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Cross-modal semantic priming in schizophrenia

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Abstract

Work on implicit memory in normal subjects has demonstrated the influence of stimulus modality on the retrieval of semantic information. The present study examined the effects of auditory and visual semantic priming on the recognition of visual words using a lexical decision task. Performance was studied in a group of 20 patients with DSM–IV schizophrenia and 26 normal volunteers of similar age and sex. There were two versions of the task: ipsimodal, in which the word or nonword visual target followed 400 ms after the onset of a visual word prime which may or may not be semantically related to the target; and cross-modal, in which the visual target followed 400 ms after the onset of an auditory word prime. Both groups showed significant priming in both modality conditions, although the schizophrenia patients exhibited significantly greater priming in the cross-modal condition. Priming effects in the ipsimodal condition did not differ substantially between patients and controls. The priming effects in the two conditions correlated with each other in the schizophrenia patients only. The results suggest that priming may occur through amodal semantic representations. In schizophrenia, there appears to be increased cross-modal connectivity (reduced modality modularity and informational encapsulation) between lexical representations that could result in impaired language, particularly speech, processing. (*JINS*, 2002, *8*, 884–892.)

Keywords: Semantic priming, Modality, Schizophrenia, Dysmodularity

INTRODUCTION

Priming paradigms have long been used in studies of semantic memory. The main outcome measure of such experiments is the priming effect, that is, facilitation of word recognition (e.g., *doctor*) due to prior exposure to a semantically related word (e.g., *nurse*). As well as being of heuristic value for understanding normal cognition, semantic priming paradigms have been used to investigate mechanisms underlying psychopathology. There have been several studies on patients with schizophrenia, some showing a tendency to increased priming (Kwapil et al., 1990; Spitzer et al., 1993) although other studies have shown normal (Chapin et al., 1992; Ober et al., 1995; Perry et al., 2000) or reduced priming (Passerieux et al., 1995; Vinogradov et al., 1992).

Increased priming in schizophrenia has been interpreted as an indication of greater spread of activation or disinhibition within a semantic store. Those authors who have found reduced semantic priming in schizophrenia explain their findings in terms of an impairment of extralexical processes (rather than semantic store itself), such as the ability to construct and maintain contextual representations (Barch et al., 1996). The inconsistencies between studies probably reflects differences in study designs, notably stimulus onset asynchrony (SOA) and subject factors, including current symptoms and diagnostic subtype (Passerieux et al., 1995; Rossell et al., 2000) and possibly medication effects (Barch et al., 1996). In order to control for such potential confounds as medication, the investigators contrasted the patients with and without a particular symptom (for example thought disorder) receiving similar treatment, rather than contrasting patients with schizophrenia and those with another psychiatric disorder. These studies have replicated increased priming under certain conditions (Manschreck et al., 1988; Spitzer et al., 1993; Weisbrod et al., 1998).

The vast majority of the semantic priming studies in schizophrenia have been conducted in a same-modality version where a visual prime precedes the visual target (ipsimodal priming). However, in the real world people have to

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deal with information coming at them in different modalities, such as auditory, visual, linguistic, visuospatial, etc. This raises several questions, such as "What is the role of stimulus modality in the processing of semantic information?" "What effect does stimulus modality have on semantic processing by people with schizophrenia?" Semantic priming provides an opportunity to address this question by, for example, contrasting words presented visually and auditorily.

In normal subjects, robust facilitation of lexical decision task performance (identification of words *vs.* word-like letter strings) is observed when an auditory prime is followed by a semantically related visual target (Slowiaczek, 1994; Swinney et al., 1979). Thus, a priming effect is observed even though the two components of the task come from different modalities, although it is usually less than when the prime and target belong to the same modality (see Anderson & Holcomb, 1995, and Discussion section of this article). Importantly, modality does influence priming, for example between printed and spoken synonyms (Roediger & Blaxton, 1987), or when the written words from different languages were processed by bilinguals (Kirsner et al., 1980). Schacter and Graf (1989) found that a modality shift (from a visual to an auditory prime) reduced subsequent retrieval of semantic information. Thus, modality-specific processes seem to subserve the identification of visual and auditory words, even though meaning may be processed in a common (amodal) store.

