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Summation priming in aphasia: Evidence for alterations in semantic integration and activation

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Abstract

The present study used a lexical decision paradigm to study the summation of priming effects in normal and aphasic participants. The amount of priming produced by pairs of definitionally converging associative words was compared to the amount of priming produced by pairs of single associative words and non-words in two experiments in which the ISI between primes and targets varied from 200 ms (Experiment 1) to 600 ms (Experiment 2). Control subjects showed a pattern of additive summation priming at the short ISI and overadditive summation priming at the longer ISI. Broca's aphasics showed overadditive priming at the short ISI and no significant priming at the longer ISI; Wernicke's aphasics showed no significant priming at the short ISI and additive priming at the longer ISI. These results suggest that aphasics differ from normals in their ability to integrate the activation derived from multiple linguistic associations and may provide an account of some of the clinical phenomenology of these patients.
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Keywords: Priming; Aphasia; Lexical processing; Summation

Since the early 1980s, the semantic priming paradigm has proven to be a useful tool in the study of the language disorders of aphasia. Its sensitivity to the brief events that mark the course of the processing of language has revealed the presence of basic dissociations between linguistic knowledge structures and the operations required to access those structures (Blumstein, Milberg, Dworetzky, & Rosen, 1991; Milberg & Blumstein, 1981). One of the most compelling of these dissociations has been between the performance of patients with the classic diagnoses of Broca's and

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Wernicke's aphasia. Patients with Wernickes' aphasia are more likely to perform poorly on tasks that require direct decisions regarding semantic, syntactic, or phonological knowledge, while showing evidence of the implicit influence of such knowledge on the performance of timed lexical decisions. In contrast, patients with Broca's aphasia are more likely to demonstrate relative preservation on those tasks requiring judgments based directly on linguistic knowledge, while showing much less consistency in their ability to benefit from this knowledge in the form of consistent increases in lexical decision speed (Blumstein, Milberg, & Shrier, 1982; Milberg, Blumstein, Katz, Gershberg, & Brown, 1995). On the basis of these findings it has been proposed that aphasic patients retain certain forms of linguistic knowledge, but have deficits involving the dynamics of activation of linguistic information (McNellis & Blumstein, 2001; Milberg et al., 1995).

Though semantic, phonological (Milberg, Blumstein, & Dworetsky, 1988), and syntactic (Blumstein et al., 1991) priming studies have provided evidence of the preservation of certain forms of linguistic knowledge, and deficits in the activation of that knowledge in different forms of aphasia, most experiments conducted on patients with aphasia were designed to explore the dynamics of activation between word pairs. These experiments do not reflect the fact that auditory language processing requires the integration of linguistic information. In most cases, the interpretation of any given word is ultimately nuanced by the sentential and extralinguistic context in which the word occurs, as well as the listener's and speaker's expectancies or intentions. Real language processing, even at the single word level, usually requires (and is likely dependent on) the processing of multiple associations, between lexical, semantic, and phonological representations. In most cases, however, language processing requires the integration of multiple word meanings as they appear in time within a sentence.

Semantic and even phonological processing (Grossberg & Meyers, 2000) requires an integrative mechanism that allows for more than one associative link to be weighed or processed before an accurate response can be generated. The basic requirement of the integration of multiple linguistic associations through the concept of "summation of activation" was first used as a psychological construct to describe human cognition in the "logogen" model of Morton (1969) and the "spreading activation" model of Collins and Loftus (1975). Summation of activation across and between levels of representation of linguistic knowledge is often the primary mechanism used to solve the problem of pattern recognition and content driven retrieval in almost all contemporary models of cognition (Anderson, 1997; Dell, 1986; Masson, 1995; McClelland & Rumelhart, 1986).

Though priming paradigms, in large part, have provided the empirical basis for spreading activation models in humans, summation-like phenomena in lexical processing has only recently begun to be explored in normal adults (Algarabel, Pitarque, & Soler, 1988; Beeman et al., 1994). Balota and Paul (1996) point out that summation of priming effects logically may take three basic forms: additive, underadditive, and overadditive. For example, Fig. 1 depicts a simple case[1] in which a summating node S_c receives activation from two input nodes I_a and I_b. Note that this illustration depicts a case using simultaneous inputs though summation of activation may occur with simultaneous or temporally offset inputs. It is likely that normal language processing requires summation in both situations (i.e., the integration of co-occurring and temporally offset information). As Balota and Paul (1996) note, the output of Σ_c may be equal to (i.e., additive), greater (i.e., overadditive) or less (i.e., underadditive) than the sum of I_a and I_b, allowing one to describe the input/output functions relating the three nodes as additive, overadditive, or underadditive, respectively. It may be argued

[1] For simplicity of presentation we will use this localist example, though the issue presented also pertains to distributed models.

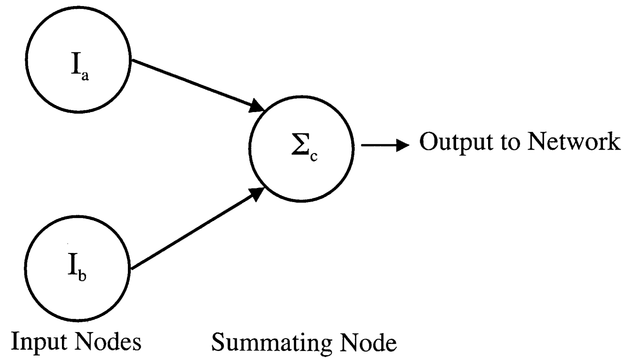

Fig. 1. Diagram of a hypothetical relationship between input nodes and a summation node with a network architecture.

that these patterns of summation priming reflect different forms of integration of spreading activation between linguistic representations.

