Measuring Cognitive Distance

in the Network Representations of Texts

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Abstract

Pairs of words are identified more quickly as coming from different sentences the further apart the words are in the network representation of their native text. How is the distance between the words measured? According to the Network Connection hypothesis, the distance between two words is the length of the network path between the propositions to which they belong, as measured by a process of spreading activation. According to the Location Code hypothesis, the distance between two words is the difference between codes that record the locations of their propositions in the network representation. The results of three experiments supported the Network Connection hypothesis.

A judgment made from memory about a pair of stimuli may reflect distance relationships among the mental representations of the stimuli. Distance effects such as these have been used to explore the mental representation of semantic knowledge. The underlying assumption of this work has been that the mental representations of semantic knowledge structures can be characterized as networks. The experimental strategy has been to use knowledge structures, such as texts, for which some theoretical principle predicts network representations that do not parallel surface form. The object has been to show patterns of response time and/or error rate that correlate with distances in the predicted representations as opposed to distances in surface form.

Much of this work has used a priming methodology. The crucial phenomenon has been facilitation (reduction in response time and/or error rate) in the recognition of a word from a text consequent to the prior processing of another word from the same text. The work has sought to account for patterns of facilitation in terms of distances in network representations (McKoon & Ratcliff, 1980; McKoon, Ratcliff, & Seifert, 1989; Ratcliff & McKoon, 1978; van den Broek & Lorch, 1993). For purposes of illustration, consider an important early study by McKoon and Ratcliff (1980). The texts for the study resembled the text shown in Table 1. Network representations were predicted for the texts on the basis of the principle of *argument overlap*, which holds that two propositions are linked in memory if they share a common argument (Kintsch & van Dijk, 1978; van Dijk & Kintsch, 1983). The network representations all had the branching structure diagrammed in Figure 1. Participants read the texts and then made recognition judgments to words from the texts. Words from Propositions 2 and 5 primed one another more than words from Propositions 3 and 6, which, in turn, primed one another more than words from Propositions 4 and 7. The three pairs of propositions were equally close in the text's surface form. At the same time, however, the network path between Propositions 2 and 5 was shorter than the path between Propositions 3 and 6, which in turn was shorter than the path between Propositions 4 and 7. These results were thus taken as confirming the psychological reality of the network predicted by the principle of argument overlap.

Insert Table 1 about here

Insert Figure 1 about here

At the same time that particular distance effects have been informative about principles of mental

representation, the general fact of their occurrence has been informative about principles of cognitive processing. Distance effects in priming tasks have traditionally been attributed to a process of spreading activation. In this account, priming occurs because activation spreads from the representation for the priming word to the representation for the test word, with the result that the test word is recognized more quickly and/or more accurately than would otherwise have been the case. Distance effects occur because the amount of activation spreading between the representations for a pair of words decreases with the length of the network path between those representations (McNamara, 1992a, 1992b)

Recently, however, questions have been raised regarding the viability of spreading activation as an explanatory concept. The spreading activation view of priming, in particular, has been contested (McKoon & Ratcliff, 1992; Ratcliff & McKoon, 1994, 1988). Rather than spreading activation, priming has been said to reflect a process of compound cued retrieval (Dosher & Rosedale, 1989; Ratcliff & McKoon, 1988). As a byproduct of this re-evaluation, distance effects that had previously been attributed to spreading activation have been discounted as adventitious occurrences (Ratcliff & McKoon, 1988).

It is noteworthy, then, that a different kind of semantic distance effect has been observed that may require explanation in terms of spreading activation. The stimuli for the crucial study were texts that resembled the branching texts of McKoon and Ratcliff (1980) (See Table 1 and Figure 1). Crucially, the network representations that were predicted for these texts did not parallel the surface forms of the texts. The texts served as stimuli for the Sentence Memory (SM) task. Having encoded the contents of a text in memory, participants indicated, for each of a series of pairs of words, whether the two words came from the same sentence of that text. Measures of performance (response time and/or error rate) for negative trials in this task decreased with the distance between the representations of the test words in the network representation that was predicted for the text (Dopkins, 1991, 1997). These results imply that a negative SM judgment is based at least in part on the network distance between the representations of the test words. If the distance is great enough, a negative response is emitted. Such a response is emitted more quickly the greater the distance there is between the word representations.

Two accounts have been proposed of the cognitive processing underlying the Sentence Memory distance

effect. The two accounts differ as to the way distance is assessed in a network representation. According to the Network Connection hypothesis (Dopkins, 1991, 1997), measures of performance for negative SM trials decrease with increases in the length of the network path between the propositions to which the test words belong. The length of the network path between two propositions is assessed by a process of spreading activation; the estimated distance between two propositions decreases with increases in the amount of activation spreading between them when they are both activated (Anderson, 1983a; Anderson, 1983b; McNamara, 1992a, 1992b). According to the Location Code hypothesis, measures of performance for negative Sentence Memory trials decrease with increases in the difference between the network locations of the propositions to which the test words belong. The network location of a proposition is given by an explicit code that is stored with the proposition (The two hypothesis are instantiated more concretely later).

In several experiments, Dopkins (1997) found support for the Location Code hypothesis in contradistinction to the Network Connection hypothesis. This support may not be general, however, because it was observed with the study-test procedure, in which texts are memorized. This procedure may have encouraged representations and processes that would not prevail when texts are simply read, as in the read-test procedure. The present study assesses the Network Connection and Location Code hypothesis using the latter procedure.

Testing between the Network Connection and the Location Code hypotheses is important for several reasons. First, the results may speak to the controversy concerning the concept of spreading activation (Dosher & Rosedale, 1989; McKoon & Ratcliff, 1992; Ratcliff & McKoon, 1988; Ratcliff & McKoon, 1994). Support for the Network Connection hypothesis would reinforce the viability of the spreading activation concept by demonstrating a phenomenon for which it provides a natural explanation.

