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An event-related brain potential study of schizotypal personality and associative semantic processing

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ABSTRACT

To examine whether schizotypal personality is associated with the degree to which concepts activate each other in semantic memory, event-related brain potentials (ERPs) were recorded during a delayed lexical decision task from healthy volunteers rated for schizotypy. Each target word was directly, indirectly, or not at all related to a prime word preceding it at a 300- or 750-ms stimulus-onset asynchrony (SOA). Overall, N400 amplitudes were largest for unrelated targets, smallest for directly related targets, and intermediate for indirectly related targets. Higher total Schizotypal Personality Questionnaire (SPQ) scores correlated with smaller N400 indirect priming effects (i.e., smaller N400 amplitude differences between unrelated and indirectly related targets) at both SOAs. In addition, schizotypal subscale scores were differentially associated with N400 effects. Higher SPQ Cognitive-Perceptual scores correlated with smaller N400 direct priming effects (smaller N400 amplitude differences between unrelated and directly related targets) at both SOAs, and with smaller N400 indirect priming effects at the shorter SOA. These correlations are consistent with the hypothesis that decreased use of meaningful context to activate related concepts in general, and/or to inhibit unrelated concepts, may play some role in the development of unusual beliefs.

1. Introduction

Schizotypal personality traits include unusual beliefs, ideas of reference (thoughts that external events or situations have special personal significance), odd speech, eccentric appearance or behavior, perceptual abnormalities, suspiciousness, and social isolation (American Psychiatric Association, 2000). Several of these traits appear to reflect the formation of unusual associations between concepts. For instance, odd speech in schizotypy has been characterized as "loose, digressive" (American Psychiatric Association, 2000), or "unusually circumstantial" (Hales and Yudofsky, 2003). Paranormal beliefs, magical thinking, ideas of reference, and suspiciousness also involve the supposition of meaningful associations between objects or occurrences that are normatively regarded as unrelated or co-incidental (Bressan, 2002; Gianotti et al., 2001). An association of schizotypy with a propensity for forming uncommon semantic associations is apparent on a number of language-based psychometric tests. Individuals scoring higher in magical or paranormal ideation generate more unusual responses in free word-association tests (Gianotti et al., 2001; Miller and Chapman, 1983), and give higher relatedness ratings to word pairs that are normatively unassociated (Mohr et al., 2001). In addition, individuals higher in schizotypy generate less typical exemplars of fruits in response to the category label (Kiang and Kutas, 2006).

It has been hypothesized that unusual associations in schizotypy reflect some difference in how meaningful concepts activate one another in the brain (Niznikiewicz et al., 2002; Pizzagalli et al., 2001; Moritz et al., 1999). These hypotheses assume a model of semantic long-term memory in which concepts are represented as nodes in a network, and associations between concepts are links among these nodes (Anderson and Pirolli, 1984; Collins and Loftus, 1975; Neely, 1977). As a concept node is activated – e.g., when the individual encounters its corresponding word or image – activation spreads through the network to associated nodes, falling off as a function of decreasing relatedness. The greater the activation level of a concept, the more facilitated is its processing.

According to one hypothesis, schizotypy involves an increase in the degree to which a given stimulus concept activates its relatively weaker associates in the semantic network, leading to unusual associations in language and reasoning (Mohr et al., 2001; Pizzagalli et al., 2001). Some researchers have hypothesized that this anomaly primarily affects activation that normally spreads "automatically" (without conscious control) through the semantic network relatively quickly (< approximately 350 ms) after stimulus onset — in contrast to "controlled" activation which is slower-acting and thus subject to modulation by more effortful, conscious, task-relevant strategies

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(Niznikiewicz et al., 2002; see also Neely, 1977, for discussion of the automatic/controlled distinction in semantic priming).[1] Some results from reaction-time (RT) semantic priming paradigms are consistent with the hypothesis of increased spread of activation to weaker associates in schizotypy. RT semantic priming refers to faster responses to a target stimulus when it is preceded by a related prime stimulus as compared to an unrelated prime. Semantic priming is taken to reflect greater activation of the target representation by the related prime than by the unrelated prime. Pizzagalli et al. (2001) examined priming effects for indirectly related word pairs (i.e., not directly related, but mediated by at least one other concept, e.g., CAT and CHEESE, mediated by MOUSE), which are considered relatively weak associates, in paranormal believers compared to non-believers. These indirect priming effects were larger in believers than non-believers (at least for left lateralized targets). This study employed a relatively short stimulus-onset asynchrony (SOA) of 200 ms between prime and target words, thus assessing the spread of activation at a relatively early timepoint following the prime. In another word-pair study, high scorers on the Perceptual Aberration/Magical Ideation scale exhibited greater priming than did control participants for target words that were related to their primes, but that had not been named as associates of the prime in word-association tests (Kerns and Berenbaum, 2000).[2]

