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The Fleeting Effects of Retrieval Cue Attributes in the PIER2 Memory Model

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by

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Table of Contents

List of Tables

List of Figures

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ABSTRACT

Processing Implicit and Explicit Representations (PIER2) is a model of memory that makes predictions about memory performance based on the interaction of known and newly acquired information by studying how implicitly activated associates affect episodic memory. Nelson and Zhang (2000) found a significant effect of cue connectivity in a multiple regression analysis of the variables known to affect cued recall, but at that time no manipulational experiments had studied the cue connectivity effect in the laboratory. The present paper presents a series of three experiments designed to investigate the effect of cue connectivity in the context of the PIER2 memory model to determine the importance of this variable in the prediction of cued recall. Results of the experiments were inconsistent, and a revised regression analysis performed on an updated version of Nelson and Zhang's (2000) cued recall database indicated that cue connectivity was no longer a significant predictor of cued recall performance. It was concluded that PIER2's equations do not need to be modified to include the influence of retrieval cue attributes.

Chapter One

Introduction

Processing Implicit and Explicit Representations (PIER2) is a memory model that predicts cued recall based on the relationship between to-be-remembered target words and the words that serve to "cue" memory for the studied targets (Nelson, McKinney, Gee & Janczura, 1998). This model seeks to explain the interaction between known and newly acquired information by studying how implicitly activated associates affect episodic memory. PIER2 is based on the premise that pre-existing word knowledge can be likened to an associative map of our mental lexicon, with particular emphasis on the associations between related words. The model assumes that these associative connections are implicitly activated upon experiencing a given word, and they are implicated in the successful recall of studied targets (Nelson et al., 1998).

The study of the interaction of known and new information requires knowledge of pre-existing connections between studied targets and the related words that are used as retrieval cues (Bahrick, 1970). Free association is an effective method of assessing prior word knowledge for predicting cued recall performance. In this task, participants are asked to produce the first meaningfully related word that comes to mind when presented with a given word. As more people reply with a particular response to a given cue, the presumed "strength" between the cue and that response increases. Recent free association norms provide a useful metric of the strength of the relationship between over

72,000 cue-target pairs (Nelson, McEvoy & Schreiber, 1999), and they predict 49% of the variance in the extra-list cued recall task when task reliability is taken into account (Nelson & Zhang, 2000).

As a model of cued recall, PIER2 makes specific predictions about the likelihood that a studied target will be recalled when memory is prompted with an associatively related cue. Such associations can involve direct links between the cue and target (forward and backward); indirect links between the cue and target (mediated and shared associate links); or links involving the associates of the cue or target words (connectivity and set size) (Nelson & McEvoy, in press; Nelson et al., 1998). Forward cue-to-target strength represents the likelihood that a given target is produced by a cue in free association norms; it can be considered an estimate of the probability that a given target will be produced in the absence of study. Backward target-to-cue strength refers to the probability that a given target will produce the cue in the absence of study, again measured by free association norms. Cue-target pairs can have forward strength, backward strength, or both, and these variables can be manipulated factorially. High levels of both forward and backward strength facilitate cued recall performance, with the greatest number of words correctly recalled when both of these direct connection strengths are high (Humphreys & Galbraith, 1975; Nelson et al., 1998).

Cue-target pairs may also be related through indirect connections. This type of connection is present when the two words are related through their connection with other words. Mediated connections refer to word pairs that are related through another word that is produced by the cue, which itself produces the target, e.g., UNIVERSE produces

SPACE which produces PLANET. Shared associate connections arise when both the target and the test cue produce a given associate, e.g., the cue UNIVERSE produces STAR as an associate, and the target PLANET also produces STAR as an associate. PIER2 predicts that greater levels of these indirect connection strengths help to bind the word pair together as a unit and facilitate cued recall performance, with higher levels of connection strength leading to the best recall. Figure 1 illustrates these four types of direct and indirect connections.

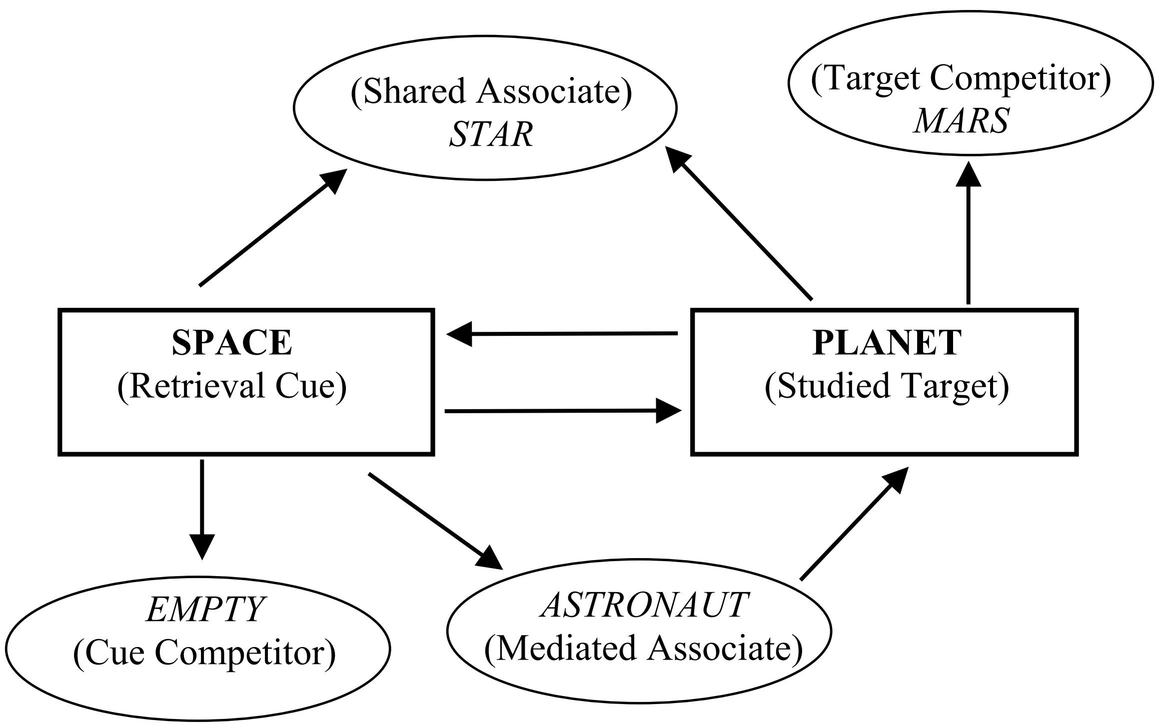

Figure 1. Direct and indirect linking connections described by the PIER2 memory model

As illustrated in Figure 2, target connectivity refers to the degree that the associates produced by the target are connected to each other. It is measured as the average number of links connecting the associates in the target's set. The more links there are amongst a target's associates, the greater the probability of correct recall (Nelson et al., 1998). Another associative feature, target set size, refers to the number of associates the target produces in free association. The fewer items in a targets' set, the more likely it is that the target will be correctly recalled (Nelson, McEvoy, Janczura & Xu, 1993; Nelson et al., 1998).