Linear (i.e., additive) and non-linear (i.e., over and underadditive) summations have been used in connectionist models to produce different information processing effects (Anderson, 1997). For example, additive summation of activation might be useful when a spreading activation network must learn new information or associations. The potential for overadditive summation to produce large and distinct levels of activation might be useful when the network must retrieve or produce a single pattern or representation that is easily discriminated from among many related patterns or representations. Non-linear summation may reflect a threshold-like process with linear characteristics at low levels of activation, and non-linear activation at high levels. Summation processes are a critical part of the operation of spreading activation models and may be important in the understanding of aphasic language deficits.

One of the paradoxes in the priming literature is how priming could be intact while language comprehension is impaired in patients with Wernicke's aphasia and conversely, how priming can be impaired while language comprehension is relatively intact in patients with Brocas's aphasia. It is possible that these dissociations reflect the intersection of the processing dynamics of lexical activation with the processes involved in the integration of these basic sources of activation (Milberg & Blumstein, 1981). It is also possible that the mechanisms that sustain activation of pairs of associations are intact in Wernicke's aphasia, while the mechanisms to sustain the summation or binding of those associations may be impaired resulting in poor language comprehension. Furthermore, it is also possible that integrative processes are intact in Broca's aphasics, allowing certain lexical functions to operate, while the more rapid short-lived inter-associational activation effects are themselves impaired. Therefore, it might be expected that under circumstances where normal subjects show additive priming, the language deficits of aphasics might be reflected in patterns of overadditivity or underadditivity. In contrast, in cases where normal subjects show overadditivity, aphasic patients may show either additivity or underadditivity. In both cases, these deviations would reflect deficits in the dynamics of lexical activation.

The most complete experimental analysis to date of summation of priming was undertaken by Balota and Paul (1996) in which they examined the effects of pairs on priming in both lexical decision and reading tasks in normal adults. Their data suggested that, in many cases, summation of priming follows a highly additive pattern. Balota and Paul (1996) examined an extensive variety of stimulus relationships across various time intervals and response paradigms. Their stimuli included primes, which were category exemplars of the target (e.g., *copper*, *bronze*, target: METAL), primes which were independent associates of lexically ambiguous targets (e.g., *kidney*, *piano*, target: ORGAN) and primes which represented both categorical and featural relationships to the target (e.g., *lion*, *stripes*, target: TIGER).

In the current study, we were interested in examining semantic relationship that reflected overadditive priming. The degree to which primes actually converge on the target and the kinds of associations represented by the primes very likely determine the degree to which overadditive effects actually occur. To this end, it is important to identify cases where primes converge to define or constrain a third lexical item. Consider the case of primes that individually are only weakly associated with the target, but as a pair, converge to uniquely constrain a specific category or concept. These constraining pairs approach being definitional of the semantic representation of the target word. For example, individually, Building and King are weak associates of Castle (and Castle may be considered a non-prototypical building). Together, however, Building and King are virtually defining associates of Castle. Overadditivity, is more likely for primes that converge or constrain the identity of the lexical item. The degree to which overadditivity would be expected is likely related to the degree to which the probability of explicitly predicting the identity of a target constrained by pairs of primes, exceeds the probability of predicting the identity of a target constrained by only a single prime.

The case of definitional or constraining prime pairs is important in the case of aphasia, because this type of associative relationship requiring that separate meanings must be integrated or "bound" is relatively complex and could be a point of particular vulnerability.

A second critical issue to understanding how summation processes might be affected in aphasic patients is related to the temporal landscape upon which most language processing is laid out. Most linguistic stimuli are presented serially in time requiring that lexical representations must be maintained for some period in order to be integrated. Summation may therefore be affected by the rate of rise and fall and peak levels of interlexical activation and may be sensitive to the real time offset of arriving lexical stimuli. As Fig. 2 shows, for example, a rapidly decaying wave of activation will result in less summation than a slowly decaying wave of activation. Varying the time interval in which primes are presented can be used to determine if temporal parameters of summation are affected differently in aphasic patients and normal participants.

In the present study a priming paradigm is used consisting of converging associations to examine how aphasics and controls integrate activation from pairs of prime words. The study compares how primes summate at a relatively brief ISI of 200 ms (Experiment 1) and a longer ISI of 600 ms (Experiment 2) to determine how summation changes over time in both normal and aphasic participants.

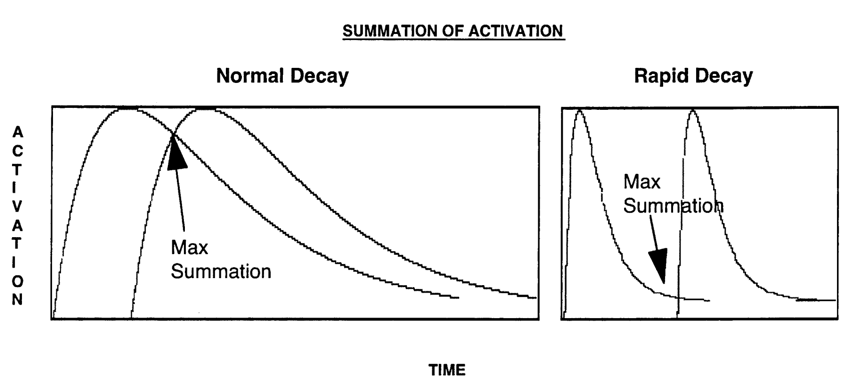

Fig. 2. The relationship between summation and decay of activation.

1. Method

1.1. Development of stimuli for Experiments 1 and 2

1.1.1. Participants

Thirty Brown University students volunteered as a class exercise.