Other results, however, have suggested that, instead of or in addition to being characterized by increased activation of weak associates, schizotypy is characterized by increased activation of strong associates. These studies used electrophysiological data — namely, the N400 component of the scalp-recorded event-related brain potential (ERP), as an index of semantic priming. The N400 is a relative negativity peaking approximately 400 ms after presentation of any potentially meaningful stimulus, such as a word or picture. Its amplitude is reduced (made less negative) by a host of factors facilitating an item's processing (reviewed in Kutas and Federmeier, 2000) — including greater relatedness to a preceding item (Kutas and Hillyard, 1980; Kutas, 1985; Holcomb and Neville, 1990; Holcomb and Neville, 1991; Stelmack and Miles, 1990). With all else held constant, the amplitude of the N400 can thus serve as a measure of the degree to which concepts activate one another in semantic memory: the greater the activation, the smaller the N400 negativity. Niznikiewicz et al. (2002) found that, at an SOA of 450 ms, women with schizotypal personality disorder (SPD) and control women had similar N400 amplitudes to unrelated word-pair targets, but SPD women had smaller (less negative) N400 amplitudes than control women to related targets. At a longer SOA of 1000 ms, the groups did not differ in N400 amplitudes for any of the stimuli. These results suggested that the interval between prime and target may indeed be critical in determining whether or not reliable group differences obtain: SPD was reliably characterized by greater activation of associated words only at short intervals. In addition, it is important to note that since it is unclear whether the word-pair stimuli in this study were based on word-association norms, it is possible that the pairs, although directly related, may have been only relatively weak associates, making the results consistent with increased activation of weak associates in schizotypy.

According to a different (non-mutually exclusive) hypothesis, schizotypy may be accompanied by decreased use of context to activate related concepts in general, or to inhibit unrelated concepts (Niznikiewicz et al., 2002, 1999; Kiang and Kutas, 2005). Consistent with this hypothesis, schizotypy has been found to be associated with larger than normal N400 amplitudes to *congruent* sentence endings (Niznikiewicz et al., 1999, 2004), and to exemplars of a category following the category definition (Kiang and Kutas, 2005), suggesting less than normal contextual activation. In another study, SPD was associated with a less than normal difference between N400 amplitudes to congruent and incongruent sentence endings, again consistent with decreased use of sentential context (Kimble et al., 2000).

Not only is decreased use of context not necessarily mutually exclusive with increased or more broadly spreading activation of related items, but it has been proposed that both may occur but with different time courses: thus, schizotypy may be characterized by increased or broader activation of related concepts at relatively short SOAs, but by deficient use of context at longer SOAs (Moritz et al., 1999; Niznikiewicz et al., 2002). Taken together, the experimental results are generally consonant with this pattern. The experiments by Pizzagalli et al. (2001) and Niznikiewicz et al. (2002), whose results suggested increased or broader activation of related concepts with higher schizotypy, employed SOAs of 200 and 450 ms, respectively. In contrast, the results suggesting decreased context use to activate related items or to inhibit unrelated items have come from experiments with longer SOAs, including sentence contexts which build up over several seconds.

In the present study, we sought further evidence on how schizotypal personality, semantic relatedness and time interact to modulate semantic priming effects. To this end, we studied participants from a non-clinical population, who were rated on schizotypy. We examined N400 amplitude of the ERP in these individuals as they read word pairs that were strongly (directly) related, weakly (indirectly) related or unrelated, and that were presented one word at a time, at both short and long SOAs (300 and 750 ms) for each participant. In constructing the stimuli, we used word-association norms to verify that directly related word pairs were strongly normatively associated, and that indirectly related pairs were not normatively associated (even though the prime and the mediating concept, as well as the mediating concept and the target, were normatively associated).

We hypothesized that, over all participants, consistent with previous N400 studies of indirectly related word pairs (Kreher et al., 2006; Hill et al., 2005; Silva-Pereyra et al., 1999; Weisbrod et al., 1999), N400 amplitude would be largest (most negative) to unrelated targets, smallest (least negative) to directly related targets, and intermediate to indirectly related targets. Furthermore, we hypothesized that, if schizotypy is associated with *increased activation of weakly related concepts* such as indirectly related words, then schizotypy would be correlated with larger N400 amplitude differences between unrelated and indirectly related targets, i.e., larger N400 *indirect priming effects* — stemming from smaller (less negative) N400 amplitudes to indirectly related targets. Likewise, if schizotypy is associated with *increased activation of strongly related concepts*, as reflected in smaller N400 amplitudes to directly related targets, then schizotypy would be correlated with larger N400 amplitude differences between unrelated and directly related targets, i.e., larger N400 *direct priming effects*. Moreover, if, as previously hypothesized (Moritz et al., 1999; Niznikiewicz et al., 2002), increased activation of related concepts occurs only at short SOAs, then the correlation between schizotypy and increased indirect and/or direct priming effects would be seen only at the 300-ms SOA and not at the 750-ms SOA.