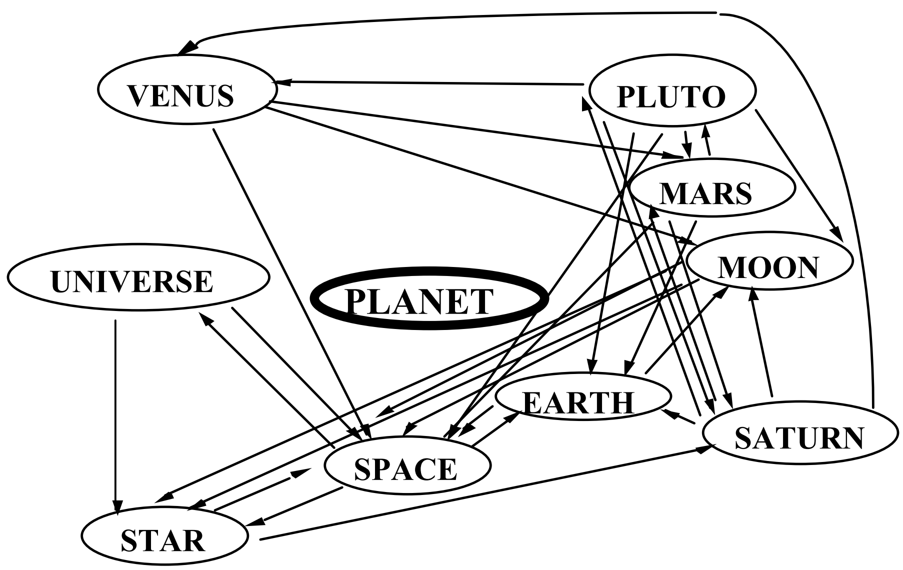

Figure 2. Connectivity among PLANET's associates

Nelson and Zhang (2000) performed a multiple regression analysis on 2,272 cue-target word pairs from 29 cued recall experiments from their laboratory. The purpose of this study was to determine which variables could be used to predict cued recall performance. When statistically controlling for correlated features, the simultaneous multiple regression analysis indicated that the following ten variables contributed significantly to predictability: forward cue-to-target strength, backward target-to-cue strength, shared associate strength, mediated associate strength, target connectivity, target set size, printed target frequency (per one million words), target concreteness (rated on a scale of 1 to 7), cue set size, and cue connectivity. As can be seen, this analysis encompasses all six features described above, along with two more target characteristics, and two cue characteristics. Cue set size refers to the number of associates that the cue produces in free association. Both cue and target set size vary independently and have similar effects on cued recall. Namely, the fewer associates a word has, the better remembered it is as a target word and the better it is as a test cue. Cue connectivity, similar to target connectivity, is a measure of the connectedness of the cue's associates. According to the findings of Nelson and Zhang (2000), greater connectivity among the associates of the cue should result in higher rates of recall. It is important to note here that each of these variables contributed significant predictability in the regression equation, even though the features were sometimes correlated in the overall free association database from which the word pairs were drawn (Nelson & Zhang, 2000). Because multiple regression procedures adjust for these correlations, analysis of the standardized beta weights estimates the independent contribution of each variable to cued recall performance.

Although cue connectivity exhibited significant effects in the regression analysis, specific findings were not considered, because at that time no experiments had been completed that manipulated this feature under controlled conditions. PIER2 makes no specific predictions about cue connectivity, and by its silence one would assume that the model would predict a null result. The present series of experiments seeks to examine this apparent contradiction between theory and data, and to determine the importance of cue connectivity in the prediction of cued recall performance. We will examine the effect of cue connectivity in controlled experiments, to determine whether the results of the regression will hold up under carefully manipulated experimental conditions.

A series of three experiments examined the relative contribution of cue connectivity to cued recall performance. In each case, cue connectivity was manipulated with a second variable of interest, whose effects have been previously demonstrated, serving as a manipulation check on the materials. According to PIER2's predictions, no cue connectivity effect was expected. The first experiment crossed cue connectivity and cue set size, where it was expected that cues with smaller sets would best facilitate recall performance. This hypothesis follows directly from the results of the Nelson & Zhang (2000) regression analysis. The next experiment crossed cue connectivity and target connectivity. Again, based on the results of the multiple regression, it was predicted that recall would be best when the targets came from densely associated sets. Finally, the third experiment crossed cue connectivity and cue resonance. As shown in Figure 3, high levels of cue resonance indicate that a cue has a high likelihood of being produced by its associates.

It is known from numerous experimental studies that high levels of target resonance facilitate cued recall performance, and these effects do not interact with target connectivity (Nelson, McEvoy & Pointer, 2003; Nelson et al., 1998). Theoretically, experiencing a word automatically activates numerous implicit connections to, from, and among its associates. In PIER2, all of these connection strengths add up to increase the accessibility of a studied target, thus contributing to the likelihood that it will be recovered at test.

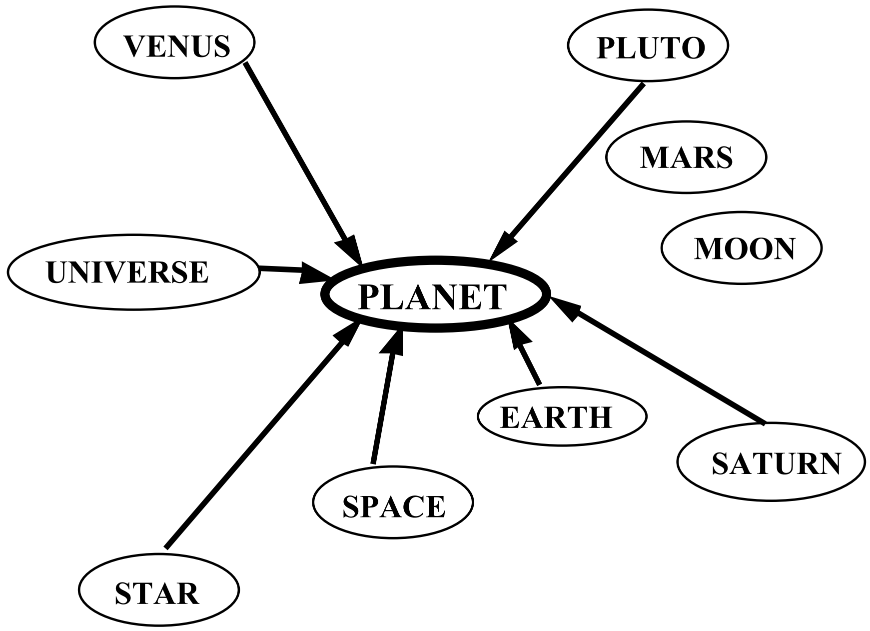

Figure 3. Resonant links to PLANET

It is important to note that each of the connection strengths contribute independently to total target activation, regardless of whether the activation produced by return links to the target via resonant connections. As such, resonant connections increase target activation by adding their activation strengths to the other implicitly activated links. All of these implicit connections produce greater total activation, which facilitates cued recall performance due to greater target accessibility (Nelson et al., 2003). Thus, high levels of cue resonance may mimic the beneficial effects of target resonance on cued recall performance.