1.1.2. Stimuli

Definitionally related triplets were constructed to contain primes that were unassociated to each other, although each had some semantic relationship to the target, e.g. (*meal*, *morning*, *breakfast*). The prime target relationships were of two types: categorical (*meal–breakfast*) and featural (*morning–breakfast*). Categorical primes were category names of which the target were clearly members. To create a design that would be sufficiently simple to use with patients, categorical primes were always presented first in each trial. Featrural primes were chosen to have a semantic relationship to the target that was independent of the category prime and always served as the second prime in each trial. For all triplets, the coupling of the prime pairs was strongly suggestive of the target identity.

1.1.3. Procedure

Each subject was given a stapled packet containing the stimuli. Each stimulus item appeared on a separate sheet of white paper, printed in black ink, and centered on the page. To the right of each item appeared a blank line. Packets were distributed such that 10 subjects received packets containing only categorical primes, 10 subjects received packets containing only featural primes, and 10 subjects received packets containing both categorical and featural primes. All subjects were instructed to write on the blank provided, the first word that came to mind after reading the preceding word(s).

1.1.4. Results

For those stimuli chosen to form the test triads, 3% of subjects generated the critical target, e.g. (*breakfast*), when given the categorical prime, e.g. (*meal*), 2% of subjects generated the critical target when given the featural prime, e.g. (*morning*), and 58% of the subjects generated the critical target when given both the categorical and featural primes, e.g. (*meal*, *morning*). Based on these results we were able create a total of 12 definitionally related triplets (see Appendix A).

2. Experiment 1

2.1. Participants

Sixteen young adults (6 males and 10 females; mean age = 22.3 years), recruited from the Brown University campus, nine Broca's aphasics (7 males and 2 females; mean age = 63.2 years) and six Wernicke's aphasics (6 males; mean age = 67 years) were paid to participate in the experiment. The patients were identified at Rhode Island Hospital, Memorial Hospital, and the Providence Veterans Administration Hospital, all located in Providence, RI, as well as, the Harold Goodglass Aphasia Research Center of the Boston Veterans Administration Medical Center and the Braintree Hospital Rehabilitation Network, both located in the Boston area. All aphasic patients suffered a single stroke to the left hemisphere. The aphasia classification of each patient was based on a composite of results including the Boston Diagnostic Aphasia Exam (BDAE) (Goodglass & Kaplan, 1983), clinical assessment, and neuroimaging findings, CT or MRI. All participants were right handed, native English speakers. Table 1 provides additional characteristics for each patient. Note that one additional Wernicke's patient was tested but was eliminated from the sample because of abnormal reaction time latencies that were approximately 3 SD slower than the rest of the sample.

2.2. Stimuli

A male speaker of American English produced all stimuli presented in the prime positions. A female speaker of American English produced all stimuli presented in the target position. In a sound treated booth, the stimuli were recorded onto a Sony TCD-D7 DAT tape recorder with a Sony ECM-909A stereo microphone. Using an IBM compatible computer with a Data Translation DT-2821 board, the stimuli were digitized at a rate of 20 kHz with 9 kHz KHRON-HITE low pass filters and 12 bit quantization. The stimuli were converted to 22 kHz in resampling software to be compatible with audio output. Three repetitions of each item were recorded. The clearest token was chosen as the test stimulus, as determined by informal listening by one of the experimenters (KSG).

Test stimuli consisted of 12 definitionally related triplets generated from the preliminary task, e.g. (*meal*, *morning*, *breakfast*) henceforth condition RR; 12 triplets in which the categorical prime and a nonword preceded the critical target, e.g. (*meal*, *foncern*, *breakfast*) henceforth condition RN, 12 triplets in which a nonword and the featural prime preceded the critical target, e.g. (*jarm*, *morning*, *breakfast*) henceforth condition NR, and 12 triplets in which two nonwords preceded the critical target, e.g. (*jarm*, *foncern*, *breakfast*) henceforth condition NN.

Nonwords (as opposed to words semantically unrelated to the target) were used as fillers to reduce the likelihood of activating semantic information relative to either prime or target stimuli. The use of real word fillers might produce uncontrolled priming or inhibitory effects and variations in strategies used by the participants. An attempt was made to match the duration of the word and non-word prime stimuli. The average duration of the word primes was 622 ms (SD = 150 ms), and nonword primes was 545 ms (SD = 119). Though this difference was marginally significant ($t = 1.963$, $p < .06$), it was not felt that this would make a significant difference in the performance of the participants. If anything there might be a bias toward slightly shorter RTs (because of the slightly shorter SOAs in the conditions containing nonwords), reducing the overall size of the priming effects obtained. Test word primes were matched for frequency (Francis & Kucera, 1982). The average frequency for prime 1 and prime 2 was 76.33 and 103.58, respectively; $p > .56$.

In addition to the test stimuli, distractors were developed. These distractors were included to present subjects with conditions in which the word targets were preceded by semantically unrelated primes. To that end, 12 triplets in which two unrelated primes preceded the word target, e.g. (*jewel*, *orange*, *cough*), 12 triplets in which an unrelated prime and a nonword preceded the word target, e.g. (*pesert*, *orange*, *cough*), and 12 triads in which a nonword and an unrelated prime preceded the word target, e.g. (*jewel*, *mitter*, *cough*), served as distractors.