Alternatively or in addition, we hypothesized that if schizotypy is characterized by *decreased use of context to activate both directly and indirectly related concepts*, then schizotypy would be associated with reduced N400 amplitude differences between unrelated targets and both types of related targets (i.e., smaller N400 *direct and indirect priming effects*), due to larger N400 amplitudes to directly and indirectly related targets. Moreover, if decreased context use in schizotypy occurs

[1] Such a controlled process could occur, for example, in an experimental paradigm in which prime-target word pairs are sequentially presented and some of the targets are related to their preceding prime. Participants might detect a relationship between some primes and targets; subsequently, upon seeing each prime, they might predict an expected target or set of targets, increasing activation of the corresponding representations in semantic memory (Barch et al., 1996). However, the correspondence of early and late semantic processing with automatic and controlled responses, respectively, is not clear-cut, as there is evidence that conscious, top-down processes can modulate early activation (Barch et al., 1996; Hill et al., 2005), and conversely that unconscious processing can affect later activation (Deacon et al., 1999).

[2] In this study, the prime was presented until the participant named it (up to a maximum duration of 1500 ms), and was then followed by a 350-ms interval until target onset; thus SOAs potentially ranged from 350 to 1850 ms.

only at long SOAs, then the correlation of schizotypy with reduced N400 priming effects would be seen only at the 750-ms SOA and not at the 300-ms SOA.

We also hypothesized that specific subsets of schizotypal traits might be differentially related to N400 semantic priming effects. Empirically, individuals' scores on schizotypal traits have been found to load on three semi-independent factors (Reynolds et al., 2000; Raine et al., 1994; Rossi and Daneluzzo, 2002). These factors have been termed *cognitive-perceptual* (comprising ideas of reference, odd beliefs, unusual perceptual experiences, and suspiciousness); *disorganized* (odd behavior and odd speech); and *interpersonal* (social anxiety, lack of close friends, constricted affect, and suspiciousness (Raine et al., 1994). Given the putative role of semantic priming differences in the development of disorganized speech and unusual ideation, we predicted that the disorganized and cognitive-perceptual factors of schizotypy would be those specifically correlated with the N400 priming differences hypothesized above.

2. Materials and methods

2.1. Participants

28 healthy participants [15 female, 18 to 23 years of age, mean age 19.7, SD = 1.5] were recruited from the University of California, San Diego (UCSD) campus. All were undergraduate students. Exclusion criteria included: left-handedness, as assessed by the Edinburgh Inventory (Oldfield, 1971); and any self-reported history of: exposure to a language other than English at home as a child, reading difficulties, visual impairment, current or past neurological or psychiatric disorder, or current use of neurological or psychotropic medications. 13 participants reported having a left-handed first-degree relative. Participants gave written informed consent and were compensated with course credit or cash. The study procedure was approved by the UCSD Human Research Protections Program.

2.2. Rating scales

Participants completed the Schizotypal Personality Questionnaire (SPQ; Raine, 1991), a self-report measure of schizotypy. It consists of 74 dichotomous-choice (Yes or No) questions, comprising 9 subscales corresponding to each of the 9 DSM-IV schizotypal traits (American Psychiatric Association, 2000). These subscales have been found to load onto 3 factors: Cognitive-Perceptual (comprising the Ideas of Reference, Odd Beliefs, Unusual Perceptual Experiences and Suspiciousness subscales), Disorganized (Odd Behavior and Odd Speech), and Interpersonal (Social Anxiety, No Close Friends, Constricted Affect and Suspiciousness) (Raine et al., 1994). The maximum total SPQ score is thus 74; maximum possible factor scores are Disorganized: 16; Cognitive-Perceptual: 33; and Interpersonal: 33.

Participants also completed the Peabody Picture Vocabulary Test (PPVT; Dunn and Dunn, 1997) as a measure of receptive vocabulary.