However, Rundus (1973) presents evidence that may indicate a negative effect of cue resonance. Rundus found that presenting part of a free recall list as recall cues for the other items on the list impaired individuals' ability to remember the rest of the items on the list. As the number of items presented as retrieval cues increased, participants' free recall performance for the rest of the items decreased. Rundus suggests this may be due to participants repeatedly sampling the given retrieval cues, which may block access to the rest of the items from the list (1973). These findings may have implications for the effects of cue resonance on cued recall performance. When cue resonance is high, a large proportion of a cue's associates have connections directed back toward the cue. Theoretically, the test cue may activate both the connections to its associates, and connections from the associates back toward the cue. Resonant links may increase the probability of repeatedly sampling the cue itself rather than one of its associates. Given these differing assumptions about the relationship between resonant connections and recall performance, the results of manipulating cue resonance were indeterminate. High levels of cue resonance may mimic the positive effects of target resonance, or it may result in an inhibition effect that decreases the efficiency of that cue as a retrieval aid. Thus, the effect of cue resonance in Experiment 3 cannot be predicted with any certainty

.

Chapter Two

General Method

Design and Participants

A series of three experiments examined the effect of cue connectivity and three separate variables of interest on cued recall performance. Each experiment formed a 2 x 2 within-subjects factorial. Experiment 1 contrasted cue connectivity (high, low) with cue set size (small, large). Experiment 2 examined the effects of cue connectivity (high, low) and target connectivity (high, low), and Experiment 3 contrasted cue connectivity (high, low) with the probability of resonant connections back to the cue (high, low). A total of one hundred-ten undergraduate students (30 in Experiment 1, 40 each in Experiments 2 and 3) participated in the experiments in exchange for extra credit points. Participants ranged in age from 18 to 53, with a median age of 20. One participant's age was not reported. Eighty-eight percent of the participants were female, and 12% were male. The ethnic make-up of the participant pool was 61.8% Caucasian, 13.6% African American, 11.8% Hispanic, 6.4% Asian, and 6.4% "other." Each participant in every experiment was randomly assigned to one of two separate lists.

Procedure

Participants were run in individual sessions. All three experiments utilized intentional learning instructions that directed the participant to read aloud a list of words and to remember as many of the words as possible for a subsequent memory test, without being told how they would be tested. All experimental stimuli were presented in uppercase letters in the center of a Macintosh computer screen. After a short practice phase to acclimate the participants to the rate of presentation, the 24 targets for the assigned list were randomly presented for each participant at 3s each. At test, participants were informed that they would now see a series of meaningfully related words to cue their memory for the words that they just studied. Each cue was presented on the computer screen one at a time, and participants were required to read the cue aloud, and then attempt to produce the studied word that is meaningfully related to that cue. If they were unable to produce a studied word, they were allowed to guess any word that is related to the presented cue. This phase of the experiment was self-paced, and the presentation of the cues was randomized for each participant.

Materials

The experimental lists for each experiment are located in Appendix A. Twenty-four cue-target pairs were chosen for each of the lists in each experiment using a free association database (Nelson et al., 1999). Each list was carefully constructed to ensure that there were no known direct connections and less than 3 measured indirect connections between any of the items except a cue and its intended target by using the *ListChecker* program (Schreiber, 1993). See Table 1 for a comparison of all experimental conditions for each of the experiments.

Table 1

Mean and standard deviation values for all experimental manipulations in each experiment.

High Cue Connectivity				
Experiment 1	Small Cue Set Size		Large Cue Set Size	
	Mean	*SD*	Mean	*SD*
Cue Connectivity	3.26	*(.49)*	2.94	*(.11)*
Cue Set Size	7.67	*(.52)*	20.17	*(2.09)*
Experiment 2	High Target Connectivity		Low Target Connectivity	
	Mean	*SD*	Mean	*SD*
Cue Connectivity	3.33	*(.27)*	3.05	*(.23)*
Target Connectivity	2.95	*(.40)*	.55	*(.15)*
Experiment 3	High Cue Resonance		Low Cue Resonance	
	Mean	*SD*	Mean	*SD*
Cue Connectivity	3.32	*(.39)*	3.03	*(.12)*
Cue Resonance	.78	*(.05)*	.11	*(.05)*

Low Cue Connectivity				
Experiment 1	Small Cue Set Size		Large Cue Set Size	
	Mean	*SD*	Mean	*SD*
Cue Connectivity	.56	*(.21)*	.62	*(.12)*
Cue Set Size	6.59	*(1.03)*	18.00	*(.00)*
Experiment 2	High Target Connectivity		Low Target Connectivity	
	Mean	*SD*	Mean	*SD*
Cue Connectivity	.62	*(.15)*	.66	*(.10)*
Target Connectivity	2.75	*(.24)*	.66	*(.09)*
Experiment 3	High Cue Resonance		Low Cue Resonance	
	Mean	*SD*	Mean	*SD*
Cue Connectivity	.64	*(.11)*	.67	*(.09)*
Cue Resonance	.74	*(.04)*	.10	*(.08)*

Experiment 1.

Experiment 1 contrasted high and low levels of cue connectivity with small and large values of cue set size. Cue connectivity averaged 3.10 connections per associate (*SD* = .30) when high, and .59 (*SD* = .16) when low. Cue set size averaged 7.13 (*SD* = .78) when small, and 19.09 (*SD* = 1.04) when large. Additionally, other variables that are known to affect cued recall were held constant. Across all experimental conditions, target set size averaged 14.50 (*SD* = 4.50), target frequency averaged 59.13 (*SD* = 42.32) per million words, and target concreteness averaged 5.14 (*SD* = 1.11). All of the cues had a weak cue-to-target forward strength (*M* = .10, *SD* = .03) and a low level of target-to-cue backward strength (*M* = .02, *SD* = .02). The strengths of indirect connections, such as shared associate strength (*M* = .02, *SD* = .02) and mediated associate strength (*M* = .02, *SD* = .02), were also kept constant in each of the lists.

Experiment 2.

Experiment 2 contrasted high and low levels of cue connectivity with high and low levels of target connectivity. Cue connectivity averaged 3.19 (*SD* = .25) when high, and .64 (*SD* = .13) when low. Target connectivity averaged 2.85 (*SD* = .32) when high, and .60 (*SD* = .12) when low. Across all experimental conditions, cue set size averaged 15.42 (*SD* = 4.10), target set size averaged 13.67 (*SD* = 5.46), target frequency averaged 70.69 (*SD* = 75.95) per million words, and target concreteness averaged 4.87 (*SD* = 1.57). All of the cues had relatively weak cue-to-target forward strength (*M* = .08, *SD* = .03) and a low level of target-to-cue backward strength (*M* = .01, *SD* = .02). The strengths of indirect connections, such as shared associate strength (*M* = .02, *SD* = .02) and mediated associate strength (*M* = .02, *SD* = .02), were also kept constant in each of the lists.

Experiment 3.