Equivalent conditions were also created using nonword targets. These stimuli were of the same design as the word stimuli. They consisted of 12 triplets in which two word primes preceded the target, e.g. (*tire*, *love*, *bilm*), 12 triplets in which a word prime and a nonword preceded the target, e.g. (*tire*, *beace*, *bilm*), 12 triplets in which a nonword and an unrelated prime preceded the target, e.g. (*nad*, *love*, *bilm*), and 12 triplets in which two nonword primes preceded the target, e.g. (*nad*, *beace*, *bilm*). As with the word priming conditions, 12 triplets in which two unrelated primes preceded the nonword target, e.g. (*sack*, *roof*, *pather*), 12 triplets in which an unrelated prime and a nonword preceded the nonword target, e.g. (*sack*, *rudge*, *pather*), and 12 triads

Table 1
Patient summary for Experiments 1 and 2

Patient classification	Gender	Age at onset	Age at testing	Auditory comprehension (*z*-score)	Lesion
Broca	M	61	81	+0.52	L CVA involving most of Broca's area with extension across to the L frontal horn. Extension to insular structures, the putamen, globus pallidus, the anterior limb of the internal capsule, and the head of the caudate nucleus. Superior lesion extension includes the lower pre-motor and motor cortex areas, the white matter deep to them, and the anterior one-third of the periventricular white matter
Broca	M	56	58	+1.02	L CVA resulting in temporo-parietal lesion involving less than half of Wernicke's area with superior extension into the supra-marginal gyrus area. The superior extension includes a small anterior lesion in the anterior one-third of the periventricular white matter
Broca	M	46	70	+0.83	L CVA involving the posterior half of Broca's area and a portion of the middle frontal gyrus. Lesion extends into the white matter deep to these areas. The lesion continues superiorly into the lower pre-motor, motor, and sensory cortex areas for the mouth and lower face. The lesion extends deep into the anterior half of the periventricular white matter
Broca	F	48	51	+0.81	L CVA involving all of the inferior frontal gyrus, including all of Broca's area and the white matter deep to it. The lesion also involves the insular cortex and the lateral putamen with posterior extension across the anterior temporal isthmus
Broca	M	41	65	+0.87	L CVA resulting in dorsolateral frontal lobe lesion involving the inferior and middle frontal gyri. Lesion includes all of Broca's area and the white matter deep to Broca's area. The lesion continues superiorly and includes the lower two-thirds of the pre-motor, motor, and sensory cortex areas, as well as the white matter and periventricular white matter deep to these areas
Broca	F	45	55	+0.95	L left insular lesion extending to the anterior temporal lobe. It spares the anterior region of Broca's area, as well as Wernicke's area
Broca	M	42	55	+0.96	L CVA involving the entire lenticulostriate artery distribution of the middle cerebral territory including the left caudate nucleus, globus pallidus, and the intervening anterior internal capsule. Lesion also involves the medial temporal cortex, insula, PVWM, and the anterior temporal lobe

Table 1 (*continued*)

Patient classification	Gender	Age at onset	Age at testing	Auditory comprehension (z-score)	Lesion
Broca	M	58	62	+0.77	L CVA involving all of Broca's area and the white matter deep to Broca's area. Patchy Extension into a portion of the subcallosal Fasciculus. Additional anterior extension into part of the middle frontal gyrus. Lesion includes all of the insular structures, as well as the putamen. Superior lesion extension involves the lower pre-motor and motor cortex areas and the white matter deep to them
Broca	M	51	72	+0.69	L CVA involving part of Broca's area with deep extension including all of the subcallosal fasciculus, putamen, caudate, anterior limb of the internal capsule, and part of the temporal isthmus
Wernicke	M	71	72	+0.34	L temporal lobe hemorrhage
Wernicke	M	60	72	+0.87	L CVA resulting in posterior temporal lobe lesion with superior extension into the supramarginal and angular gyri
Wernicke	M	62	64	+0.37	L CVA damaging the temporal and parietal lobes extending into the basal ganglia and internal capsule region
Wernicke	M	71	80	+0.42	Large L posterior hemorrhage in the parietal occipital region
Wernicke	M	51	62	−0.80	L CVA deep to angular gyrus lesioning the arcuate fasciculus and the temporal isthmus. Lesion includes the posterior periventricular white matter
Wernicke	M	48	52	+0.54	L posterior parietal lobe hemorrhage

in which a nonword and an unrelated prime preceded the nonword target, e.g. (*linute*, *roof*, *pather*), served as distractors.

In summary, the experimental list consisted of 168 trials with 84 "word" responses and 84 "nonword" responses. Twelve blocks, each containing 14 triplets, were created. The 14 triplets consisted of one triplet from each of the 14 previously described conditions. An individual target was presented only once within each block. Thus, each block contained seven "word" responses and seven "nonword" responses, with no repeated targets. Triplets were randomized within blocks. To counterbalance order of blocks across subjects, half of the subjects received blocks 1–12, while half of the participants received blocks 12–1.

2.3. Procedure

The young adults were tested individually in a sound-treated room, seated in front of a two button response box. Stimuli were presented to subjects over Koss PRO/4XTC digital stereo headphones. Participants were told they would hear three consecutive stimuli and their task was to decide if the third stimulus was an English word or not. They were required to press a button labeled "Word" if the third stimulus was an English word or to press a button labeled "Nonword" if the third stimulus was not an English word. They were instructed to respond as quickly as possible without sacrificing accuracy. Lexical decision latencies and accuracy were recorded.

A practice list consisting of 12 triplets was presented before each testing session. There were no conceptually related triplets within the practice list. A complete testing session lasted for approximately 30 min and consisted of the practice list and the experimental list. In both word and nonword priming conditions, the interstimulus interval (ISI) between prime 1 and prime 2, and prime 2 and the target was 200 ms and the intertrial interval (ITI) was 3000 ms.

The procedures for the aphasic patients were identical to those described for the young adult participants, with two exceptions. Stimuli were presented to the patients on an IBM compatible laptop computer with an ESS AudioDrive Playback board and the ITI was 6000 ms.