Second, the two hypotheses have different practical implications for the way the SM task is used in exploring mental representations of semantic knowledge. The Location Code hypothesis implies that the SM task will be useful for inferring the large-scale organization of the propositions in network representations but may not always be useful for deciding whether or not particular links are present between propositions. As long as the presence or absence of a link does not dictate a significant change in the large-scale organization of the

propositions in a network representation, its presence or absence will not be reflected in SM performance. The Network Connection hypothesis, in contrast, implies that the SM task will be useful for studying all sorts of connectivity in network representations. SM performance will be sensitive to the presence of any and all links between a given pair of propositions (this matter is discussed further later).

The general strategy in the present study was to use texts for which the principle of argument overlap predicted network representations that did not parallel surface form and in whose network representations the Network Connection and Location Code hypotheses predicted different patterns of inter-proposition distance. An attempt was made to account for performance on negative SM trials on the basis of a) distance in the predicted network representations, as given by the Network Connection hypothesis, and b) distance in the network representations, as given by the Location Code hypothesis. The first goal was to show that one of the two sorts of network distance accounted for negative SM performance independently of surface form distance. The second goal was to find which sort of network distance gave the best account of SM performance.

Experiment 1

Experiment 1 was an initial attempt at testing Network Connection, Location Code, and Surface Form predictions with the read-test procedure. On each trial, the participant read a text and then responded to a series of pairs of words, indicating, for each pair, whether they belonged to the same sentence of the text. Each of the crucial texts for the experiment had the same basic structure as the sample shown in Table 1. Each of the sentences of the text corresponded to a single proposition. The principle of argument overlap predicted that the network representation of the text would have the branching structure shown in Figure 1.

The following four critical word pairs were tested for each text: words from Propositions 1 and 5 (1-5 pair), words from Propositions 1 and 8 (1-8 pair), words from Propositions 4 and 5 (4-5 pair), words from Propositions 4 and 8 (4-8 pair). (Given the one-one correspondence between sentences and propositions, propositions will be identified with the surface form positions of their corresponding sentences.)

Different patterns of results were predicted for these critical pairs under the assumption that SM performance reflected a) distance in the network representation, as measured according to the Network Connection hypothesis, b) distance in that representation, as measured according to the Location Code

hypothesis, or c) distance in surface form. The experiment tested these predictions. Because our previous work in this area had shown response-time data to be too variable to give reliable results in this sort of analysis, the predictions were tested in terms of the error-rate data for the experiment.

Network Connection predictions. The assumption here is that error rate for negative SM trials decreases with increases in Network Path Length – that is, the length of the network path between the propositions to which the test words belong. The propositions in the 4-8 pair are separated by 14 network links; the propositions in the 1-8 and 4-5 pairs are separated by 8 links; the propositions in the 1-5 pair are separated by 2 network links. Thus, error rate should be lower for the 4-8 pair than for the 1-8 and 4-5 pairs, and lower, in turn, for the 1-8 and 4-5 pairs than for the 1-5 pair.

Location Code predictions. The assumption here is that error rate for negative SM trials decreases with increases in Location Code Difference – that is, the difference between the network location codes of the propositions to which the test words belong. In order to formulate predictions, it is necessary to specify how network locations are differentiated. Given that Dopkins (1997) found support for the Location Code hypothesis, it is reasonable to start with the system of differentiation that he used. Assume, then, that, as in Dopkins (1997), proposition location is differentiated hierarchically, in terms of ordinal values at two different levels of analysis. The location of a proposition is given by: a) the ordinal value of the branch to which the proposition belongs and b) the ordinal value of the proposition within that branch. The words in all of the critical pairs belong to different branches of the network. Thus, the crucial factor for these pairs is the difference between the within-branch positions of the propositions to which the test words belong. The propositions in the 1-8 pair hold positions 1 and 4, respectively. The propositions in the 4-5 pair hold positions 4 and 1, respectively. Thus, the Location Code Difference for the 1-8 and 4-5 pairs is 3. The propositions in the 1-5 pair hold the same position (position 1) within their respective branches. The same is true of the propositions in the 4-8 pair (which hold position 4). Thus, the Location Code Difference for the 1-5 and 4-8 pairs is 0. It follows that error rate should be lower for the 1-8 and 4-5 pairs than for the 1-5 and 4-8 pairs.

Surface Form predictions. The assumption here is that error rate for negative SM trials decreases with increases in Surface-position Difference – that is, the difference between the surface positions of the

propositions to which the test words belong. The propositions in the 1-8 pair differ by 7 positions. The propositions in the 1-5 pair differ by 4 positions and the same is true of the propositions in the 4-8 pair. The propositions in the 4-5 pair differ by 1 surface position. It follows that error rate should be lower for the 1-8 pair than for the 1-5 and 4-8 pairs, and lower, in turn, for the 1-5 and 4-8 pairs than for the 4-5 pair.

Method

Participants. The participants were 18 students at the George Washington University. They received extra credit in a psychology class in exchange for their efforts.

Materials. Sixteen texts were used to test the experimental hypothesis and nine filler texts were used to camouflage the experimental manipulation.