2.3. Stimuli

The stimuli included 52 directly related, 52 indirectly related and 52 unrelated prime-target word pairs. For each directly related pair, the target was selected from among the words most commonly given as associates to the prime in the word-association norms of Nelson et al. (1999). Mean response probability of directly related targets (i.e., the proportion of individuals who produced that word in response to the prime, in the norms) was 0.36 (SD = 0.23). Indirectly related pairs included 35 pairs used in previous studies (Balota and Lorch, 1986; McNamara and Altarriba, 1988; Richards and Chiarello, 1995), and 17 new pairs. For each indirectly related pair, the prime and target were not associates according to the norms (i.e., the target was not among the words produced by more than one individual in response to the prime), but the mediating word was an associate of the prime (mean response probability 0.38, SD = 0.22), and the target was an associate of the mediating word (mean response probability 0.19, SD = 0.18). Finally, for each unrelated pair, the prime and target were not associates according to the norms. Across these three conditions, targets were matched for mean length, log frequency (Francis and Kucera, 1982), concreteness (Wilson, 1988), and number of orthographic neighbours (Wilson, 1988). Across the conditions, primes were also matched for mean length and log frequency. In addition, the stimuli included 156 word-nonword prime-target pairs, whose targets were pronounceable nonwords from among those used by Deacon et al. (2004). No word occurred more than once among all the stimuli. Examples of prime-target pairs used in the experiment are shown in Table 1.

The 312-trial stimulus list included all of the above prime-target pairs in a fixed randomized order. It was divided into four blocks of 78 trials each. In addition, the list had two versions, in which the ordering of prime-target SOAs across blocks was counterbalanced. In version A, prime-target pairs were presented with SOA of 300 ms in blocks 1 and 3, and 750 ms in blocks 2 and 4; in version B, the SOA was 750 ms in blocks 1 and 3, and 300 ms in blocks 2 and 4.

2.4. Experimental procedure

Participants were tested in a single session in a sound-attenuated, electrically-shielded chamber. They were seated 100 cm in front of a video monitor on which the stimuli were visually presented, with each letter subtending on average approximately 0.36° of visual angle horizontally, and up to 0.55° vertically. Words were displayed in yellow letters (all capitalized) on a black background.

Each participant was presented with the stimulus list, with short rest breaks between blocks. Half the participants received each version of the list. Each trial consisted of the following sequence: a) a row of preparatory fixation crosses at the center of the screen for 500 ms; b) blank screen for 250 ms; c) prime word for 250 ms; d) blank screen for 50 ms (in 300-ms SOA trials) or 500 ms (in 750-ms SOA trials); e) word or nonword target for 250 ms; f) blank screen for 1250 ms; g) the prompt *Yes or No?* until participants responded with a button-press (see below); and h) blank screen for 3000 ms until onset of the next trial. All stimuli were presented centered on the screen.

Upon presentation of the prompt, participants were required to press one of two buttons, on joysticks held in the right and left hands respectively. One button (labeled "Yes") signaled that the target was a word, while the other button (labeled "No") signaled that it was a nonword. The assignment of buttons was divided equally among participants, counterbalanced across the two versions of the stimulus list. This lexical-decision task was included to allow verification that participants were attending to the stimuli.

2.5. Electrophysiological data collection and analysis

The electroencephalogram (EEG) was recorded from 26 tin electrodes embedded in an electro-cap, and referenced to the left

Table 1
Examples of prime-target stimulus pairs used in the experiment.

Directly related word pairs	Indirectly related word pairs (prime-mediator-target)	Unrelated word pairs	Word-nonword pairs
TOAD-FROG	CORK-WINE-GRAPE	GRAIN-SHRUB	JAIL-AGLEM
HEEL-TOE	NAVY-ARMY-TANK	DIALOGUE-CORD	CORNER-DOFUD
UNCLE-AUNT	BLADE-KNIFE-FORK	ILLNESS-TOWER	JOB-GUD
METAL-STEEL	BULL-COW-MILK	BAKER-HUNGRY	CANDLE-LICIN
CAPTAIN-SHIP	SPLASH-WATER-DRINK	WIFE-TEAM	CAVERN-OSPONT
COLOR-BLUE	TOOTH-BRUSH-HAIR	MOUTH-MARKET	FIG-VAD

mastoid. Electrodes were equally spaced across the scalp, with positions and labels as shown in Fig. 1. Blinks and eye movements were monitored via electrodes placed on the outer canthus (left electrode serving as reference) and infraorbital ridge of each eye (referenced to the left mastoid). Electrode impedances were kept below 5 kΩ. The EEG was processed through Grass amplifiers set at a bandpass of 0.01–100 Hz, continuously digitized at 250 Hz, and stored on hard disk for later analysis.

The EEG was re-referenced off-line to the algebraic mean of the left and right mastoids. ERPs were computed for epochs extending from 100 ms before stimulus onset to 920 ms after stimulus onset. Individual trials containing artifacts due to eye movement, excessive muscle activity or amplifier blocking were rejected off-line before time-domain averaging; approximately 7% of trials were lost due to such artifacts. If data from a participant contained excessive blinks, they were corrected using a spatial filter algorithm (Dale, 1994); this was applied to 5 participants' data.