Modality effects on semantic processing in schizophrenia have seldom been investigated. However, such effects would be expected to play an important role in language-related tasks such as perception of speech which is often bimodal in natural settings, and which is known to be affected by the disease (Kuperberg et al., 1998). In this respect, the "dysmodularity" concept of schizophrenia (David, 1994) offers certain predictions and a theoretical background. The concept implies a breakdown in informational "encapsulation" (Fodor, 1983) which could lead to increased "cross-talk" between information streams of different sensory modalities and confusion between thought and perception (see also Nasrallah, 1985). This could occur prior to semantic processing or within the semantic system itself. One way to test the dysmodularity hypothesis is to investigate modality-specific influences on language processing. An obvious matched comparator for non-specific facilitation or indeed distractibility, would be the degree of influence a prime (or distractor) has on a subsequent target, within modality. One could predict that a deficit in "modality modularity" (Easton et al., 1997) would present itself as a lack of modality-specific influences on processing of speech items. If so, the cross-modal priming effect would not show the normal reduction in comparison to priming within the same modality (i.e., there would be equal or increased cross-modal priming). Evidence of cross-modal abnormalities in schizophrenia was first recognized by the Georgian psychologist Uznadze (1966) and later reported by Onifer (1980) who showed increased cross-modal semantic priming in schizophrenia relative to normal subjects using spoken sentences to prime visual lexical decision. Physiological support for abnormally extensive cross-modal transfer comes from our fMRI study (Surguladze et al., 2001) demonstrating increased overlap between auditory speech-activated brain areas and those activated by meaningless nonspeech mouth movements presented visually.

The aim of the current study was to examine the relationships between the modality of lexical stimuli and priming effects in schizophrenia. In line with the dysmodularity hypothesis we predicted that modality-specific processing is impaired in schizophrenia and that this would lead to an increase in cross-modal *versus* ipsimodal semantic priming. We also predicted that cross-modal priming would be greater in people with schizophrenia *versus* healthy controls. Additionally, a relationship between symptoms was sought. Specifically, we predicted an association between increased priming and those symptoms previously shown to relate to source monitoring deficits such as hallucinations (Brébion et al., 1997).

METHODS

Research Participants

Two groups of subjects (schizophrenia patients and normal controls) performed a primed lexical decision task. 20 patients fulfilling DSM–IV criteria for schizophrenia (American Psychiatric Association, 1994) were recruited from the wards ($n = 13$) and outpatient clinics ($n = 7$) of the Maudsley Hospital, London. The diagnoses were made by senior attending clinicians and were corroborated by the research psychiatrist (S.S.) after reviewing the patients' medical notes and carrying out semi-structured interviews. Normal control participants ($N = 26$) were drawn from hospital employees and local community dwellers. The exclusion criteria for all participants were: English as a second language, specific reading or sensory disability, substance abuse (for at least 6 months prior to testing), neurological illness, a history of ECT and left- or mixed-handedness (Oldfield, 1971). All subjects gave written informed consent and were paid a small sum for their participation. The study was approved by the local research ethics committee.

The schizophrenia patients were all taking antipsychotic medication (mostly "typical" agents) at doses that ranged from 10 to 1600 mg of chlorpromazine equivalents (Taylor et al., 2001) per day ($M = 668.1$ mg). Their psychopathology was rated on the following scales by the research psychiatrist (S.S.) who had been trained in their administration: the 24-item Brief Psychiatric Rating Scale (BPRS; Ventura et al., 1993); Scales for the Assessment of Negative and Positive Symptoms (SANS and SAPS; Andreasen, 1983, 1984).

Patients and controls were comparable in terms of age and gender. Compared to controls, schizophrenia patients had significantly lower estimated premorbid IQ (National

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Adult Reading Test; NART, Nelson 1990) and lower educational achievement level (Table 1).

Procedure

There were two conditions: *ipsimodal*, comprising a visual prime and visual target, and *cross-modal*, comprising an auditory prime and visual target. In both conditions the same stimulus onset asynchrony (SOA) of 400 ms was used—that is, the time from presentation of prime to appearance of target. We did not want the prime and target to overlap and we found that 400 ms was the minimum gap which prevented overlap between the spoken auditory prime and visual target. This relatively short SOA has been shown to minimize the influence on priming of controlled processes such as of expectancy (Neely, 1991).