Procedure. Participants were tested in groups of four. Microcomputers were used to present the texts and collect the responses, with each participant being tested at a separate microcomputer. The experiment consisted of 25 trials. Each trial began with a ready signal. When participants pressed the space bar, a text appeared on the screen in its entirety. Participants had as much time as they wanted to read the text. When participants pressed the space bar again, the text disappeared and a message appeared instructing them to press the space bar to initiate presentation of the word pairs. The pairs were presented one at a time, with participants initiating presentation of each one by pressing the space bar. Participants pressed the "B" and the "N" keys respectively to indicate that the words in the pair did and did not come from the same sentence. The words remained on the screen until participants responded. There were eight word pairs for each text. For the experimental texts, four of the word pairs were the critical pairs described earlier. The rest of the word pairs for the experimental texts and all of the pairs for the filler texts were used to balance the number of positive and negative pairs and to camouflage the nature of the experimental manipulation. After participants had responded to the last pair for a given text, two yes/no comprehension questions were presented, one at a time. Then participants were asked to write out on a piece of paper one thing that they could remember about a specified character from the text. Participants were instructed to respond as quickly as possible to the word pairs, without sacrificing accuracy. They were told to strive only for accuracy in responding to the comprehension and recall questions.

Results

Figure 2 gives the mean response time and error rate for the four critical pairs. As was case throughout the present study, response times greater than 10,000 ms were truncated at that value. Response time was shortest for 4-8 pair, with the 1-8, 4-5, and 1-5 pairs producing progressively longer response times. Error rate was lowest for 4-8 pair, with the 1-8, 4-5, and 1-5 pairs producing progressively higher error rates. Notice that error rate paralleled response time. A speed-accuracy tradeoff did not occur.

Insert Figure 2 about here

Regression analyses were conducted to fit the error-rate data more precisely to the three sets of predictions. Separate analyses were conducted against the variability due to participants and items. The 72 cases in the participants analysis were the error rates that the 18 individual participants accrued for the 4 critical pairs. The 64 cases in the items analysis were the error rates that the 16 individual texts accrued for the 4 critical pairs. The predictor variables in each analysis were Network Path Length, Location Code Difference, and Surface-position Difference. 17 dummy variables were included in the participants analysis to estimate the variability due to Participants. 15 dummy variables were included in the items analysis to estimate the variability due to Items. Network Path Length accounted for a significant amount of the variance in the data. $t1(51) = 3.40$, $SE = .002$; $t2(45) = 3.76$, $SE = .002$. (*t1* and *t2* report the results of the participants and items analyses. For this and all subsequent analyses, alpha was set at .05). The coefficient for Network Path Length was -.008. Location Code Difference did not account for a significant amount of the variance in the data, $t1(51) = .25$, $SE = .007$, $t2(45) = .27$, $SE = .006$. Surface-position Difference also did not account for a significant amount of the variance in the data, $t1(51) = .23$, $SE = .005$; $t2(45) = .26$, $SE = .004$. Overall, the regression equations accounted for 56% and 63% of the variance in the data in the participants and items analyses, respectively.

Discussion

The Network Connection hypothesis accounted for a significant amount of the variance in the error-rate data from the SM task. The Location Code hypothesis did not account for a significant amount of the variance in the data. Evidently, the support that Dopkins (1997) obtained for the Location Code hypothesis with the study-test hypothesis does not extend to the read-test procedure. The Surface Form predictions also did not account for a significant amount of the variance in the data.

Experiment 2

Experiment 2 attempted to pit Network Connection, Location Code and Surface Form predictions more directly against one another using the read-test procedure. The crucial texts were a subset of those that were used in Experiment 1. As before, it was assumed that the texts were represented in terms of the network shown in Figure 1, and that network location was differentiated in terms of the hierarchical system outlined earlier. Six critical word pairs were tested for each text: words from Propositions 4 and 5 (4-5 pair), words from Propositions 4 and 6 (4-6 pair), words from Propositions 4 and 7 (4-7 pair), words from Propositions 1 and 8 (1-8 pair), words from Propositions 2 and 8 (2-8 pair), and words from Propositions 3 and 8 (3-8 pair). Notice that one word in each pair came from a proposition in the fourth ordinal position of one of the branches of the text (that is, either Proposition 4 or Proposition 8). For purposes of exposition, this word will be called the *late word*. Notice that the other word in each pair came from a proposition in either the first, second, or third ordinal proposition in the other branch of the text. This word will be called the *early word*. Different patterns of results were predicted for the critical pairs under the assumption that SM performance reflected a) distance in the network representation, as measured according to the Network Connection hypothesis, b) distance in that representation, as measured according to the Location Code hypothesis, or c) distance in surface form.

Network Connection predictions. Given that the late word lies at the end of one branch of the network, then to get to the early word from this point we must travel back on that branch to the branch point and then out on the other branch to the early word. The larger the ordinal position of the early word, the more links we must traverse to reach it. For 4-5 and 1-8 pairs we must traverse 8 links; for 4-6 and 2-8 pairs we must traverse 12 links; for 4-7 and 3-8 pairs we must traverse 12 links. Thus, the Network Path Length for the

two test words increases as the within-branch position of the early word increases from 1 to 3. Error rate decreases with increases in Network Path Length. It follows that error rate should decrease as the within-branch position of the early word increases from 1 to 3.

Location Code predictions: The words in all of the critical pairs belong to different branches of the network. Thus, the crucial factor will be the differences between their within-branch positions. The late word always has within-branch position 4. For 4-5 and 1-8 pairs, the early word has within-branch position 1; thus, Location Code Difference is 3. For 4-6 and 2-8 pairs, the early word has within-branch position 2; thus, Location Code Difference is 2. For 4-7 and 3-8 pairs, the early word has within-branch position 3; thus, Location Code Difference is 1. In sum, Location Code Difference decreases as the within-branch position of the early word increases from 1 to 3. Error rate decreases with increases in Location Code Difference. It follows that error rate should increase as the within-branch position of the early word increases from 1 to 3.