Experiment 3 contrasted high and low levels of cue connectivity with high and low levels of cue resonance. Cue connectivity averaged 3.17 (*SD* = .25) when high, and .66 (*SD* = .10) when low. Cue resonance averaged .76 (*SD* = .05) when high, and .11 (*SD* = .07) when low. Across all experimental conditions, cue set size averaged 11.82 (*SD* = 4.26), target set size averaged 15.13 (*SD* = 4.17), target frequency averaged 75.17 (*SD* = 92.10) per million words, and target concreteness averaged 5.04 (*SD* = 1.30). All of the cues had a moderate cue-to-target forward strength (*M* = .11, *SD* = .05) and a low level of target-to-cue backward strength (*M* = .04, *SD* = .04). The strengths of indirect connections, such as shared associate strength (*M* = .05, *SD* = .05) and mediated associate strength (*M* = .03, *SD* = .03), were also kept constant in each of the lists.

Chapter Three

Results

Analyses of Variance

Experiment 1.

The probability of correct recall of the target as a function of cue connectivity and cue set size is shown in Figure 4.

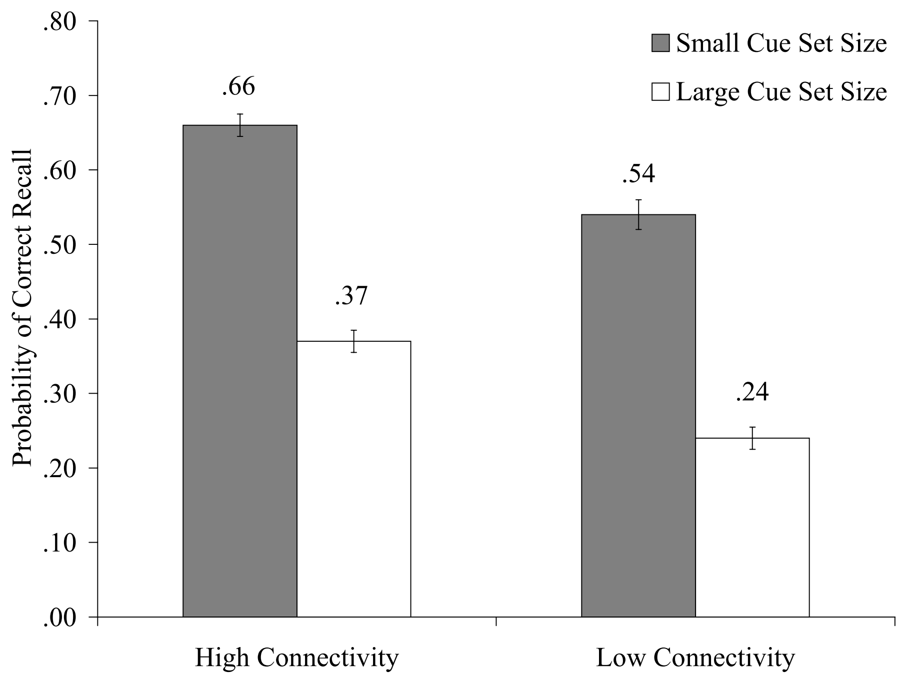

Figure 4. . Probability of cued recall as a function of cue connectivity and cue set size

A two-factor analysis of variance (ANOVA) confirmed the hypothesis of significant main effects of both variables on probability of correct recall. The effect of cue connectivity, $F(1, 29) = 14.73$, $MS_e = .03$, indicated that the probability of correct recall was greater when cues had densely connected sets ($M = .51$, $SD = .22$) than when cues had more sparsely connected sets ($M = .39$, $SD = .23$). There was also an effect of cue set size, $F(1,29) = 169.32$, $MS_e = .02$, indicating that targets cued with words from small sets were more likely to be recalled ($M = .60$, $SD = .18$) than targets that were cued with words having larger sets ($M = .30$, $SD = .18$). The interaction between cue connectivity and cue set size was not significant, $F < 1$.

Experiment 2.

As shown in Figure 5, the second experiment did not replicate the findings of Experiment 1. In Experiment 2, the cue connectivity effect was not significant ($F < 1$). As expected, the target connectivity effect was significant, $F(1,39) = 79.86$, $MS_e = .03$. Targets with more densely connected sets were recalled more often ($M = .60$, $SD = .20$) than targets with more sparsely connected sets ($M = .37$, $SD = .19$). There was also a significant cue connectivity by target connectivity interaction, $F(1,39) = 6.53$, $MS_e = .03$, indicating a greater effect of target connectivity when cue connectivity was high (30% mean difference) than when cue connectivity was low (15% mean difference).

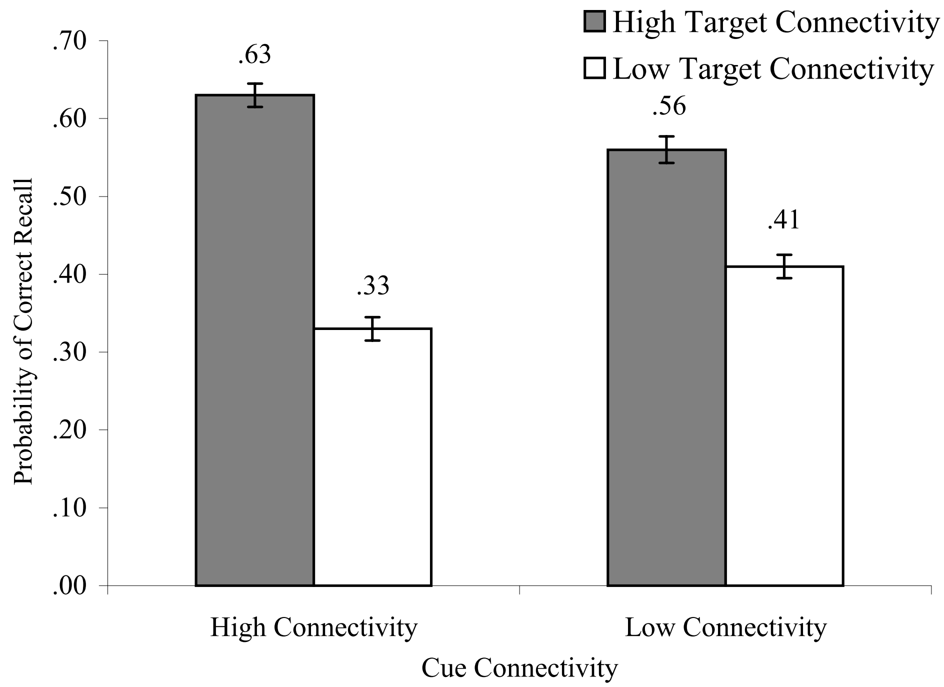

Figure 5. Probability of correct recall as a function of cue connectivity and target connectivity

Experiment 3.