To assess the timing of semantic processing of targets, for each trial N400 peak latency was measured as the interval between stimulus (target) onset and the largest negative peak between 250 and 550 ms post-stimulus.

N400 amplitude was measured as mean voltage from 300–500 ms post-stimulus. For each participant, N400 effects were defined as the mean voltage from 300–500 ms post-stimulus for the difference waves between ERPs for: unrelated targets minus directly related targets (*direct priming effect*), and unrelated targets minus indirectly related targets (*indirect priming effect*).

2.6. Statistical analysis

For each SOA condition, N400 peak latency and N400 amplitude were each analyzed in a repeated-measures analysis of variance (ANOVA) over all participants with Target (directly related vs. indirectly related vs. unrelated) and Electrode (26 levels, corresponding to all recording sites) as within-subject variables. *p*-values for ANOVA within-subject factors are reported after Greenhouse-Geisser Epsilon correction. Pairwise comparisons of factor-level means were made using the Tukey procedure for simultaneous pairwise comparisons, with a family confidence coefficient of 0.95.

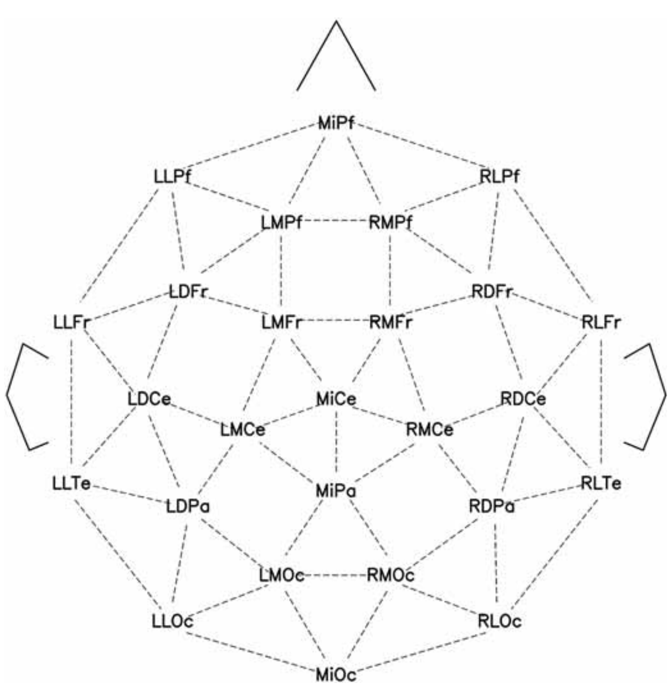

Fig. 1. Schematic diagram of the electrode array, with nose at the top.

Based on the observed distribution of N400 effects across the scalp in the grand-average ERPs, a representative site where these effects were prominent (MiPa; Pz in the International 10–20 system) was chosen for computation of statistical significance of Pearson pairwise correlation coefficients *r* between SPQ total/factor scores and N400 measures (N400 mean amplitude for each target condition, and N400 effects).

3. Results

3.1. Rating scales

Table 2 shows rating scale scores for the study sample. The distribution of SPQ scores was consistent with previous reports from non-selected community samples (Kiang and Kutas, 2006; Rossi and Daneluzzo, 2002; Wang et al., 2004). Independent-samples *t*-tests showed that men and women did not differ on mean SPQ total and factor scores, or PPVT scores (all $p > 0.10$).

3.2. Behavioral data

Overall, participants correctly classified 99% of the word targets in the lexical-decision task, indicating that they were attending to the stimuli and task. Across individuals, percentage of correct responses was not significantly correlated with SPQ total or factor scores (all $p > 0.10$).

The lexical-decision task involved a delayed response, and thus was not designed to assess RT priming. Nevertheless, participants' response times (time from response prompt to button press) differed significantly by target condition [$F(2,81) = 3.26$, $p < 0.05$]. Mean response times were 587 ms for directly related targets, 619 ms for indirectly related targets, and 630 ms for unrelated targets, with response times for directly related and unrelated targets differing significantly from each other. Moreover, higher SPQ total scores were correlated with longer response times for both indirectly related ($r = 0.44$, $p = 0.02$) and unrelated targets ($r = 0.45$, $p = 0.02$). Higher SPQ Cognitive-Perceptual scores were correlated with longer response times for directly related ($r = 0.40$, $p = 0.04$), indirectly related ($r = 0.53$, $p = 0.003$), and unrelated targets ($r = 0.55$, $p = 0.002$).

3.3. Grand average ERPs

Grand average ERPs ($n = 28$) at all electrodes are shown for the 300-ms and 750-ms SOAs in Fig. 2.