2.4. Results

Only the reaction times (RTs) from the correct identification of critical real word targets (i.e., YES responses) were used for this analysis. Table 2 shows a summary of the mean errors across the priming conditions. Error rates (No responses and failure to respond on a given trial) divided by the total number of trials for that condition were 5.3, 6.0, and 11.7% for the Normals, Broca's, and Wernicke's, respectively. Before the RT data were analyzed, correct RTs that were 2 SD from the mean of each condition, for each subject, were removed as outliers. The data were analyzed separately for the Normals, Broca's, and Wernicke's patients because of a lack of homogeneity of variance between the groups ($F_{max}(4, 30) = 6.65$, $p < .01$).

Table 3 shows the reaction-time data across conditions. The data from the four priming conditions: NN, NR, RN, and RR were subjected to a one-way ANOVA. There was a main effect of priming condition for the young normal controls, $F(3, 45) = 4.924$, $p < .005$. This suggested that there was semantic priming relative to the NN, baseline condition. Simple effects showed that the RR condition, $F(1, 45) = 14.567$, $p < .0004$ and the NR condition, $F(1, 45) = 4.978$, $p < .03$ resulted in faster lexical decision RTs than the NN baseline. There was also a strong trend for the RN condition, $F(1, 45) = 3.264$, $p < .07$ to result in faster lexical decision RTs than the NN condition.

The critical analysis in the current context was the relationship between the priming effect derived from each of the related primes presented individually (i.e., RN and NR) to the magnitude of priming derived from the condition in which both related primes were presented (i.e., RR). To compare the priming for RR vs. RN + NR, we created difference scores by subtracting the priming scores for the RN and NR conditions from the NN baseline and then summing these two values (i.e., (RT RN − RT NN) + (RT NR − RT NN) and for the RR condition (RT RR − RT NN). We were thereby able to determine whether the priming effects for RR was equivalent to the priming effect of RN + NR (additivity), less than the priming effect

Table 2

	NR	RN	RR	NN
Mean number of errors per experimental condition for each participant group at the 200 ms inter-stimulus interval				
Young normals	0	0	.06	.06
Broca's aphasics	.11	.11	.33	.11
Wernicke's aphasics	.83	.33	0	1.33
Mean number of errors per experimental condition for each participant group at the 600 ms inter-stimulus interval				
Young normals	0	0	0	.06
Broca's aphasics	0	.33	.11	.22
Wernicke's aphasics	1.50	.50	.17	1.17

Table 3

	NR	RN	RR	NN
Mean reaction times (ms) per experimental condition for each participant group at the 200 ms inter-stimulus interval				
Young normals	969.45	977.18	940.59	1010.10
Broca's aphasics	919.94	916.88	862.99	920.68
Wernicke's aphasics	1076.61	1041.96	1015.36	1130.19
Mean reaction times (ms) per experimental condition for each participant group at the 600 ms inter-stimulus interval				
Young normals	956.24	917.19	867.53	965.49
Broca's aphasics	915.13	874.95	881.79	924.61
Wernicke's aphasics	1126.44	1050.94	1046.51	1129.28

of RN + NR (underadditivity) or greater than the priming effect of RN + NR (overadditivity).

Fig. 3 shows the priming scores for each priming condition relative to the NNT baseline for the normal subjects. An ANOVA comparing RN + NR to RR did not show a significant difference $F(1, 15) < 1$, indicating that at a ISI of 200 ms, young normal controls show a pattern of additive summation priming in the RR condition.

An analysis of variance based on the reaction-time data in Table 3 showed that similar to the young normal controls, Broca's aphasics also showed a main effect of priming condition, $F(3, 24) = 5.787$, $p < .004$, again suggesting that there was semantic priming relative to the NN condition. However, the analysis of simple effects revealed a different pattern. RR did differ from NN, $F(1, 24) = 12.163$, $p < .002$. Unlike the normals, neither the NR $F(1, 24) < 1$ nor the RN $F(1, 24) < 1$ differed from the NN condition.

As Fig. 4 shows, a different pattern of results appears when the derived scores are analyzed. In this case, an ANOVA comparing RN + NR to RR was significant $F(1, 8) = 7.089$, $p < .02$, indicating that at an ISI of 200 ms, unlike young normal controls, Broca's aphasics showed a pattern of overadditive additive summation priming in the RR condition.

Finally, Table 2 shows that Wernicke's aphasics differ from both Broca's aphasics and normal controls in that they did not show a main effect for priming condition $F(3, 15) = 1.008$, $p > .10$. This pattern was surprising given numerous previous observations of robust semantic priming effects and may have been due to the

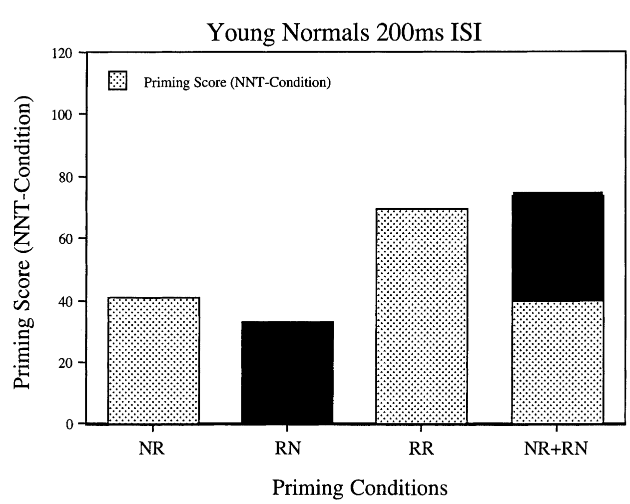

Fig. 3. Priming scores (condition—baseline) from Experiment 1 for young normal participants.