The results of Experiment 3 indicate significant main effects of cue connectivity, $F(1,39) = 6.72$, $MS_e = .04$, and cue resonance, $F(1,39) = 19.87$, $MS_e = .03$, as well as a significant interaction, $F(1,39) = 6.77$, $MS_e = .04$. In general, targets that were cued with words having densely connected sets were recalled more often ($M = .60$, $SD = .22$) than targets that were cued with words having more sparsely connected sets ($M = .51$, $SD = .22$). Also, targets that were cued with words having fewer resonant connections were better recalled ($M = .61$, $SD = .21$) than those cued with words having many resonant connections ($M = .50$, $SD = .23$). This finding is in direct contrast to the usual findings of a beneficial effect of high levels of target resonance on probability of correct recall and supports Rundus' (1973) assertion of an inhibitory effect produced by high levels of resonance. Each of these main effects was modulated, however, by the effect of the other manipulated variable. As shown in Figure 6, high cue connectivity benefited recall only when cue resonance was low. Similarly, low cue resonance benefited recall only when cue connectivity was high. An LSD of .12 indicated that the effect of cue resonance was evident only at high levels of cue connectivity (19% mean difference). When cue connectivity was low, there was no significant difference (3% mean difference) in cued recall performance between low and high levels of cue resonance.

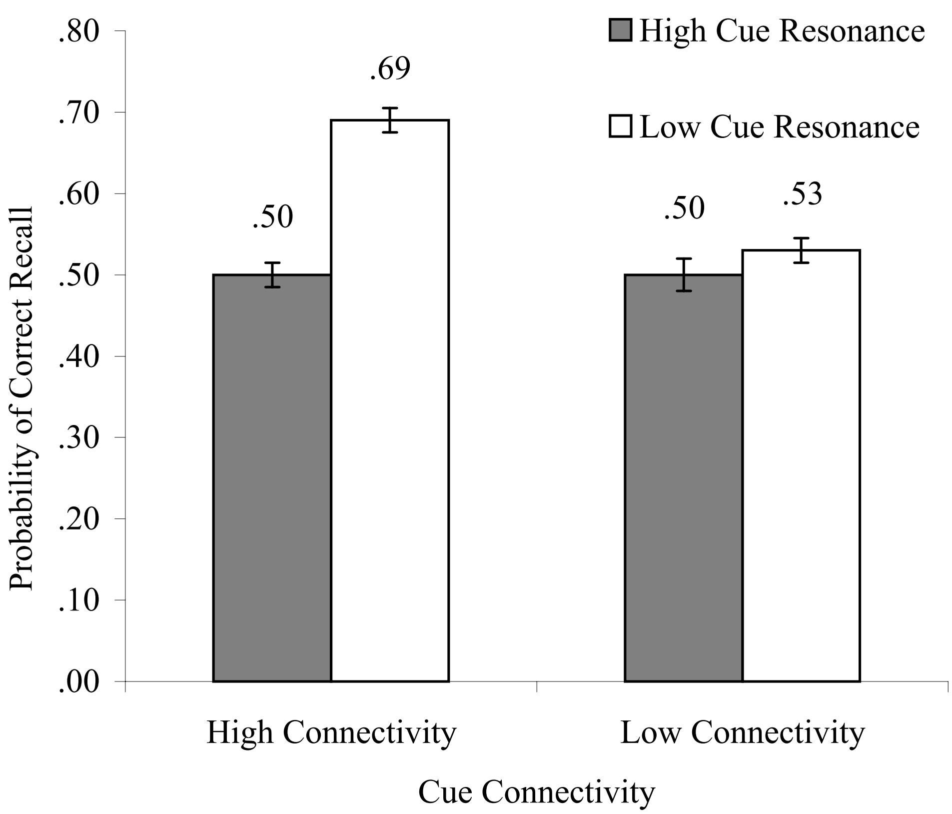

Figure 6. Probability of correct recall as a function of cue connectivity and cue resonance

Regression Analyses

Overall, this series of experiments produced disparate effects of cue connectivity, both as a main effect and as it interacted with other variables of interest, that indicate this variable may contribute inconsistently to cued recall performance. In addition, cue set size and target connectivity effects were replicated, but cue resonance was shown to have the opposite of the beneficial effect of target resonance. In order to more closely examine the relationship between these and other variables that may have contributed to these results, a simultaneous multiple regression analysis was run on the pooled data from the combined experiments.

Many of the variables that affect cued recall are weakly correlated with each other in such a way that it is difficult to determine whether the observed effects are due to the experimental manipulations, or if they arise out of the correlations with other variables (Nelson & Zhang, 2000). The multiple regression procedure is commonly used to control correlational relationships between naturally correlated variables statistically. Each experimental list was designed to manipulate only the specified variables of interest, and to hold constant the average values of those other variables that are known to affect cued recall. However, there may have been enough variability within the controlled variables to produce unintended correlations. By switching the level of analysis to the item level, we can examine and control these potential relationships.

Table 2 presents the standardized betas and standard errors for the experimental variables of interest. Taken together, the 11 variables entered into the regression equation explained 37% of the variance in cued recall, $R = .65$, $F(11, 132) = 8.55$, MS_{res}

= .04. The variables included in the regression analysis were the 9 of the 10 variables shown to affect cued recall performance in Nelson and Zhang (2000), and the two other cue characteristic variables that were manipulated in this series of experiments. Although Nelson and Zhang (2000) found that target concreteness was a significant predictor of cued recall performance, it was not included in the present analyses because it decreased the number of items used in the regression analyses with little change to the outcome.

Table 2

Multiple regression of feature variables as predictors cued recall across all experiments that manipulated cue connectivity.

	Statistics	
	$F(11, 132) = 8.55$ Adjusted $R^2 = .37$	
Feature Variables	Standardized β	Standard Error
Cue Connectivity	.22*	(.015)
Cue Resonance	-.26*	(.083)
Cue Set Size	-.28*	(.004)
Target Set Size	-.17*	(.003)
Target Frequency	-.09	(.031)
Target Connectivity	.31*	(.022)
Target Resonance	-.05	(.088)
Forward Strength	.17*	(.392)
Backward Strength	.26*	(.523)
Shared Associate Strength	.07	(.429)
Mediated Associate Strength	.05	(.563)

Note: Target Frequency = [log (.5+Target Frequency)]; Target Frequency was transformed to a logarithmic scale to achieve normalcy; * denotes significance at the α = .05 level.

Seven of the eleven variables proved to be significant predictors of cued recall: cue connectivity (standardized $\beta = .22$, $t = 2.56$); cue resonance (standardized $\beta = -.26$, $t = -2.87$); cue set size (standardized $\beta = -.28$, $t = -2.96$); target set size (standardized $\beta = -.17$, $t = -2.13$); target connectivity (standardized $\beta = .31$, $t = 3.64$); forward cue-to-target strength (standardized $\beta = .17$, $t = 2.41$); and backward target-to-cue strength (standardized $\beta = .26$, $t = 2.90$). Analysis of the zero-order and partial correlations in Table 3 did not indicate any unexpected relationships between these variables. Cue resonance is correlated with backward strength ($r = .56$, $pr = .60$), but this relationship was anticipated because the backward target-to-cue associative link is one of the links that determines the probability of a resonant connection to the cue from its associates. Target frequency, target resonance, shared associate strength, and mediated associate strength were not significant predictors of cued recall performance in this analysis (largest $t = -1.18$).