3.4. N400 analyses

3.4.1. 300-ms SOA

At the 300-ms SOA, mean N400 peak latency was 381 ms for directly related targets, 376 ms for indirectly related targets, and 386 ms for unrelated targets, with no significant difference between these conditions [$F(2,54) = 0.91$, $p = 0.41$, $\varepsilon = 0.91$].

Over all electrodes, N400 amplitude was largest (most negative) for unrelated targets (mean $= -0.14$ μV), intermediate for indirectly

Table 2
Means, standard deviations and ranges of rating scale scores for the study sample ($n = 28$).

Scale	Mean	SD	Range	Maximum possible score
SPQ (total)	17.4	10.6	1–37	74
SPQ COGNITIVE-PERCEPTUAL FACTOR	7.8	5.3	0–19	33
SPQ INTERPERSONAL FACTOR	6.6	5.4	0–21	33
SPQ DISORGANIZED FACTOR	4.6	4.3	0–12	16
PPVT	186.1	6.3	170–197	204

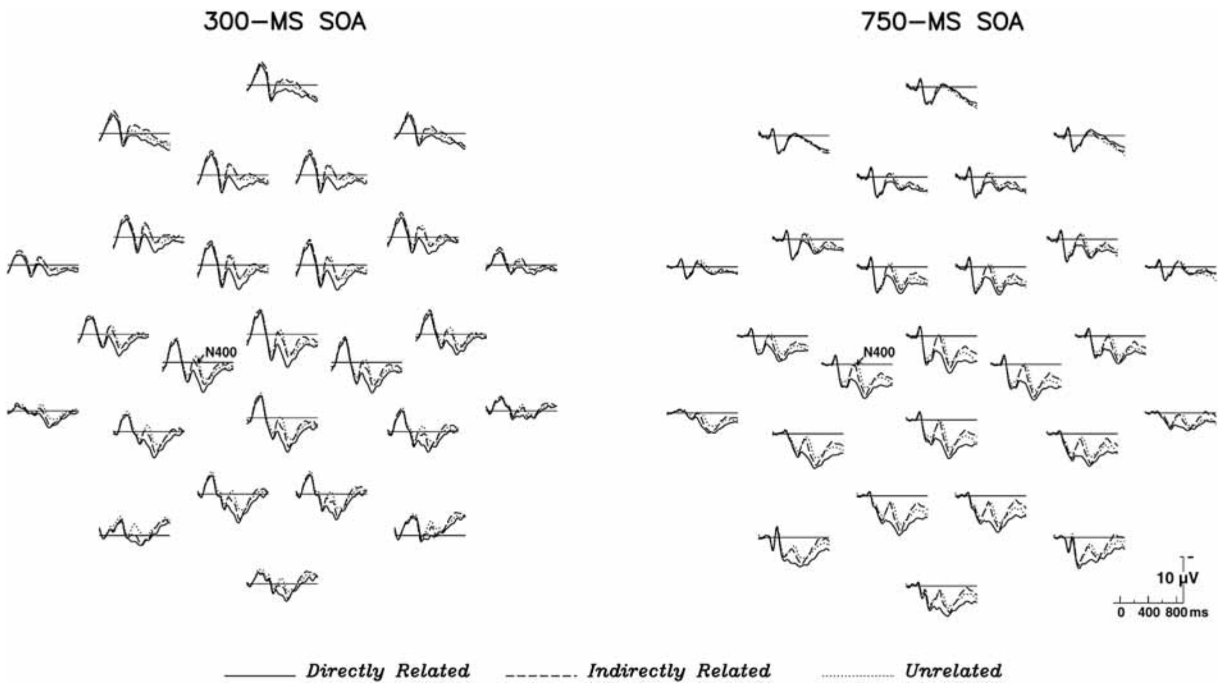

Fig. 2. Grand average ERPs for all participants ($n=28$), for the three target word types, at all electrode sites. Negative voltage is plotted upward. Electrode sites are arranged as in Fig. 1.

related targets (0.41 µV), and smallest (most positive) for directly related targets (2.36 µV) [$F(2,54)=25.39$, $p<0.0001$, $\varepsilon=0.76$], with all three conditions significantly different from one another. The differences in N400 amplitudes among target types were broadly distributed over the scalp, and largest medially and parieto-occipitally [Target × Electrode interaction: $F(50, 1350)=4.55$, $p=0.0007$, $\varepsilon=0.10$], a distribution consistent with previous N400 studies of word reading (Kutas and Van Petten, 1994; Federmeier and Kutas, 1999).

Pairwise correlations between SPQ total/factor scores and N400 effects at MiPa, across all participants, are shown in Table 3. Since the N400 has a negative amplitude, *positive* r-values indicate that the N400 effect was *smaller* with higher schizotypy scores. Higher SPQ total scores were correlated with smaller indirect priming effects. Higher SPQ Cognitive-Perceptual scores were significantly correlated with smaller direct and indirect priming effects.