In each condition (visual–visual or auditory–visual) the subjects were presented with 90 pairs of stimuli, where the first word represented a prime, and the second stimulus—a target. The targets were 30 nonwords and 60 words. Thirty of the words were semantically related to the prime, by being exemplars of the same category, the others comprised unrelated words. Thus the relatedness proportion was .33 overall (or .5 for words) which was the same in both ipsimodal and cross-modal conditions. Related pairs were selected from previously published lists including French and Richards (1992; neutral words only), and Shelton and Martin (1992). All word stimuli had a frequency between 10 and 200 per million (Kucera & Francis, 1967). Word targets and primes across relatedness conditions were matched for frequency and also concreteness and imageability (Toglia & Battig, 1978). The mean relatedness index was 20.4% (Moss & Older, 1996). Nonwords were created from the real words by changing one letter (hence they were matched for length) and checked against an English dictionary. All were legally spelled and pronounceable, for example, *wiker*, *sone*, etc. All the word stimuli consisted of one or two syllables and were easily recognizable either visually or auditorily. Examples of related word pairs were *bread–cake*; *car–wagon*, and unrelated: *doctor–bucket*.

Prime–target pairs were arranged in pseudorandom order, with the constraint of no more than two of any word pair type (related, unrelated, nonword) in succession. Different but matched lists were used in the two modality conditions. Relatedness indices for cross-modal and ipsimodal stimuli were 21.1% and 20.0%, respectively.

We used the *go–no-go* (single choice) paradigm in order to minimize the controlled process of postlexical matching (Neely, 1991; Neely et al., 1989). This procedure has been used in other studies with schizophrenia patients (e.g., Ober et al., 1997; Poole et al., 1999). The subjects were advised that they would see (or hear—in the cross-modal condition) a real word, followed by either another word or a senseless string of letters, in each trial. They were required to press the response button as quickly and as accurately as they could, if the second (target) stimulus was a word, and not to press the button if the target was not a real word.

Ipsimodal condition: visual–visual task

Stimuli were presented on the screen (35 cm) of portable computer with 133 MHz coprocessor, fast-decay Super VGA graphics monitor, and a millisecond timer to control stimulus presentation and response timing.

Visual stimuli–words and nonwords appeared in white on a black background, in uppercase (Times New Roman, 36-point font) in the center of the screen approximately 0.75 m from the subject. The subject had to attend first to a fixation cross for 1500 ms, after which a prime word was presented for 250 ms, followed by a blank screen for 150 ms, and then the target word appeared and remained for 3000 ms, which stayed visible regardless of the subject's response. This ensured that the experiment was rhythmically and consistently paced. After the target disappeared, an intertrial interval followed with a fixation cross for 1500 ms.

Table 1. Demographic and clinical data: schizophrenia patients *versus* controls

	Controls ($n = 26$)		Patients ($n = 20$)	
Variable	*M*	(*SD*)	*M*	(*SD*)
Age (years)	30.3	(7.5)	34	(9.9)
Gender (F/M)	14/12		9/11	
Education, years	16.1	(2.5)	12.4	(3.1)*
NART-IQ (*SD*)	109.9	(9.0)	101.9	(10.9)*
Mean length of illness, years (range)			8.6	(3–25)
Mean SANS (range)			6.95	(0–18)
Mean SAPS (range)			8.2	(0–17)
Mean BPRS (range)			42.7	(29–67)
Medication, mg (*M* and range in cpz equivalents)			668.12	(10–1600)

Brief Psychiatric Rating Scale (BPRS); Scales for the Assessment of Negative and Positive Symptoms (SANS and SAPS); National Adult Reading Test (NART); Chlorpromazine (cpz).
*Student's *t* test, $p < .01$.

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Cross-modal condition: auditory–visual task

In this condition, the procedure was modified so that the priming word was presented binaurally through headphones. The words were digitally recorded on to a personal computer from a single male native English speaker. Auditory primes were monosyllabic or short bisyllabic words, with the stress on the first syllable. The interval between the beginning of auditory primes to the presentation of visual targets (SOA) was consistently 400 ms, although the prime lasted between 200 and 350 ms ($M = 275$ ms)—due to the differences in the length of the auditory stimuli. Intertrial interval and the target word presentation time were the same as in the ipsimodal condition, that is, 1500 ms and 3000 ms, respectively.