Surface Form predictions: For word pairs 4-5, 4-6, and 4-7, Surface-position Difference increases from 1 to 3 as the within-branch position of the early word increases from 1 to 3. For word pairs 1-8, 2-8, and 3-8, however, Surface-position Difference decreases from 7 to 5 as the within-branch position of the early word increases from 1 to 3. Error rate decreases with increases in Surface-position Difference. It follows that, as the within-branch position of the early word increases from 1 to 3, the error rate for word pairs 4-5, 4-6, and 4-7 should decrease and the error rate for word pairs 1-8, 2-8, and 3-8 should increase.

Method

Participants. The participants were 86 students at The George Washington University. They received extra credit in a psychology class in exchange for their efforts. Four participants were replaced because they had very high error rates (error rates for at least 4 conditions at or above .5, or error rates above .66 for one or more conditions - no participant performed this poorly in Experiment 1). The number of participants was substantially higher than for Experiment 1 but the contrasts at issue were more refined than the contrasts of Experiment 1. According to the Network Connection hypothesis, the words in the 1-5 pair from Experiment 1 were separated by two network links, the words in the 4-5 and 1-8 pairs by 8 links, and the words in the 4-8 pair by 14 links. The maximum difference across pairs was 12 links. In contrast, the words in the 4-5, 4-6, and

4-7 pairs of the present experiment were separated by 8, 10, and 12 links. Similarly for the words in the 1-8, 2-8, and 3-8 pairs. The maximum difference across pairs was 4 links.

Materials. Twelve of the experimental texts from Experiment 1 were used to test the experimental hypothesis. Six of the filler texts from Experiment 1 were used to camouflage the experimental manipulation.

Procedure. There were ten pairs of test words for each text. For the experimental texts, six of these were the critical pairs described earlier. The rest of the pairs for the experimental texts and all of the pairs for the filler texts were used to balance the number of positive and negative pairs and to camouflage the nature of the experimental manipulation. In other respects, the procedure was the same as for Experiment 1.

Results

Figure 3 gives the mean response times and the error rates for the critical pairs as a function of the within-branch position of the early word. Response time stayed more or less constant and error rate decreased as the position of the early word increased.

Insert Figure 3 about here

Regression analyses were conducted to fit the error-rate data to the three sets of predictions. The 516 cases in the participants analysis were the error rates that the 86 participants accrued for the 6 critical pairs. The 72 cases in the items analysis were the error rates that the 12 individual texts accrued for the 6 critical pairs. Because a close negative correlation existed between the predictions of Network Connection and the Location Code hypotheses, the Within-branch Position of the early word was used as the predictor for both hypothesis (recall that the Network Connection and Location Code hypotheses predicted that error-rate would, respectively, decrease, and increase with increases in the within-branch position of the early word). The other predictor variable was Surface-position Difference. Eighty-five dummy variables were included in the participants analysis to estimate the variability due to Participants. Eleven dummy variables were included in the items analysis to estimate the variability due to Items. Within-branch Position accounted for a significant amount of the variance in the data. $t1(428) = 4.9$, $SE = .005$; $t2(58) = 2.05$, $SE = .012$. The coefficient for Within-branch Position was -.025, in agreement with the predictions of the Network Connection hypothesis. Surface-

position Difference also accounted for a significant amount of the variance in the data, *t1(428)* = 7.37, *SE* = .002; *t2(58)* = 3.12, *SE* = .005. The coefficient for Surface-position Difference was -.014. Overall, the regression equations accounted for 56% and 56% of the variance in the data in the participants and items analyses, respectively.

Discussion

As in Experiment 1, the Network Connection hypothesis accounted for a significant amount of the variance in the data. Again, the predictions of the Location Code hypothesis were not confirmed. In addition, the Surface Form predictions accounted for a significant amount of the variance. In contrast to the case of Experiment 1, negative Sentence Memory responses were evidently partially based on Surface Position-difference in this experiment.

The results of Experiments 1 and 2 suggest that the hierarchical version of the Location Code hypothesis does not fare well under the read-test procedure. Would another version of the Location Code hypothesis fare better under that procedure? In the hierarchical version of the Location Code hypothesis, the network location of a proposition is given by: a) the ordinal value of the network branch to which the proposition belongs and b) the ordinal value of the proposition within that branch. Thus, the differentiation of network branches is independent of the differentiation of position within branches. Consider what happens if we dispense with the hierarchical aspect and integrate the two pieces of information. More concretely, let us assume that the network representation of a text is embedded in a two-dimensional mental space. The network location of a given proposition is simply its location in the mental space. This version of the Location Code hypothesis is more general than the hierarchical version. To see this, note the contrast in the way the two versions differentiate the two branches in the network representation of a simple branching text. The hierarchical version holds simply that the two branches are associated with different ordinal values. In contrast, the spatial version allows the branches to be arranged in a number of different ways in mental space. Figure 4 shows several of the possible arrangements. Notice that the arrangement in Figure 4C is essentially the same arrangement that is assumed

under the hierarchical version of the hypothesis.

Insert Figure 4 about here

The spatial version of the Location Code hypothesis can accommodate the results of Experiments 1 and 2. In fact, these results are roughly what would be predicted under this version of the hypothesis if the branches of the network representation were arranged as in Figure 4C. Can we show that the Network Connection hypothesis is superior to the spatial version of the Location Code hypothesis? Experiment 3 sought to do so.

Experiment 3

Testing the spatial version of the Location Code hypothesis is challenging because the network distances that it predicts for a text depend on the way the text's network representation is configured in mental space, and because the representations of most texts are capable of many different configurations. Certainly this was true of the texts of Experiments 1 and 2, as is shown in Figure 4. In light of these considerations, Experiment 3 was designed so that less uncertainly would exist than in Experiments 1 and 2 as to the way that the network representations of the texts would be configured under the spatial version of the Location Code hypothesis. As a consequence of this reduced uncertainty, it was possible to make predictions under this version of the Location Code hypothesis.