None of the SPQ total and factor scores were significantly correlated with N400 amplitude at MiPa for any of the target conditions (all $p>0.10$).

Table 3
Correlation coefficients r of SPQ total and factor scores with N400 effects at MiPa ($n=28$ participants).

	Direct priming effect	Indirect priming effect
300-ms SOA		
SPQ total	0.13	0.44*
Cognitive-perceptual	0.46*	0.38*
Disorganized	0.10	0.25
Interpersonal	−0.28	0.35
750-ms SOA		
SPQ total	0.22	0.38*
Cognitive-perceptual	0.48*	0.34
Disorganized	0.03	0.23
Interpersonal	−0.03	0.33

*$p<0.05$.
**$p<0.01$.

3.4.2. 750-ms SOA

At the 750-ms SOA, over all electrodes, N400 peak latency was shortest for directly related targets (mean = 368 ms), intermediate for indirectly related targets (373 ms), and longest for unrelated targets (383 ms) [$F(2,54)=3.34$, $p=0.05$, $\varepsilon=0.83$], with all three conditions significantly different from one another.

Over all electrodes, N400 amplitude was largest (most negative) for unrelated targets (mean = 1.06 µV), intermediate for indirectly related targets (1.72 µV), and smallest for directly related targets (3.29 µV) [$F(2,54)=18.69$, $p<0.0001$, $\varepsilon=0.98$], with all three conditions significantly different from one another. The differences in N400 amplitudes among target types were broadly distributed over the scalp, and largest medially and parieto-occipitally [Target × Electrode interaction: $F(50, 1350)=7.13$, $p<0.0001$, $\varepsilon=0.10$].

Pairwise correlations between SPQ total/factor scores and N400 effects at MiPa, across all participants, are shown in Table 3. At the 750-ms SOA, like at the 300-ms SOA, higher SPQ total scores were significantly correlated with smaller indirect priming effects. Higher SPQ Cognitive-Perceptual scores were significantly correlated with smaller direct priming effects.

Higher SPQ Interpersonal scores were significantly correlated with reduced (more positive) N400 amplitudes at MiPa (midline parietal site) for both unrelated targets ($r=0.47$, $p=0.01$) and directly related targets ($r=0.49$, $p=0.009$). There were no other significant pairwise correlations between SPQ total/factor scores and N400 amplitudes at MiPa for the different target types (all $p>0.15$).

4. Discussion

In this experiment, we investigated the relationship between schizotypal personality and associative semantic processing by using the N400 component of the ERP elicited during a delayed lexical-decision task. Participants were presented with prime words, each followed by a target letter string that was either a real word or a pseudoword. One third of the target words were directly associatively related to the prime (such as TOY–DOLL), one third were only indirectly associatively related (i.e., via a mediating word; CAT–[MOUSE]–CHEESE), and one third were unrelated (FURNACE–SHELL). Across all participants, N400 amplitudes to target words were largest (most negative) for unrelated words, smallest (least negative) for directly related words, and intermediate for indirectly related words.

In addition, higher SPQ total scores were significantly correlated with smaller N400 indirect priming effects (i.e., N400 amplitude differences between target words unrelated and indirectly related to the prime, at both prime-target SOAs (300 and 750 ms). Higher SPQ Cognitive-Perceptual factor scores were significantly correlated with smaller N400 direct priming effects (N400 amplitude differences between target words unrelated and directly related to the prime), at both SOAs; and with smaller N400 indirect priming effects at the 300-ms SOA.

The correlations of higher SPQ total and Cognitive-Perceptual scores with smaller N400 priming effects are consistent with an association of overall and cognitive-perceptual schizotypy with decreased activation of concepts related to a prime, decreased inhibition of concepts unrelated to it, or both. Our data do not allow us to unequivocally distinguish between these possibilities, because SPQ total and Cognitive-Perceptual scores were not significantly correlated with raw N400 amplitudes for any of the target conditions.

This finding appears to corroborate previous reports of an association between schizotypy and decreased N400 priming effects (Kiang and Kutas, 2005; Kimble et al., 2000; Niznikiewicz et al., 2004, 1999). These previous studies used either relatively long SOAs of 2400 to 2800 ms (Kiang and Kutas, 2005), or sentence contexts (Kimble et al., 2000; Niznikiewicz et al., 2004, 1999), which also build up over a relatively long time interval. Taken together, these findings appear most consistent with the hypothesis that cognitive-perceptual schizotypy is associated with less efficient use of context to initiate or maintain activation of related concepts and/or inhibition of unrelated concepts, beginning as early as 300 ms following a contextual stimulus, and continuing thereafter.