The procedure was explained carefully to subjects prior to testing, followed by a practice block consisting of 15 trials, for each of the conditions. Order of condition was balanced across subjects.

Analysis

The priming effect was calculated in three ways:

A. the difference between unrelated and related RT in milliseconds;

B. the difference between the unrelated and related RTs after they have been trimmed and log-transformed (see Ratcliff, 1993);

C. the percentage decrease of RT in the related condition in comparison to the unrelated condition, namely, the proportional priming effect. The formula of this measure is (1 − RT related/RT unrelated) × 100 (see also Spitzer et al., 1993).

To compare the priming effects between the two subject groups and analyze the possible influence of modality of presentation, a 2 × 2 × 2 within- and between-subject measures ANCOVA was performed for diagnostic group (patients, controls), modality (ipsi- and cross-modal) and relatedness (related, unrelated). NART-IQ scores were entered as a covariate to control for the differences in estimated level of IQ between the patients and controls. In this analysis we used the trimmed and log-transformed data. Another 2 × 2 ANCOVA was performed for the proportional priming index as the dependent variable, with modality as the within-subjects factor and diagnostic group as the between-subjects factor.

RESULTS

The main outcome measures were accuracy and reaction time (RT). Analyses were carried out to determine whether there were order effects and these revealed no main effects or interactions. Hence order was not considered further.

Accuracy

Both subject groups demonstrated a high level of accuracy in their lexical decision performance. However, the patients made significantly more errors than controls and these were both false positive as well as false negative errors (Table 2). Patients made significantly fewer errors in the cross-modal priming condition than the ipsimodal condition. Using the accuracy data on false negatives responses

Table 2. Accuracy data from priming experiments: Schizophrenia patients ($n = 20$) *versus* controls ($n = 24$)

Modality	Accuracy	Controls	Patients	$t(44)$	p
Ipsimodal	Percent correct	98.9 (9.2)	88.5 (8.9)[a]	5.98	<.001**
	False positive	.62 (.57)	6.1 (6.5)[b]	−4.3	<.001**
	False negative	.35 (.69)	4.3 (5.1)[c]	−3.86	<.001**
	Related	.08 (.27)	1.75 (2.0)		
	Unrelated	.27 (.53)	2.55 (3.1)		
	Priming effect*	.19[d]	.80[e]	−1.65	.105
Cross-modal	Percent correct	98.9 (1.2)	92.5 (7.6)[a]	4.22	<.001**
	False positive	.69 (.84)	3.9 (5.4)[b]	−2.97	.005**
	False negative	.35 (.89)	2.9 (5.2)[c]	−2.4	.02**
	Related	.12 (.33)	.9 (2.0)		
	Unrelated	.23 (.59)	2.0 (3.4)		
	Priming effect*	.11[d]	1.1[e]	−2.3	.023**

Note. Significant within-*patient group* (paired *t* tests): [a]difference in rate of correct responses between modalities [$t(19) = -4.1$, $p = .001$]; [b]false positive errors between modalities [$t(19) = 3.2$, $p = .005$]; [c]false negative errors (omissions) between modalities [$t(19) = 2.1$, $p = .047$]. Similar within-*control group* comparisons were nonsignificant. [d]Controls priming effects between modalities [$t(25) = -.7$, $p = .49$] and [e]patients priming effects [$t(19) = .64$, $p = .53$].
*Priming effect is the difference in errors to unrelated minus related word pairs.
**Significant, $p < .05$.

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(absence of response to related targets *versus* absence of response to unrelated targets) we were able to infer priming effects. It appeared that in both conditions the subjects made more false negative responses (withheld button presses) to unrelated targets in comparison to related targets, in other words, they demonstrated priming effects. Between-group comparisons revealed that the priming effect in the cross-modal condition was significantly greater in the patients, whereas the priming effect in the ipsimodal condition did not differ significantly between the groups.