Two kinds of text (hereafter Linked and Unlinked texts) were used in the experiment. Samples are shown in Table 2. The principle of argument overlap predicted that the network representations of the two kinds of text would be as shown in Figures 5 and 6, respectively. Both kinds of text had the same basic structure as the texts for Experiments 1 and 2. Again, propositions that were adjacent in surface form were for the most part linked by argument overlap relationships. Again, propositions 1 and 5 were also linked by such a relationship, so that the text broke down into two branches. Both kinds of text differed from the texts of Experiments 1 and 2 in that propositions 4 and 8 were also linked by an argument overlap relationship. The purpose of this link was to restrict the way the branches of the texts could be arranged in mental space. It was assumed that, given this link, the branches would be arranged as parallel series of propositions, as in Figure 6A (An objection to this assumption is dealt with later). The two kinds of text differed in the following way. Whereas propositions 2 and 3 and propositions 6 and 7 were linked by the same noun argument in Linked texts, these pairs of propositions

were linked by different noun arguments in Unlinked texts (as in the texts of Experiments 1 and 2). This difference was the key to distinguishing the Network Connection hypothesis from the spatial version of the Location Code hypothesis.

Insert Table 2 about here

Insert Figure 5 about here

Insert Figure 6 about here

The task was the same as for Experiments 1 and 2. Four critical pairs were tested for each text: Pair I, consisting of a) the verb from proposition 1 and b) noun argument E, which linked propositions 5 and 6 (see Figures 5 and 6) ; Pair II, consisting of a) the verb from proposition 6 and b) noun argument B, which linked propositions 1 and 2; Pair III, consisting of a) the verb from proposition 3 and b) noun argument F, which linked propositions 7 and 8; and Pair IV, consisting of a) the verb from proposition 8 and b) noun argument C, which linked propositions 3 and 4.

The Network Connection hypothesis predicted that performance on the critical pairs would be worse for Linked than for Unlinked texts. This followed because the branches of the network representation would be more closely connected for the Linked than the Unlinked texts. In contrast, the spatial version of the Location Code hypothesis predicted that responses to the critical pairs would not differ for Linked and Unlinked texts. This followed because the two network branches would be configured as parallel series of propositions for the Linked and Unlinked texts. This arrangement would be dictated by the network links that were present, for both kinds of text, between propositions 1 and 5 and propositions 4 and 8. The link that would be present, for Linked texts, between propositions 2 and 3 and 6 and 7 would not alter this basic arrangement. Because the network representations of the Linked and Unlinked texts would be configured in the same way, the spatial version of the Location Code hypothesis predicted that performance on the critical pairs would not differ for the two kinds of text.

Method

Participants. The participants were 104 students at The George Washington University. They received extra credit in a psychology class in exchange for their efforts.

Materials. The sixteen texts were modified versions of the experimental texts from Experiment 1. The nine filler texts were the same as were used in Experiment 1. Linked and Unlinked versions were created for each experimental text. The experimental texts were rotated through the Linked and Unlinked versions in such a way as to create two materials sets.

Procedure. Participants were randomly assigned to materials sets. There were ten pairs of test words for each text. For the experimental texts, the four critical pairs were as was described earlier. The rest of the pairs for the experimental texts and all of the pairs for the filler texts were used to balance the number of positive and negative pairs and to camouflage the nature of the experimental manipulation. In other respects, the procedure was the same as for Experiment 1.

Results

Figure 7 gives the mean response times and the error rates for the critical pairs in the Linked and Unlinked condition. Because the Location Code hypothesis predicted no differences among the conditions, the two hypotheses could not be tested with regression analyses as in Experiments 1 and 2. Instead, the data were examined with analyses of variance. Response time to the critical pairs did not differ in the Linked and Unlinked conditions, $F1(1,102) = 1.95$, $MSe = 217{,}239$; $F2(1,14) = 2.93$, $MSe = 35{,}068$. Error rate was higher in the Linked than the Unlinked condition, $F1(1,102) = 6.43$, $MSe = .025$; $F2(1,14) = 4.87$, $MSe = .005$.

Insert Figure 7 about here

Discussion

The results of the experiment support the Network Connection hypothesis over the spatial version of the Location Code hypothesis. The error-rate data suggest that the network distance between the critical pairs was smaller in the Linked than the Unlinked condition. The Network Connection hypothesis predicts this result because the critical pairs were more closely connected in the network representations of the Linked than the Unlinked texts. The spatial version of the Location Code hypothesis does not predict this result. The most plausible assumption under this hypothesis is that the two network branches were arranged as parallel series of propositions in mental space in both the Linked and Unlinked condition.

One might perhaps attempt to reconcile these results with the spatial version of the Location Code

hypothesis under the assumption that the middle propositions of the two branches were closer in mental space in the Linked than the Unlinked condition. One might attribute this greater closeness to the connection that was present, in the Linked but not the Unlinked condition, between propositions 2, 3, 6, and 7. The idea, then would be that the two network branches were arranged as parallel series of propositions in the Linked condition, but that the middle propositions in both branches bowed away from one another in the Unlinked condition, because they were not connected as in the Linked condition. Under this account, however, one would predict the error-rate disadvantage for Linked texts to be greater for Pairs II and III than for Pairs I and IV. This was not the case, however. To confirm this, the error-rate data were subjected to a post hoc analysis in which Pairs I and IV were collapsed in one Pair Type category and Pairs II and III were collapsed in the other Pair Type category. The analysis revealed that error rate was higher in the Linked than the Unlinked condition, $F1(1,102) = 6.43$, $MSe = .012$; $F2(1,14) = 4.87$, $MSe = .003$, and that error rate was higher to Pairs I and IV than to Pairs II and III, $F1(1,102) = 99.79$, $MSe = .011$; $F2(1,14) = 10.36$, $MSe = .016$. Most important, the effects of Text Type and Pair Type did not interact in the error-rate data, $F1(1,102) = 1.38$, $MSe = .006$; $F2(1,14) < 1$. Thus, the results are difficult to reconcile with the spatial version of the Location Code hypothesis.