Although the *strength* of shared associates and mediated associates was carefully controlled when constructing the experimental lists, during the analysis of the experimental data it was discovered that cue connectivity was unintentionally confounded with both the *number* of shared associates ($r = .62$) and the *number* of mediated associates ($r = .64$). In order to determine the effect of this confounding on the results, a second multiple regression analysis was conducted that substituted the number of shared associates and the number of mediated associates as potential predictors of cued recall in place of the corresponding strength measures. According to this new regression equation, these variables explain 38% of the variance in cued recall, $R = .65$, $F(11, 132) = 8.96$,

Table 3

Zero-order and partial correlations of feature variables across all experiments that manipulated cue connectivity

	QCONN	QRESO	QSS	TSS	TFREQ	TCONN	TRESO	FSG	BSG	SASG	MSG	*P*(Rc)
QCONN	---	.35	.47	-.28	.06	.35	.08	-.02	-.30	-.01	.04	.22
QRESO	-.01	---	-.42	.14	.04	-.17	.05	-.12	.60	.06	.02	-.24
QSS	.35	-.36	---	.10	-.03	-.20	.01	-.18	.13	-.17	-.28	-.25
TSS	-.14	-.04	-.02	---	.17	.51	-.22	.12	-.14	-.16	.05	-.18
TFREQ	.06	.11	.07	.19	---	-.16	.41	.06	-.01	-.17	.13	-.10
TCONN	.22	-.07	-.19	.32	-.05	---	.22	-.11	.09	.14	-.03	.30
TRESO	.21	.12	-.05	-.08	.40	.18	---	.05	.02	-.10	.17	-.05
FSG	-.13	.00	-.27	.11	-.04	.09	-.02	---	.08	-.01	-.01	.21
BSG	-.19	.57	-.24	-.13	-.03	-.03	.00	.12	---	.04	-.25	.25
SASG	-.06	.15	-.38	-.13	-.28	.20	-.09	.08	.13	---	.22	.07
MSG	.02	.05	-.38	.04	.13	.16	.20	.07	-.19	.27	---	.06
P(Rc)	.10	-.05	-.29	-.13	-.20	.38	.04	.29	.18	.29	.17	---

Note: Zero-order correlations are shown below the diagonal; partial correlations are shown above the diagonal. QCONN is Cue Connectivity, QRESO is Cue Resonance, QSS is Cue Set Size, TSS is Target Set Size, TFREQ is [log (.5+Target Frequency)], TCONN is Target Connectivity, TRESO is Target Resonance, FSG is Forward Strength, BSG is Backward Strength, SASG is Shared Associate Strength, MSG is Mediated Associate Strength, and *P*(Rc) is Probability of Correct Recall.

MS_{res} = .034. In this regression equation, the significant predictors of cued recall were cue resonance, cue set size, target set size, target connectivity, forward cue-to-target strength, backward target-to-cue strength, and *number* of shared associates. Table 4 shows the standardized betas and standard errors for each of the variables in the revised regression equation.

Table 4

Multiple regression substituting number of shared associates and mediated associates as predictors of cued recall across all experiments that manipulated cue connectivity.

	Statistics	
	F(11, 132)	8.96
	Adjusted R^2	.38
Feature Variables	Standardized β	Standard Error
Cue Connectivity	.13	(.021)
Cue Resonance	-.23*	(.084)
Cue Set Size	-.33*	(.003)
Target Set Size	-.19*	(.003)
Target Frequency	-.07	(.031)
Target Connectivity	.22*	(.025)
Target Resonance	.01	(.092)
Forward Strength	.17*	(.388)
Backward Strength	.20*	(.516)
# of Shared Associates	.24*	(.014)
# of Mediated Associates	-.06	(.010)

Note: Target Frequency = [log (.5+Target Frequency)]; Target Frequency was transformed to a logarithmic scale to achieve normalcy; * denotes significance at the α = .05 level.

Also, Table 5 presents the zero-order and partial correlations among the variables. In this analysis, cue connectivity is moderately correlated with number of shared associates (r = .62, pr = .42) and with cue resonance (r = .01, pr = .32), and target connectivity is correlated with number of shared associates (r = .61, pr = .47). These correlations indicate that controlling the means and variance estimates in the individual experiments was an insufficient method for controlling correlations among the feature variables in the aggregated data. It is important to note here that although cue connectivity, the original variable of interest, was a significant predictor of cued recall when the *strength* measures of shared associates and mediated associates were utilized in the regression equation, it was *not* a significant predictor when the corresponding *number* measures of shared and mediated associates were used.

Finally, since the publication of Nelson and Zhang (2000), the results of seven new experiments (including Experiment 1 from the present series) have been added to the cued recall database, bringing the total number of experiments to 36. This revised database was analyzed with a regression equation using cue connectivity, cue resonance, target connectivity, target resonance, target frequency, forward strength, backward strength, number of shared associates, and number of mediated associates, as well as two new variables - number of cue competitors and number of target competitors - as the predictor variables. Cue and target competitors are unique associates of the respective cue and target that do not link to the other member of the word pair. These competitor variables are subsets of cue and target set sizes, respectively, which have been adjusted to account for a single backward target-to-cue associative link, the number of shared

Table 5

Zero-order and partial correlations of manipulated variables substituting number of shared associates and mediated associates

	QCONN	QRESO	QSS	TSS	TFREQ	TCONN	TRESO	FSG	BSG	# SA	# MED	*P*(Rc)
QCONN	---	.32	.34	-.35	.03	.04	.07	-.02	-.29	.42	.41	.10
QRESO	-.01	---	-.46	.15	.02	-.09	.02	-.12	.62	-.12	.00	-.21
QSS	.35	-.36	---	.12	-.01	-.26	.01	-.18	.20	.11	-.06	-.32
TSS	-.14	-.04	-.02	---	.19	.37	-.20	.11	-.17	.12	.16	-.21
TFREQ	.06	.11	.07	.19	---	-.10	.36	.05	-.01	-.13	.16	-.08
TCONN	.22	-.07	-.19	.32	-.05	---	.31	-.09	.00	.47	-.12	.19
TRESO	.21	.12	-.05	-.08	.40	.18	---	.04	.03	-.28	.26	.01
FSG	-.13	.00	-.27	.11	-.04	.09	-.02	---	.08	-.01	.03	.21
BSG	-.19	.57	-.24	-.13	-.03	-.03	.00	.12	---	.18	-.09	.20
# SA	.59	-.14	.15	.14	-.13	.58	-.04	.00	-.05	---	.23	.17
# MED	.65	-.02	.20	.09	.21	.24	.31	-.06	-.18	.48	---	-.06
P(Rc)	.10	-.05	-.29	-.13	-.20	.38	.04	.29	.18	.34	.05	---

Note: Zero-order correlations are shown below the diagonal; partial correlations are shown above the diagonal. QCONN is Cue Connectivity, QRESO is Cue Resonance, QSS is Cue Set Size, TSS is Target Set Size, TFREQ is [log (.5+Target Frequency)], TCONN is Target Connectivity, TRESO is Target Resonance, FSG is Forward Strength, BSG is Backward Strength, # SA is Number of Shared Associates, # MED is Number of Mediated Associates, and *P*(Rc) is Probability of Correct Recall.