Reaction Time

In subsequent analyses we used only RT data from correct responses. As expected, the reaction time was generally slower in the schizophrenia patients and variance greater. Hence, the following measures were taken to aid group comparisons, as recommended by Ratcliff (1993).

First, all the raw RT scores were trimmed so that responses exceeding the mean by more than 2 standard deviations were eliminated. Then we used a log transformation of all trimmed RT data, a measure commonly employed to reduce skew (Barch et al, 1996). The trimmed mean RTs and logs of trimmed RTs for related and unrelated conditions for each group, across the different modality conditions are shown in Table 3.

Paired *t* tests comparing RTs to related and unrelated prime-target pairs were highly significant in both modality conditions and both groups ($p < .001$). This was true for both raw and trimmed RT data. The significance of all priming effects within subjects was also established by a one-sample *t* test against zero for each group. All the tests (two-tailed) demonstrated a statistically significant priming effect (reduction in RT between unrelated and related items) in both groups and for both conditions (ipsi- and cross-modal) at the level of $p < .001$. Further analysis was conducted using only trimmed and log-transformed RT data.

Since the schizophrenia patients differed significantly from controls in the estimated level of intelligence—NART, or "premorbid IQ" was entered as a covariate into the ANCOVA design with diagnostic group as the independent variable and relatedness and modality as dependent variables.

The results of the ANCOVA were as follows: The covariate (IQ) was significant ($p = .006$); there was a significant main effect of diagnosis and of relatedness, that is, the priming effect was significant for the whole sample ($p < .001$). There was a significant interaction between relatedness and diagnostic group [$F(1,43) = 8.81$; $p = .005$], which reflected greater overall priming in the patient group. The three-way interaction of Relatedness (priming) × Modality × Group approached significance ($p = .07$), as did the main effect of modality, suggesting a differing effect of modality on priming in the two subject groups (Table 4). In other words, the schizophrenia patients tended to show greater priming in the cross-modal condition than normal controls.

Priming, expressed as a proportional improvement in RT was calculated in order to control for baseline performance as well as because it is also easy to understood intuitively. As a further check we correlated proportional priming indices with mean raw RTs to related targets and the correlation was not significant ($r < .2$) in both patients and controls and in cross-modal and ipsimodal conditions. The results showed that proportional priming effects were significant for both groups in both modality conditions (Table 5, Figure 1).

We calculated an ANCOVA with the proportional priming index as the dependent variable, diagnostic group as the between-group and modality as the within-group measure with IQ included as the covariate. Once again, IQ contributed significantly to the model and the analysis showed that priming differed according to diagnosis (significant main effect of diagnosis in this analysis [$F(1,43) = 8.96$, $p = .005$]. There was no difference overall in proportional priming across the modalities but there was a significant three-way interaction between relatedness, modality and diagnosis [$F(1,43) = 4.34$, $p = .04$]. The direction of the between-group differences was the same as with the log RT analysis, that is, schizophrenia patients had significantly greater priming effects in the cross-modal condition.

Within-Group Analyses

To further explore the interaction between diagnosis and modality, patients and controls were analysed separately with respect to the magnitude of priming in the ipsi- *versus* cross-modal conditions. It emerged that, regardless of whether proportional or log transformed indices of priming were used as the dependent variables, schizophrenia patients showed similar degrees of priming in both conditions while the controls showed significantly greater ipsimodal than cross-modal priming (Table 5).

Table 3. Schizophrenia patients and controls: Reaction time (RT) means in milliseconds and standard deviations for primed (related) and unprimed (unrelated) words in ipsimodal and cross-modal conditions (RTs are trimmed and log-transformed)

	Condition															
	Cross-modal–related				Cross-modal–unrelated				Ipsimodal–related				Ipsimodal–unrelated			
Group	*M*	(*SD*)	Log	(*SD*)	*M*	(*SD*)	Log	(*SD*)	*M*	(*SD*)	Log	(*SD*)	*M*	(*SD*)	Log	(*SD*)
Controls ($n = 26$)	535.6	(97.4)	6.27	(.18)	575.7	(102.5)	6.34	(.17)	555.0	(87.7)	6.31	(.15)	639.5	(113.9)	6.45	(.17)
Patients ($n = 20$)	837.7	(232.4)	6.69	(.27)	1019.5	(262.5)	6.89	(.28)	886.6	(238.8)	6.75	(.28)	1120.0	(387.5)	6.96	(.35)