General Discussion

Summary of results. The present study explored performance in the SM task under the read-test procedure. Performance on negative trials in the task reflected network distance, independently of surface form distance. The results suggest that SM distance effects can be used to study network representations encoded as a byproduct of comprehension.

The Network Connection hypothesis gave a better account than the Location Code hypothesis of the process by which network distance was reflected in SM performance. Experiments 1 and 2 pitted the Network Connection hypothesis against the hierarchical version of the Location Code hypothesis. Experiment 3 pitted the Network Connection hypothesis against a more general version of the Location Code hypothesis in which network location was differentiated in terms of a mental space. The results of all of the experiments supported the Network Connection hypothesis.

What are we to make of the fact that the present study found no support for the hierarchical version of the Location Code hypothesis, using the read-test procedure, whereas Dopkins (1997) found support for that version of the hypothesis, using the study-test procedure. By implication, different representations and processes prevail under the two procedures, with the representations and processes of the study-test procedure being particularly favorable to the Location Code hypothesis. Intuitively, this is quite plausible. The network positions of a text's propositions must be encoded in order for network distance to be measured in the manner that the Location Code Hypothesis proposes. The network positions of a text's propositions may be more likely to be encoded when the text is memorized to a high level of performance, as is the case with the study-test procedure, than when the text is simply read, as is the case with the read-test procedure.

Underlying mechanisms. The Network Connection hypothesis holds that SM distance is estimated by a process of spreading activation. The SM distance between two propositions is given by the amount of activation spreading between them when words from the two are activated. Of course, the idea of spreading activation is controversial. Compound cueing has been put forward as an alternative means of explaining phenomena heretofore explained in terms of spreading activation. By demonstrating a phenomenon for which spreading activation provides a natural explanation, the present results reinforce the viability of the concept.

Practical implications. The present results should help us to use the SM distance effect more intelligently in exploring the network representations of texts. As was discussed in the introduction, the Location Code hypothesis implies that SM distance will be useful only for inferring the large-scale organization of the propositions in network representations whereas the Network Connection hypothesis implies that SM distance will be useful for studying all sorts of network connectivity. For example, consider a Linked and an Unlinked text such as were used in Experiment 3. Recall that propositions 2 and 3 and propositions 6 and 7 are linked with the same argument in the Linked text and with different arguments in the Unlinked text (See Figures 5 and 6). The difference between the Linked and the Unlinked text may be difficult to detect under the Location Code hypothesis because the large-scale organization of the representations does not differ. In contrast, the difference between two texts such as these will be detectable under the Network Connection hypothesis because activation will spread more easily between the two branches of the Linked than the Unlinked text.

In summary, the present results imply that, for texts that are encoded as a byproduct of comprehension, the accuracy of a negative Sentence Memory response to a pair of words depends on the length of the path between the words in the text's network representation.

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Table 1

Sample Text from Experiments 1-2

(1) The surgeon pinched the aide. (2) In response, the aide clobbered the intern. (3) The intern dropped the patient. (4) The patient clutched the nurse. (5) Then the surgeon stabbed the anesthesiologist. (6) The anesthesiologist bloodied the technician. (7) The technician wiped herself on the resident. (8) The resident summoned the orderly.

Note. The numbers in parentheses label the sentences for the purposes of the present discussion. They did not appear during the experiment.

Table 2

Sample Text from Experiment 3 in Linked and Unlinked Version

Linked version

(1) The surgeon pinched the aide. (2) In response, the aide clobbered the intern. (3) The intern dropped the patient. (4) The patient clutched his wife. (5) Then the surgeon stabbed the anesthesiologist. (6) The anesthesiologist bloodied the intern. (7) The intern wiped herself on the resident. (8) The resident apologized to the wife.

Unlinked version

(1) The surgeon pinched the aide. (2) In response, the aide clobbered the intern. (3) The intern dropped the patient. (4) The patient clutched his wife. (5) Then the surgeon stabbed the anesthesiologist. (6) The anesthesiologist bloodied the technician. (7) The technician wiped herself on the resident. (8) The resident apologized to the wife.

Note. The numbers in parentheses label the sentences for the purposes of the present discussion. They did not appear during the experiment.

Figure Captions

Figure 1. Diagram of the network representation of a sample text from Experiments 1 and 2. The propositions of the text are identified (P1 - P8) in terms of the positions of the corresponding sentences in the text's surface form. Arguments shared by propositions are identified with the letters (A – G).

Figure 2. Experiment 1: Response time and error rate for the critical pairs.

Figure 3. Experiment 2: Response time and error rate for the critical pairs as a function of the within-branch position of the early word.

Figure 4. Diagram of three ways in which the network representation of a text from Experiments 1 and 2 might have been configured in mental space under the spatial version of the Location Code hypothesis.

Figure 5. Diagram of the network representation of a Linked text from Experiment 3. The propositions of the text are identified (P1 - P8) in terms of the positions of the corresponding sentences in the text's surface form. Noun arguments shared by propositions are identified with the letters (A – F, X).