associates, and the number of mediated associates. The competitor values generate "noise" that decreases the probability of cued recall when factored into the denominator of PIER2's Equation 3 (Nelson & McEvoy, 2003). This new regression equation explains 38% of the total variance in cued recall performance, $R = .62$, $F(11, 3074) = 171.55$, $MS_{res} = .044$. When this number is corrected for reliability, the proportion of variance explained goes up to 60%[1]. Contrary to the results of Nelson and Zhang (2000), cue connectivity is no longer a significant predictor of cued recall performance in this revised regression analysis (standardized $\beta = .01$, $t < 1$), though each of the other variables were significant predictors. See Table 6 for the standardized betas and standard errors for each of the variables in this regression equation. Table 6 also includes estimates of the amount of variance explained by each of the feature variables. We now have an inconsistent effect of cue connectivity both in the series of experiments in which it was manipulated, as well as a null effect in a global database of many experiments conducted in our lab in the past decade. Importantly, as shown in Table 7, there are no *unexpected* zero-order or partial correlations between the feature variables. Although cue connectivity is correlated with number of shared associates ($r = .54$, $pr = .31$) and number of mediated associates ($r = .46$, $pr = .34$), it is only weakly correlated with the probability of correct recall ($r = .12$, $pr = .01$), indicating that any variance explained by cue connectivity is mostly taken up by its relationship with the number of shared and mediated associates. The additional data points in the revised database, which now

[1] Following Nelson and Zhang (2000), the true correlation between free association and cued recall was computed as $r_{X'Y'} = \dfrac{r_{XY}}{\sqrt{r_{XX}}\sqrt{r_{YY}}}$

Table 6

Multiple regression analysis of 36 experiments in revised cued recall database

Feature Variables	Standardized β	Standard Error	% Variance Explained
		Statistics	
		$F(11, 3074) = 171.55$ Adjusted $R^2 = .38$	
Cue Connectivity	.01	(.007)	.00%
Target Connectivity	.08*	(.005)	.90%
Cue Resonance	-.06*	(.020)	.30%
Target Resonance	.10*	(.021)	.20%
Target Frequency	-.13*	(.006)	1.40%
Forward Strength	.36*	(.034)	20.30%
Backward Strength	.19*	(.027)	1.80%
# of Shared Associates	.05*	(.003)	.10%
# of Mediated Associates	.11*	(.003)	1.80%
# Cue Competitors	-.16*	(.001)	2.80%
# Target Competitors	-.17*	(.001)	8.20%

Note: Target Frequency = [log (.5+Target Frequency)]; Target Frequency was transformed to a logarithmic scale to achieve normalcy; * denotes significance at the $\alpha = .05$ level.

Table 7

Zero-order and partial correlations of feature variables from 36 experiments in revised cued recall database

	QCONN	QRESO	Q#CMP	T#CMP	TFREQ	TCONN	TRESO	FSG	BSG	# SA	# MED	*P*(Rc)
QCONN	---	.01	.08	-.11	-.06	.13	-.03	-.12	-.10	.31	.34	.01
QRESO	-.02	---	-.21	-.02	.00	.13	.15	-.22	.46	-.14	.07	-.06
Q#CMP	-.11	-.08	---	.08	-.01	-.04	.03	-.18	.23	-.10	-.10	-.18
T#CMP	-.11	-.18	.08	---	.23	.28	-.29	.11	-.25	-.19	.11	-.17
TFREQ	-.02	-.05	-.08	.27	---	-.05	.23	.10	-.10	-.04	.17	-.14
TCONN	.35	.04	-.13	.15	-.02	---	.13	-.09	-.05	.44	-.12	.08
TRESO	.06	.15	-.17	-.18	.32	-.01	---	.14	-.12	-.34	.42	.10
FSG	-.04	-.14	-.30	-.02	.15	-.03	.26	---	.10	.04	.06	.38
BSG	-.12	.44	.13	-.36	-.28	-.09	-.08	-.02	---	.06	-.09	.18
# SA	.54	-.09	-.20	-.12	-.13	.50	-.14	.05	-.04	---	.28	.05
# MED	.47	.02	-.28	-.03	.27	.19	.45	.24	-.20	.36	---	.10
P(Rc)	.12	.05	-.31	-.30	-.11	.11	.22	.44	.19	.21	.25	---

Note: Zero-order correlations are shown below the diagonal; partial correlations are shown above the diagonal. QCONN is Cue Connectivity, QRESO is Cue Resonance, QSS is Cue Set Size, TSS is Target Set Size, TFREQ is [log (.5+Target Frequency)], TCONN is Target Connectivity, TRESO is Target Resonance, FSG is Forward Strength, BSG is Backward Strength, # SA is Number of Shared Associates, # MED is Number of Mediated Associates, and *P*(Rc) is Probability of Correct Recall.

includes an experiment that factorially manipulated cue connectivity, could explain why cue connectivity was a significant predictor previously, but is no longer.

Chapter Four

Discussion

Although Nelson and Zhang (2000) found a significant effect of cue connectivity in their multiple regression analysis of twenty-nine cued recall experiments, the present results failed to consistently replicate this effect. Significant effects of cue connectivity were present as a main effect when it was crossed with cue set size or cue resonance, and as an interaction when it was crossed with target connectivity. More importantly, further analysis of the experimental stimuli revealed confounding relationships between the variables of study, which were then analyzed with regression analyses. These confounds highlight the importance of statistical control when manipulating materials variables such as these. When working with materials variables, it is not sufficient to control the means and variability estimates across experimental conditions. In order to have the most confidence in the experimental manipulation, it is most important that the *correlations* among the feature variables across each experimental condition are precisely controlled (ideal $r = 0$).

Simultaneous multiple regression analysis of the data from this series of experiments indicated that cue connectivity was *not* a significant predictor of cued recall performance, although the other variables put forth by Nelson and Zhang (2000) did still emerge as significant predictors. Finally, a revised version of the cued recall database, which includes new data from seven additional recent experiments, was again examined with multiple regression procedures. Consistent with the findings of the present study, cue connectivity was not a significant predictor of cued recall performance according to the updated cued recall database. Taken together, these analyses confirm the null effect of cue connectivity on cued recall performance.

The incongruence of the initial multiple regression results with the experimental outcomes raises an important methodological issue. Although the multiple regression procedure is designed to parse out the effect of individual variables separately from their correlation with other independent variables, this does not mean that researchers should rely solely on regression procedures when conducting their research. It is important that each variable be evaluated experimentally on its own merit, and not included in an interpretation just because it was indicated as a significant predictor in a regression analysis. Intense scrutiny of the cue connectivity effect in the context of both experiments and multiple regression procedures indicates that Nelson and Zhang (2000) were correct in discounting its importance in the prediction of cued recall performance. Even though the results of their regression analysis indicated that cue connectivity was a significant predictor of cued recall performance, that variable had not been systematically studied in the laboratory, so they were unwilling to assign importance to that regression finding until it was backed up by experimental data. The findings of the present study confirm the initial judgment that cue connectivity may not be a significant factor in determining the success of extra-list cued recall performance. This conclusion highlights the importance of utilizing *both* manipulation experiments and regression procedures when working with correlated variables. Utilizing just one of these procedures without the appropriate follow-up analysis can lead to an erroneous interpretation of the results.