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Table 4. Repeated measures ANCOVA of priming effects (log transformed RT)

	Log transformed RT	
Variable	$F(1,43)$	p
Covariate (IQ)	8.51	.006
Diagnostic group	41.2	<.001
Relatedness	17.4	<.001
Modality	3.30	.076
Group × Modality	.58	.45
Relatedness × Modality	1.14	.29
Relatedness × Group	8.81	.005
Relatedness × Modality × Group	3.31	.076

The question was addressed of whether, in either group, there was an association between priming in the cross-modal and ipsimodal conditions. Correlational analysis showed that in schizophrenia patients only, the priming effects obtained in the two conditions were highly correlated (Pearson's $r = .50$, $p = .02$ *vs.* $-.09$, $p = .65$ in controls). Spearman correlations were similar: $r_s = .48$ ($p = .03$) for patients *versus* -0.09 ($p = .67$) for controls.

Priming and Psychopathology

Correlations between priming effects and measures of psychopathology were sought. No significant associations with medication levels, SANS or SAPS items were found although some BPRS items did relate significantly to priming: Bizarre behavior, tension, and mannerisms correlated negatively with cross-modal priming effects ($r = -0.44$, $p < .05$) and anxiety correlated negatively with ipsimodal priming ($r = -0.49$, $p = .03$). All other correlations did not approach significance.

DISCUSSION

The results of this study can be summarized, from a between group perspective, as follows: Patients with schizophrenia were less accurate and slower in responding to a primed lexical decision task than normal controls; the patients demonstrated greater cross-modal priming than controls, but did not differ substantially from controls in measures of ipsimodal priming. This pattern of between-group differences was revealed in analysis of both accuracy and RT data. From a within-group perspective, relative to the ipsimodal condition, control subjects showed significantly less priming in the cross-modal condition while schizophrenic patients showed similar priming effects regardless of whether priming is ipsi- or cross-modal. This pattern of results is consistent with our predictions. Looking for the common denominator for our results we suggest that the patients failed to show the expected modality effect on priming, whereas this effect was found in the normal controls. Subsequently, the main differences between the schizophrenia patients and the controls were found with regard to cross-modal priming.

The presence of significant cross-modal priming on lexical decisions by pre-exposure to a semantically related word argues in favor of an amodal conceptual mechanism. While straightforward comparisons between within and cross modality semantic priming are sparse in the literature, the standard inference is that there is usually greater priming within modality (see Anderson & Holcomb, 1995[1]; Holcomb & Anderson, 1993; Rajaram & Roediger, 1993; Roediger & McDermott, 1993), the pattern revealed in the normal controls in the current study. Other relevant studies have shown limited transfer of semantic information between printed and spoken synonyms, or written words from different languages when processed by bilinguals (Roediger & Blaxton, 1987). This suggests that some recoding or translation of lexical representations occurs between prime and target, at some cost to priming effects when their modalities differ. The lack of significant correlation between the priming effects in the two priming conditions in the controls supports the notion that they are separable processes. In the schizophrenia group, there was essentially no modality effect, with cross-modal and ipsimodal priming being of similar magnitude. Furthermore the clear positive association between the priming effects in the cross and ipsimodal conditions in the patients (cf. controls) suggests that there is a lack of separation between the two processes.

It should be noted that the variance in the patient group was large and may have inflated the correlation coefficient. Rank order correlations were therefore used in an effort to minimize this.

The question could arise whether the differences in priming effects were due to a general lack of motivation in the patients causing an increase in response omissions. While errors were more common in the patients, accuracy was high. The analysis of the false negative responses allowed us to rule out this possibility. This showed a significant increase in the cross-modal priming effect, and no significant difference in ipsimodal priming effect relative to controls.

Conventional visual–visual semantic priming was not shown to be significantly increased in schizophrenia patients and did not correlate with any ratings of schizophrenic phenomenology. This confirms previous studies (Barch et al., 1996; Chapin et al., 1992; Ober et al., 1995) and fails to provide support for an abnormality of associations within the semantic network in the visual–lexical modality. Similarly, cross-modal priming was not related to key schizophrenic symptoms (see below).