Figure 6. Diagram of the network representation of an Unlinked text from Experiment 3. The propositions of the text are identified (P1 - P8) in terms of the positions of the corresponding sentences in the text's surface form. Noun arguments shared by propositions are identified with the letters (A - F, X,Y).

Figure 7. Experiment 3: Response time and error rate for the critical pairs.

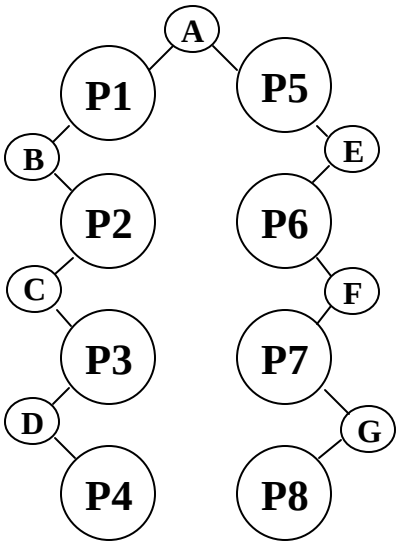
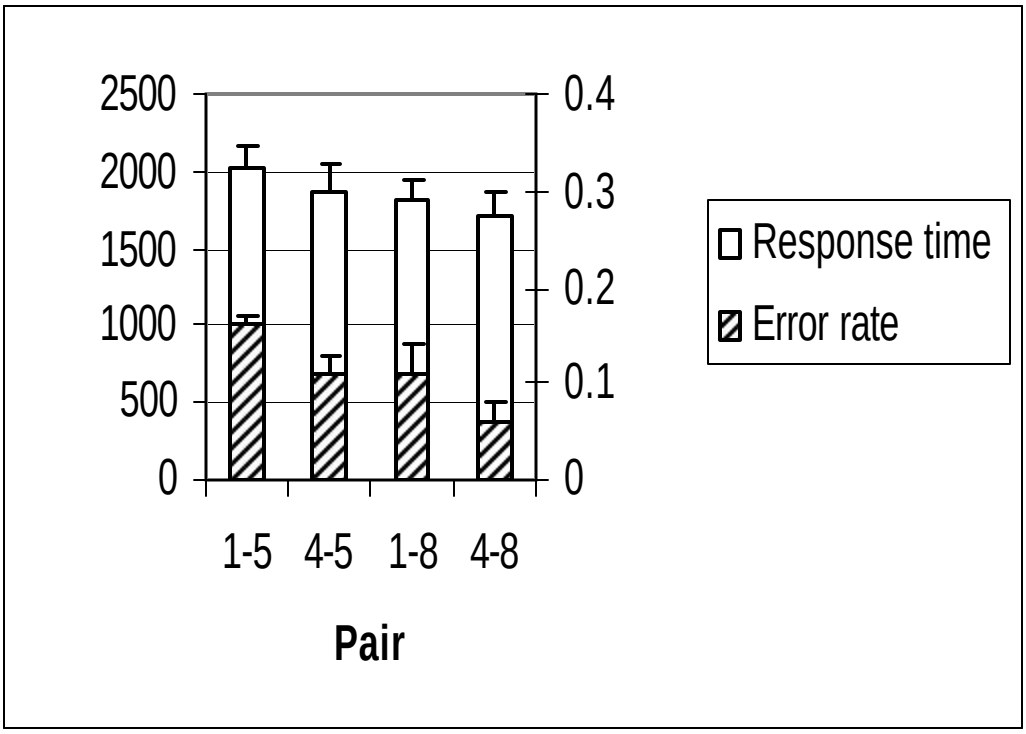


Figure 1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1500
1000
500
0
0.4
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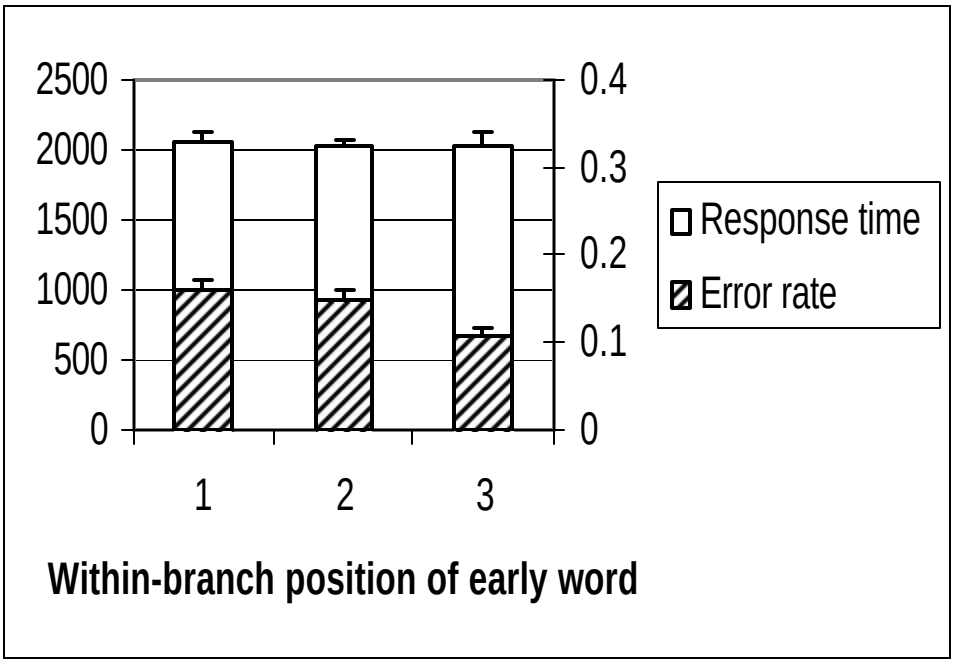
0.1
0
1-5
4-5
1-8
4-8
Pair
Response time
Error rate