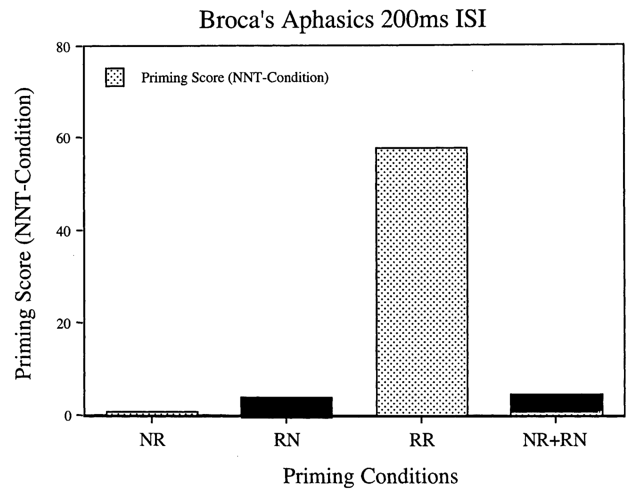

Fig. 4. Priming scores (condition—baseline) from Experiment 1 for Broca's aphasic patients.

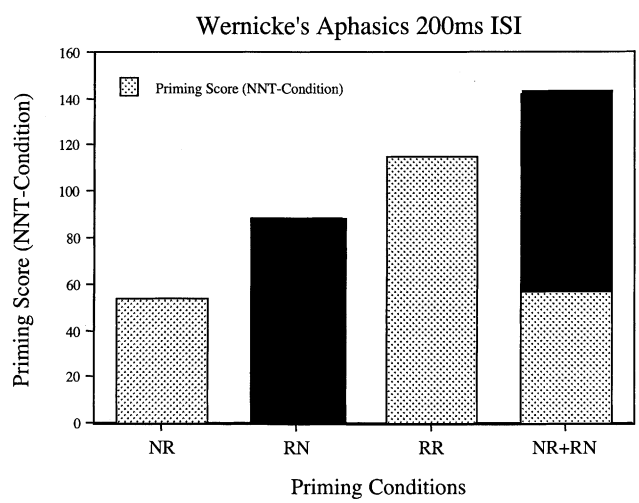

Fig. 5. Priming scores (condition—baseline) from Experiment 1 for Wernicke's aphasic patients.

variability of performance of this particular patient sample. The actual differences between the various priming conditions and the NN baseline were numerically larger in this group than the other two groups. It is therefore possible that significance might have emerged with a larger sample size. Nevertheless, because of the consistency of priming effects across previous studies, this observation may represent an important boundary condition for lexical activation in Wernicke's patients. The lack of a significant main effect precludes an analysis of the derived difference scores. Nonetheless, the data are shown in Fig. 5 and indicate that unlike Broca's and Normals, Wernicke's data appeared to indicate a pattern of underadditivity.

3. Experiment 2

3.1. Participants

Sixteen young adults (5 males and 11 females; mean age = 19.6 years), none of whom had participated in Experiment 1, were recruited for the current experiment.

All were right-handed, native speakers of English, and reported no hearing deficits. Aphasic patients who had participated in Experiment 1, also participated in Experiment 2. Order of the experiments was counterbalanced across the aphasic patients such that half of the patients participated in Experiment 1 prior to participating in Experiment 2, while the other half of the patients participated in Experiment 2 prior to participating in Experiment 1.

3.2. Stimuli and procedure

The stimuli and procedures were identical to those described in Experiment 1 with one exception. For the lexical decision task in this experiment, the ISI between prime 1 and prime 2, and prime 2 and the target was 600 ms.

3.3. Results

As in Experiment 1, only the RTs from the correct identification of critical real word targets (i.e., YES responses) were used for this analysis. The mean number of errors for all groups are shown in Table 2. Error rates were 6.2%, 6.7%, and 10.7% for Normals, Broca's, and Wernicke's, respectively. Again, before these data were analyzed correct RTs that were 2 SD from the mean of each condition for each subject were removed as outliers. The data again were analyzed separately for Normals, Broca's, and Wernicke's, patients because of the lack of homogeneity of variance between the groups ($F_{max}(4,30) = 27.72$, $p < .01$).

The reaction time data for the four priming conditions are shown in Table 3. These data were subjected to a one-way ANOVA. There was a main effect of priming condition for the young normal controls, $F(3,45) = 16.072$, $p < .0001$, once again suggesting that there was semantic priming relative to the NN, baseline condition. Simple effects showed that the RR condition $F(1,45) = 38.760$, $p < .0001$, and the RN condition $F(1,45) = 9.424$, $p < .003$, resulted in faster lexical decision RTs than the NN baseline. However, this time the NR condition, $F(1,45) < 1$, did not result in faster lexical decision RTs than the NN condition. The data showing the priming scores for young normals in the 600 ms ISI condition are shown in Fig. 6. An ANOVA comparing RN + NR to RR showed a significant difference $F(1,15) = 4.523$, $p < .05$ with the RR condition producing a net priming effect that was 40.4 ms greater than RN + NR indicating that at an ISI of 600 ms, young normal controls