[1]The only way we have been able to derive a direct comparison between a simple primed visual lexical decision task employed in two otherwise identical forms, that is, in which the prime was either visual (ipsimodal) or auditory (cross-modal), is by extrapolating data from two separate reports (Anderson & Holcomb, 1995; Holcomb & Anderson, 1993). The proportional priming effects at zero, 200 and 800 ms stimulus onset asynchronies for ipsimodal *versus* cross-modal priming were 6.42%, 4.28%, and 2.52% *versus* 4.49%, 2.33%, and 5.97%, respectively.

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Table 5. Priming effects for controls ($n = 26$) and schizophrenia patients ($n = 20$), and cross- and ipsimodal conditions

Measure	Controls	Patients	Effect size*	$F(1,43)$	p
Cross-modal priming effect					
Log RT (*SD*)	0.07 (.03)[a]	0.20 (0.1)[c]	1.87	15.37	<.001
Proportional (*SD*)	7.0% (2.9)[b]	17.3% (10.1)[d]	1.47	15.67	<.001
Ipsimodal priming effect					
Log RT (*SD*)	0.14 (.05)[a]	0.21 (0.16)[c]	0.62	1.69	.20
Proportional (*SD*)	12.9% (4.0)[b]	18.3% (11.8)[d]	0.64	1.46	.23

RT = trimmed reaction time; *SD* = standard deviation.
*mean difference/pooled *SD*
Note. Within-groups comparisons (two-tailed *t* tests): Controls: [a]log-transformed priming: [$t(25) = 5.83$, $p < .001$]; [b]proportional RT: [$t(25) = 5.87$, $p < .001$]. Patients: [c]n.s.; [d]n.s.

Before discussing the results further, a number of methodological issues need to be addressed. We did not use identical word lists in the two experimental conditions although the lexical stimuli themselves were matched in terms of frequency, imageability, concreteness, and semantic relatedness. Given that both the patients and controls were presented with the same word lists in respective modality conditions, differences in the two versions of the task could only produce the between-group effects if such differences interacted in some way with diagnosis. As we could see, the schizophrenia patients showed no difference from controls on performance of an identical ipsimodal priming task yet the groups did differ significantly on exactly the same cross-modal task.

Matching the two versions of the priming task is complicated by inherent differences between auditory and written language (see also Easton et al., 1997). The timing of the stimuli and interstimulus interval depends on different factors (reading speed *vs.* the duration of the auditory trace) and the matching of lexical items on various parameters was based on written norms. The effect of the variable length of auditory prime was examined by contrasting short and long words [based on a split about the mean (*M* length = 275 ms)]. There was no effect of length on any outcome measures. Similarly, restricting the analysis to short words (i.e., those most similar in length to the duration of visual primes) also did not materially alter the results (data available on request).

The greater mean RT and standard deviation in the patients tested was anticipated. Group comparisons of priming effects were therefore expressed in various ways including the difference in trimmed and logarithmically transformed RT between related and unrelated targets, and as a proportion, both manipulations designed to minimize the effects of the greater variance and slowness in the schizophrenia group. Closer matching of patients and controls, especially in terms of parental educational achievement would be desirable in future studies.

What are the implications of these results? The lack of "modality modularity" may be interpreted as a breakdown of modality-specific information processing operations, in other words, evidence for dysmodularity (David, 1994). The