Figure 2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500
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0.4
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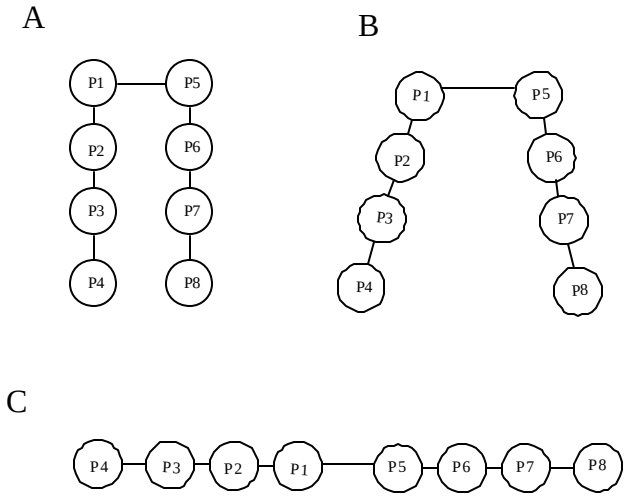
0.1
0
1
2
3
Within-branch position of early word
Response time
Error rate

Figure 3


A
P1
P5
P2
P6
P3
P7
P4
P8
B
P1
P5
P2
P6
P3
P7
P4
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C
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P3
P2
P1
P5
P6
P7
P8

Figure 4

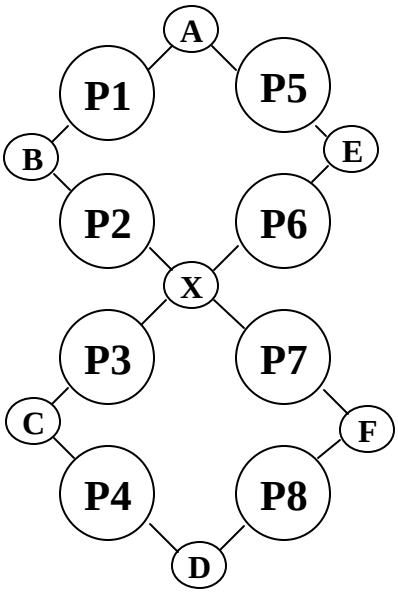


Figure 5

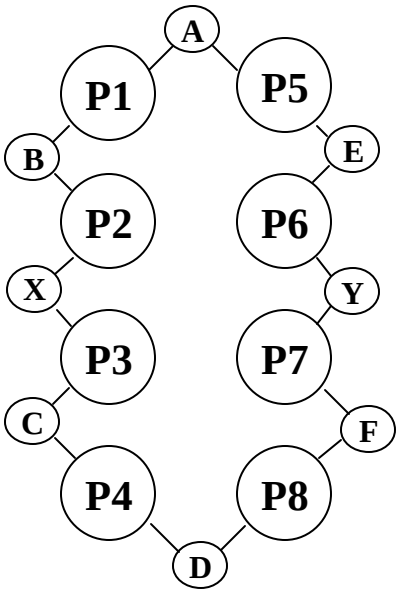
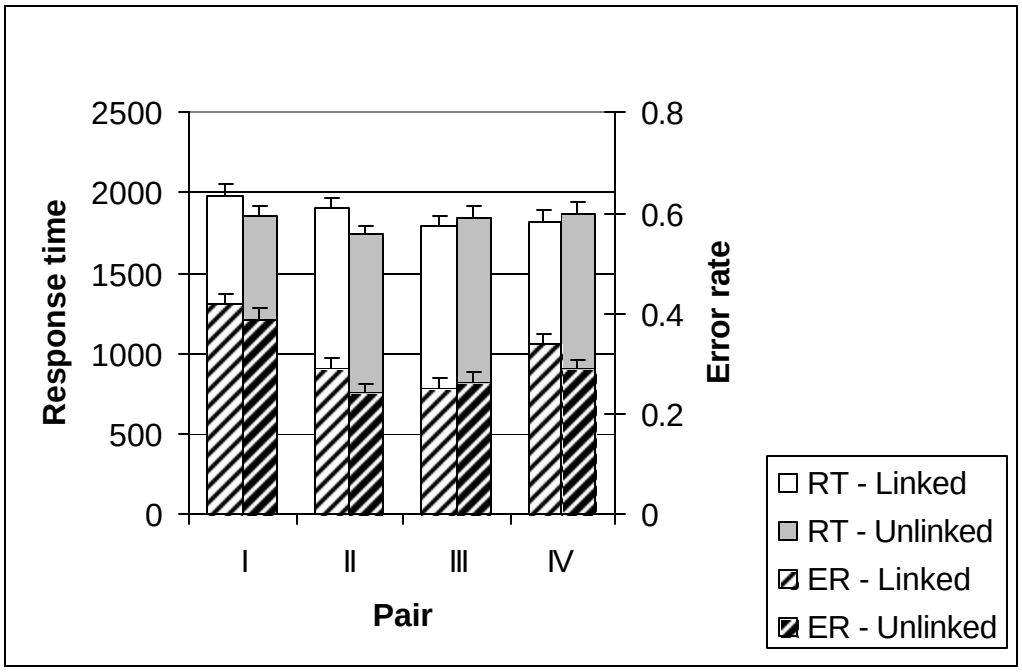


Figure 6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1500
1000
500
0
Response time
0.8
0.6
0.4
0.2
0
Error rate
I
II
III
IV
Pair
RT - Linked
RT - Unlinked
ER - Linked
ER - Unlinked

Figure 7