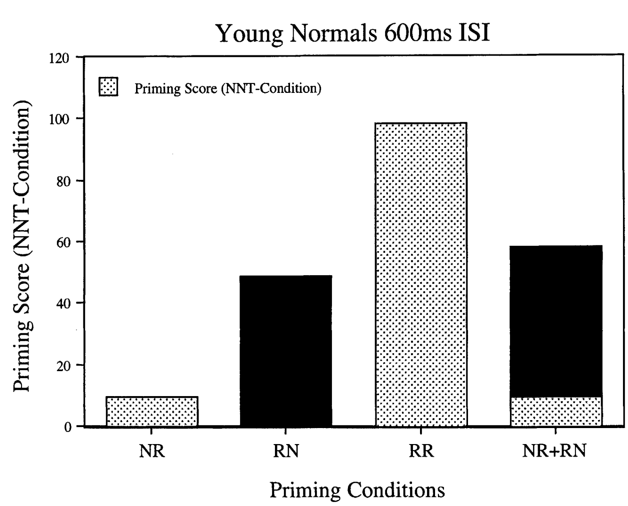

Fig. 6. Priming scores (condition—baseline) from Experiment 2 for young normal participants.

show a pattern of overadditive summation. As Table 3 shows, unlike the young normal controls, Broca's aphasics did not show a main effect of priming condition, $F(3,24) = 2.196$, $p > .05$, suggesting that overall there was no semantic priming relative to the NN condition. Although there was no effect in the RR, $F(1,24) = 3.373$ nor the NR $F(1,24) < 1$ conditions, the RN condition $F(1,24) = 4.537$, $p < .04$ did differ from the NN condition. Once again, the lack of a significant main effect precludes an analysis of the derived difference scores. However, as Fig. 7 shows, Broca's patients show a pattern that was somewhat underadditive.

Finally, the pattern for Wernicke's aphasics differed from Broca's (see Table 3) as they did show a significant main effect for priming condition $F(3,15) = 4.401$, $p < .02$. Simple effects comparing conditions to NN showed a significant priming effect in the RR condition $F(1,15) = 7.206$, $p < .02$, and RN condition $F(1,15) = 6.455$, $p < .02$, but not priming in the NR condition $F(1,15) < 1$. An analysis of the derived difference scores shown in Fig. 8 also revealed a different pattern of results than the normals. In this case the ANOVA comparing RN + NR to RR was not significant, $F(1,5) < 1$ indicating that at an ISI of 600 ms, Wernicke's aphasics showed a pattern of additive summation priming in the RR condition.

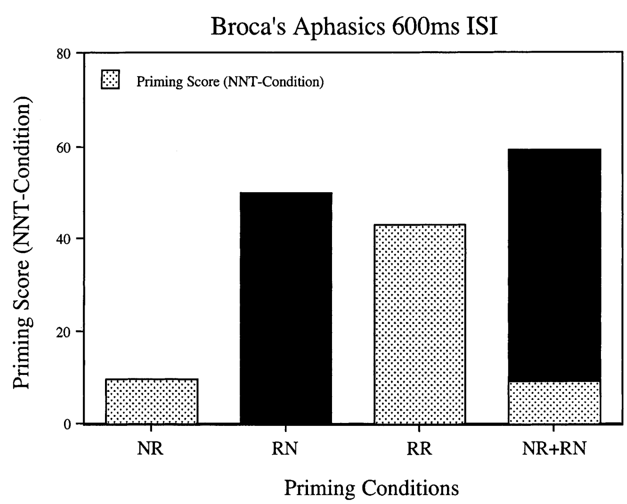

Fig. 7. Priming scores (condition—baseline) from Experiment 2 for Broca's aphasic patients.

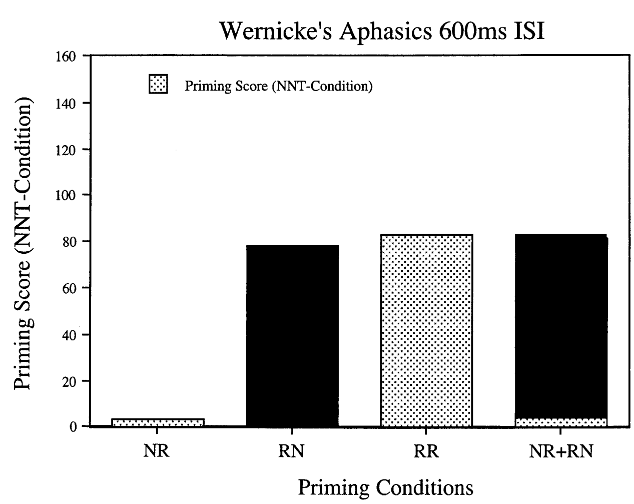

Fig. 8. Priming scores (condition—baseline) from Experiment 2 for Wernicke's aphasic patients.

4. General discussion

In two experiments we examined the phenomena of summation of activation in normal and aphasic participants utilizing definitionally related triplets (e.g., *meal*, *morning*, *breakfast*). Since the groups were analyzed separately we will first summarize the findings across both experiments for Normals, Broca's, and Wernicke's aphasics.

For normal controls, with an ISI of 200 ms, priming with the definitional prime pairs in which both primes were related to the target (RR) was *additive* when compared to the added priming effects of the two single related priming conditions (NR + RN). With an ISI of 600 ms, however, this changed to a pattern of *overadditivity*. Therefore, it appears that normal controls integrated the effects of primes differently over time. At relatively short intervals summation of priming seemed to reflect the individual contributions of each prime and did not result in priming that appeared to be enhanced by the definitional relationship provided by the converging meanings of two related words. This result is similar to the strictly additive priming effects described by Balota & Paul (1996) in their detailed study of summation of priming in normals.

In contrast, priming was clearly enhanced with pairs of convergent definitional primes at the longer 600 ms ISI. This effect can be interpreted in a number of ways in a spreading activation network context, the simplest being a non-linear relationship between the input and output of a summating node receiving activation from two other nodes (Fig. 1). This non-linearity or threshold is a common feature of network models and is often used to aid in the discrimination between competing sources of activation or patterns (Anderson, 1997). The current data might suggest that it takes time for this threshold to be reached in normal subjects. Once this threshold has been reached or exceeded, words that have been "defined" by convergent sources of activation (in this case prime pairs) receive an increased or overadditive level of activation reflecting the attainment of what is in effect a status as a distinct category. As suggested in the introductory discussion not all associations would be expected to be "convergent" in the manner of the stimuli used for this study. The current data suggest that the strong priming effects resulting from overadditive summation might be a mechanism available to normal adults to distinguish or discriminate or quickly access distinct semantic categories.