One feature variable that was significant in all of the aforementioned analyses is cue resonance. In an experiment, high levels of cue resonance had an inhibitory effect on cued recall performance, specifically when cue connectivity was high. Cue resonance also predicted a small-to-moderate significant negative effect on cued recall in each of the regression analyses, though it had no effect in the main regression analysis of Nelson and Zhang (2000). The present data provide support for Rundus' (1973) hypothesis that high levels of cue resonance can have a detrimental effect on recall performance. Although Rundus was studying the effect of providing partial list cues in a free recall paradigm, the results may apply equally to cued recall performance. Specifically, PIER2 postulates that studying a target word automatically activates the target and a multitude of implicit links between the target and its related associates. Given that the test cue is an associatively related word to the target that is activated during study and is presented during the cued recall task to aid in retrieval of the target, this procedure could closely parallel the partial-list retrieval phenomenon described by Rundus (1973). When participants are told to rely on a test cue that has many returning links from its associates (i.e., high cue resonance) to help them remember an associatively related target they just studied, the activation of multiple implicit links from the associates back to the test cue may prevent participants from recovering the studied associate (the target). Currently, PIER2's equations do not include any calculations that take into account the effect of cue resonance. Further studies are warranted to determine if this is an important feature that needs to be incorporated into future revisions of the model.

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Appendix A

Appendix A

Materials used in Experiment 1

List 1		List 2	
Cues	**Targets**	**Cues**	**Targets**
High Connectivity-Small Set Size		**High Connectivity-Small Set Size**	
ADOLESCENT	ADULT	ADOLESCENT	YOUNG
CENT	DOLLAR	EDUCATE	COLLEGE
GEM	STONE	GEM	RUBY
METHODIST	PROTESTANT	METHODIST	CATHOLIC
SOCCER	SPORT	SHRUB	PLANT
WAVES	BEACH	SOCCER	GAME
High Connectivity-Large Set Size		**High Connectivity-Large Set Size**	
ASSAULT	WEAPON	BRUISE	HIT
BIOLOGIST	PLANT	BURGLAR	ALARM
BLAST	LOUD	COMMENT	OPINION
BOTTLE	CAP	MYTH	GREEK
DISBELIEVE	FALSE	PAINTING	BRUSH
OUTLAW	COWBOY	PATRIOTIC	LOYAL
Low Connectivity-Small Set Size		**Low Connectivity-Small Set Size**	
CRUST	PIZZA	CAMERA	FILM
HOP	RABBIT	CORK	BOTTLE
LAMP	SHADE	KNOB	HANDLE
QUILL	SCROLL	POSTAGE	MAIL
SCALES	FISH	TOASTER	BREAD
SNAIL	SLUG	TUSK	IVORY
Low Connectivity-Large Set Size		**Low Connectivity-Large Set Size**	
FAILURE	PASS	BATTERY	ACID
OBSTACLE	BLOCK	BLUNT	OBJECT
PATCH	FIX	GRIND	COFFEE
RUBBER	TIRE	PATCH	HOLE
STIFF	NECK	TRACE	COPY
TAP	KNOCK	WIRE	FENCE

Appendix A (Continued)

Materials used in Experiment 2

List 1

Cues	**Targets**
High Cue-High Target Connectivity	
CHEMIST	BIOLOGIST
FAITHFUL	LOYAL
FITNESS	EXERCISE
METEOR	STAR
SCALLOP	SEAFOOD
SPONGE	BATH
High Cue-Low Target Connectivity	
ASLEEP	DREAM
ESSAY	QUESTION
JEWEL	STONE
MYTH	FALSE
ROBBER	BANK
SURGERY	BLOOD
Low Cue-High Target Connectivity	
BLACK	COLOR
FOUNTAIN	DRINK
OFFENSE	FOOTBALL
PEPPERONI	SAUSAGE
REGULATION	LAW
ROOT	STEM
Low Cue-Low Target Connectivity	
BATTERY	ACID
BOUNCE	JUMP
COMPASS	NORTH
ERASER	CHALK
FLICK	FINGER
HALF	FULL

List 2

Cues	**Targets**
High Cue-High Target Connectivity	
RELATIVE	SISTER
SPORTS	BASKETBALL
STUDENT	STUDY
TEMPLE	WORSHIP
THAW	FROZEN
WASHCLOTH	BATH
High Cue-Low Target Connectivity	
ASLEEP	DREAM
DISBELIEVE	FALSE
FARMER	TRACTOR
OUTLAW	COWBOY
PAINTING	BRUSH
VIOLENCE	BLOOD
Low Cue-High Target Connectivity	
CRICKET	INSECT
EAST	COAST
SOBER	ALCOHOL
STRETCH	EXERCISE
SWAY	MOVE
TEA	CUP
Low Cue-Low Target Connectivity	
BOOTH	TABLE
DATA	ENTRY
FINGER	TOE
POLISH	SHOE
STIFF	BOARD
TAP	KNOCK

Appendix A (Continued)

Materials used in Experiment 3

List 1		List 2	
Cues	**Targets**	**Cues**	**Targets**
High Connectivity-High Resonance		**High Connectivity-High Resonance**	
HEAR	SEE	INSTRUMENT	PIANO
NECKLACE	BRACELET	NECKLACE	DIAMOND
PLANET	SPACE	PLANET	MARS
SCHOOL	HOMEWORK	SCHOOL	BOOK
SHIRT	CLOTHES	SHIRT	TIE
SOCCER	SPORT	SOCCER	GAME
High Connectivity-Low Resonance		**High Connectivity-Low Resonance**	
BURGLARY	ROBBER	CYCLONE	STORM
FAITHFUL	TRUSTWORTHY	FAITHFUL	HONEST
FURNITURE	COUCH	FURNITURE	CHAIR
REMORSE	SORRY	MEDICATION	PRESCRIPTION
SAILING	OCEAN	SCALLOP	SEAFOOD
TESTIFY	COURT	SQUINT	GLASSES
Low Connectivity-High Resonance		**Low Connectivity-High Resonance**	
CAMERA	FILM	FATHER	DAD
DOWN	ELEVATOR	HALF	PART
FATHER	SON	PASTE	STICKY
FINGER	THUMB	PENCIL	WRITE
PENCIL	SHARP	QUIET	NOISY
TIRE	WHEEL	TIRE	FLAT
Low Connectivity-Low Resonance		**Low Connectivity-Low Resonance**	
BEGINNING	START	BIRTH	BABY
CRICKET	GRASSHOPPER	BUDGET	SAVE
FOUNTAIN	DRINK	FOSSIL	BONE
PICKLE	SOUR	HORIZON	SUNSET
QUILL	SCROLL	PIGEON	DOVE
TRIBUTE	HONOR	TUMBLE	ROLL