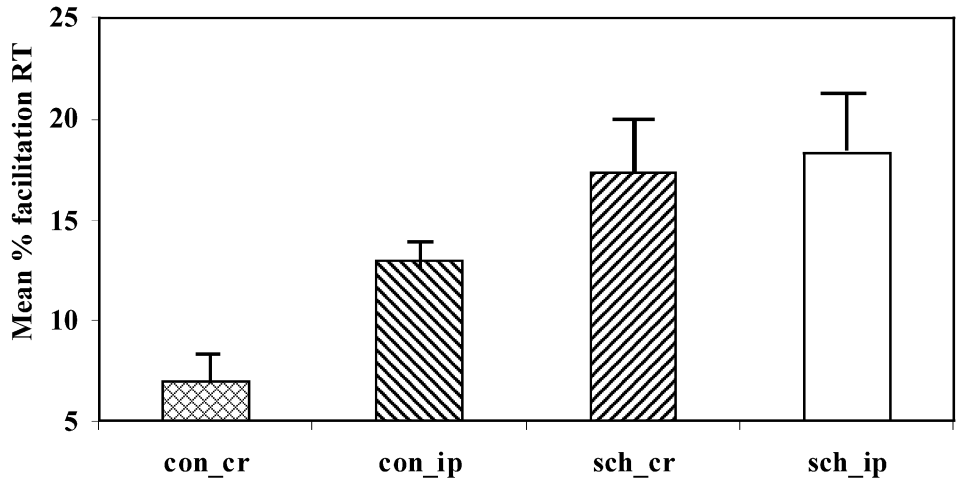

Fig. 1. Proportional priming effects for ipsi- and cross-modal priming. Schizophrenia patients ($n = 20$) and controls ($n = 26$). Con-cr: cross-modal priming in controls; Con-ip: ipsimodal priming in controls; Sch-cr: cross-modal priming in schizophrenia; Sch-ip: ipsimodal priming in schizophrenia. Error bars represent standard error.

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latter is an impairment of informational encapsulation leading to, in this case, an overlap between phonological and orthographic representations of words. It is tempting to postulate that this excessive cross-talk could result in some aspects of schizophrenic psychopathology such as abnormal perceptions. However, we found no relationship between cross-modal priming and symptoms such as delusions, hallucinations and thought disorder as rated by the SANS and SAPS. The patients in the current study were all rather chronic and were not selected on the basis of specific psychopathology. Further studies contrasting larger more diverse patient groups may be revealing. There was however, a suggestion that the integrity of motor control and behavior, as indexed by items on the BPRS, may be related to a relative lack of cross-modal priming.

Functional neuroimaging research has been able to map modality specific semantic stores (Thomson-Schill et al., 1999) as well as specific neural substrates for cross- and ipsi-modal mnemonic priming (Badgaiyan et al., 2001; Schacter et al., 1999) in normal volunteers. Badgaiyan et al. (2001) for example demonstrated increased activation in prefrontal cortex associated with cross-modal priming, but not with ipsimodal priming in normal subjects. These findings lend support to the hypothesis of different modular structures subserving ipsimodal and cross-modal priming. One prediction arising out of this is that schizophrenia patients would fail to show such modular architecture or modality specific patterns of activation on the same tasks. This was indirectly confirmed in a previous fMRI study (Surguladze et al., 2001) demonstrating a less modular organization of visual speech processing in schizophrenia.

However, a purely cognitive account of the findings in schizophrenia could be posited. The tendency for information in general to be processed amodally or converted from one modality to another could render an individual liable to source memory errors. As our schizophrenia patients demonstrated a lack of modality specificity in lexical–semantic processing, this could make them particularly vulnerable to errors in modality monitoring. The evidence for schizophrenia patients experiencing source monitoring difficulties is growing (Brébion et al., 1997; Keefe et al., 1999; Vinogradov et al., 1997). Thus, the cross-modal priming abnormality, namely, impairment in the modularity of speech processing, may contribute to source monitoring errors by weakening modality specific automatic processing, which in turn would impact on the more controlled processes that make up source monitoring. One hypothesis arising from this is that source monitoring errors would be greater in schizophrenia patients than controls when inputs are presented in two or more modalities compared with inputs from two or more sources within the same modality.

We cannot comment on whether the priming effects we observed, particularly those in the auditory–visual cross-modal condition, pertain in both directions, that is, visual–auditory, or indeed whether auditory–auditory priming is normal in schizophrenia. Further studies of this are necessary before giving a definitive account of putative abnormalities in auditory to visual priming. Similarly, contrasting studies of cross-modal indirect with direct semantic priming would be necessary to place the current findings in the framework of abnormal spreading of activation as advanced by Spitzer (1997).

To conclude, our study demonstrated increased cross-modal semantic priming in schizophrenia patients relative to controls. These results could reflect an abnormality in modality-specific processing in schizophrenia or dysmodularity affecting auditory–verbal processing in particular.

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