The patients with Broca's aphasia differed from normals in several ways. First, Broca's patients showed a pattern of summation priming with converging definitional pairs of words that was significantly overadditive in the 200 ms condition. Furthermore, this occurred in the context of non-significant priming by individual primes. Hence, consistent with a number of previous studies (Blumstein et al., 1991; Milberg & Blumstein, 1981; Milberg et al., 1995; Milberg, Blumstein, & Dworetzky, 1987) Broca's appeared to show weaker activation of individually activated semantic relationships than normals. However, unlike normals this resulted in what was in effect a categorical pattern of summation of activation at a short ISI. Again in contrast to normals, all priming was lost by 600 ms. This pattern suggests that Broca's patients have some residual capability of integrating sources of activation reflecting definitional semantic categories, but paradoxically, they do so in a shorter time frame than normals. Overall, activation, however, appears to be shorter lived than normals resulting in a loss of all priming with longer ISIs. This might suggest a lowered threshold for this type of summation in addition to weaker overall activation of semantic information than normals.

Finally, Wernicke's patients produced results different from both Broca's and Normal controls. First, they did not show a pattern of significant priming at a short ISI. This was an unusual result with this group who the literature consistently suggests show robust semantic priming effects across a variety of conditions, including short ISIs. As noted in the results section the mean priming effects were larger than either normal or Broca's patient so the lack of significance is likely related to the variability in the relatively small sample. It is possible that the complexity of this task paired with the relatively rapid presentation time of the stimuli contributed to weaker priming effects. Significant priming did in fact emerge at the longer ISI supporting this possibility. Whether significant priming emerged in the short ISI condition or not, the critical result, however, is the fact that Wernicke's never show a pattern of overadditivity. In fact their results range from a trend in the short ISI condition toward underadditivity to additivity in the long ISI condition. This suggests that even when Wernicke's patients show simple priming effects between single pairs of related words, they never show the effect of integrating converging definitional associates in the categorical manner demonstrated by both the normal controls and Broca's aphasics. Using the analogy to the spreading activation models described above, this suggests that Wernicke's can only summate semantic information linearly. This might imply a raised threshold within summating nodes or some other defect precluding truly integrative processing.

At this point it is tempting to speculate that these divergent patterns of summation of activation are related to or even causally linked to some of the clinical symptoms displayed by Broca's and Wernicke's patients. The overadditivity Broca's patients display with short ISIs suggests that they may get locked into the interpretation a of target word that may ultimately prove to be inappropriate. It may be that weak activation coupled with briefly available overadditively integrated representations reduces the flexibility and speed of access to lexical information in these patients. This may affect patients' ability to produce fluent speech and may have an impact on access to weakly activated grammatical elements of sentences. In contrast, the failure of Wernicke's patients to overadditively integrate semantic information might reduce their ability to use all but the simplest, most contextually driven interpretations of words, and might completely eliminate the interpretation of words that is determined by sentential or narrative context.

These speculations are quite premature without additional details of the integrative processes of lexical information in normals and aphasic patients. It could be argued, for example, that integration is dependent on controlled or attentional mediated semantic processes and that the current study is merely measuring the distinction between automatic and controlled processes. Though this view is not easily reconciled with the present data (e.g., Broca's showing overadditivity at the short ISI and no priming at the long ISI; Wernicke's showing no priming at the short and additivity at the long ISI), the distinction between automatic and controlled processing may nevertheless have some explanatory power for the normal data. These current data are also not consistent with the notion that Broca's aphasics suffer from slowed processing of lexical information (Prather, Zurif, Stern, & Rosen, 1992). Nevertheless, it will be important to extend the observations of summation priming to longer intervals and to conditions that minimize the participation of controlled processes. Whatever the outcome of these future studies, the current data highlight the fact that the integration of semantic information may be an important piece of the puzzle of aphasic language.

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Appendix A

RR condition	RN condition	NR condition	NN condition
Insect–queen–bee	Insect–loke–bee	Glab–queen–bee	Glab–loke–bee
Occupation–cure–doctor	Occupation–dend–doctor	Folor–cure–doctor	Folor–dend–doctor
Meal–morning–breakfast	Meal–foncern–breakfast	Jarm–morning–breakfast	Jarm–foncern–breakfast
Building–sick–hospital	Building–plub–hospital	Pircle–sick–hospital	Pircle–plub–hospital
Game–ice–hockey	Game–clant–hockey	Tood–ice–hockey	Tood–clant–hockey
Organ–think–brain	Organ–yelt–brain	Brill–think–brain	Brill–yelt–brain
Beverage–white–milk	Beverage–gace–milk	Zaster–white–milk	Zaster–gace–milk
Vegetable–cry–onion	Vegetable–mish–onion	Pindow–cry–onion	Pindow–mish–onion
Spice–sneeze–pepper	Spice–paby–pepper	Mung–sneeze–pepper	Mung–paby–pepper
Tree–needles–pine	Tree–sprink–pine	Jown–needles–pine	Jown–sprink–pine
Animal–stripes–zebra	Animal–gack–zebra	Daucet–stripes–zebra	Daucet–gack–zebra
Instrument–bang–drum	Instrument–tetter–drum	Rish–bang–drum	Rish–tetter–drum

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