER
LION
MARRIAGE
MOLECULE
NUCLEUS
OCEAN
ORGANISM
OXYGEN
PERCENT
PLANET
POLICY
POND
POPULATION
PRINCE
PRODUCT
PROFESSOR
PROTEIN
RADIATION
REACTION
RIVER
SLAVERY
SOLUTION
TEMPERATURE
THEORY
TISSUE
TOPIC
TUBE
VERB
WOOL

High Context Variability/High Word Frequency

ABILITY
ACTION
ACTIVITY
ADDITION
AFTERNOON
APPEARANCE
AREA
ATTENTION
ATTITUDE
AUTHORITY
BASIS
BREATH
CENTURY
CHAPTER
CONDITION
DANGER
DAUGHTER
DEATH
DECISION
DEFENSE
DINNER
DIRT
ENEMY
EVENING
EVENT
EXPRESSION
FACT
GENERATION
HALL
HEIGHT
HISTORY
HOUR
IDEA
IMPORTANCE
INFLUENCE
JUSTICE
KITCHEN
KNOWLEDGE
LENGTH
LOCATION
LOSS
MAJORITY
MANNER
MEAL
MEMBER
MILE
MOMENT
MONTH
MORNING
NATURE
OPERATION
PATH
PERFORMANCE
PROTECTION
QUALITY
RELIGION
ROLE
SHIRT
SITUATION
SONG
SOURCE
STRENGTH
SUNLIGHT
TERRITORY
THING
TODAY
TRANSPORTATION
TRUTH
UNIVERSITY
VARIETY
WEALTH
YOUTH

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