A number of the traits that constitute cognitive-perceptual schizotypy – ideas of reference, odd beliefs, and suspiciousness – typically involve the presumption of meaningful associations between objects or actions that would normally be regarded as unrelated or co-incidental (Bressan, 2002; Gianotti et al., 2001). For example, a person may suspect that strangers' glances or hand motions influence the person's own thoughts or feelings; that thinking negatively about others can cause harm to befall them; that statements in a professor's lecture refer specifically to events in that person's own life; or that objects in the person's home have been re-arranged by unknown persons or forces (Eckblad and Chapman, 1983). Accordingly, individual differences in how a meaningful stimulus affects activation of related concepts and/or inhibition of unrelated concepts could plausibly contribute to the development of unusual ideation. If, for instance, following some stimulus, an individual encounters another, unrelated stimulus which has been supranormally activated, this could conceivably lead to the aberrant experience that the two stimuli are meaningfully related. Consequently, the individual might infer a paranormal or self-referential connection between the stimuli in an attempt to explain this subjective experience (Gianotti et al., 2001). Furthermore, common benign stimuli might be viewed as suspicious if they do not bring to mind similar occurrences to a normal degree (Miller et al., 1989) by activating the representations of these occurrences in semantic memory.

Our data do not support an association of schizotypy with broader spread of activation to weakly related items. If this were the case, we would expect individuals with higher schizotypy to have *larger* N400 indirect priming effects, due to reduced N400 amplitudes to indirectly related targets. However, contrary to this hypothesis, we found overall schizotypy to be associated with *smaller* N400 indirect priming effects, at both the SOAs we employed. In addition, cognitive-perceptual schizotypy was also associated with smaller indirect priming effects at the 300-ms SOA.

Our results thus appear to differ from a previously reported association of higher schizotypy with larger RT indirect priming effects at short SOAs (Pizzagalli et al., 2001). These contrasting results could be due to differences in study methodology or population; unlike our study, Pizzagalli et al. (2001) used left lateralized targets, and measured cognitive-perceptual schizotypy with a questionnaire focusing on paranormal belief. In addition, although both our study and that of Pizzagalli et al. (2001) employed lexical-decision tasks (which help to verify that participants are attending to the stimuli), some researchers have suggested that this task masks the effect of spontaneous spreading activation (Balota and Lorch, 1986; Barch et al., 1996), by increasing the proportion of activation due to strategic processes (e.g., prediction of strong associates), which could decrease indirect priming effects. Thus, in our study, another task, such as pronunciation or silent reading, might have elicited increased spreading activation in individuals with higher schizotypy. Finally, the contrast between our results and those of Pizzagalli et al. (2001) could stem from a dissociation between the dependent measures from which the priming effects were inferred, namely, between electrophysiological (N400) priming effects and RT priming effects. Individuals with higher versus lower schizotypy scores might present with similar N400 indirect priming effects, but larger RT indirect priming effects, as a result of processes specifically affecting RT but not the N400. For example, suppose that individuals check for a relationship between prime and target before responding that the target is a word (as is proposed to occur by Balota and Lorch (1986) and are able to detect some meaningful relationship between indirectly related words, but not between unrelated words. Then, if individuals higher in schizotypy were to rely more on this strategy, this could lead to a greater RT difference between indirectly related and unrelated targets in these individuals relative to those with lower schizotypy.

Given the hypothesized link between semantic activation differences and disorganized speech in schizotypy (Moritz et al., 1999; Niznikiewicz et al., 2002), the lack of a significant correlation in this study between the SPQ Disorganized factor and N400 effects might seem unexpected. This negative finding is consistent with results of a previous study in which we also did not find any correlation between these variables (Kiang and Kutas, 2005). Taken together, these results suggest that disorganized or unusual speech in the general population, at least as identified by self-report, may arise from processes other than those reflected in the N400 which we presume to reflect differences in how concepts activate one another in semantic memory. A limitation of these two studies is that we recruited a general population sample, rather than individuals with extreme schizotypy scores (such as persons with SPD), in whom an association of disorganized speech with N400 anomalies might be found.

Overall, our results suggest that the factors of schizotypy are differentially related to semantic priming — just as they have been found to have dissociable relationships with other neuropsychological and neurophysiological variables. For instance, social isolation and anhedonia, but not unusual ideation or perceptions, correlate with lower performance in eye-movement (Ettinger et al., 2005; Kendler et al., 1991) and sustained-attention tasks (Chen et al., 1997). In contrast, disorganized schizotypy, in particular, correlates with difficulties on tasks of cognitive control requiring inhibition (e.g., Stroop task; (Kerns, 2006). Further research is needed to clarify the basis of these associations between specific schizotypal factors and neurocognitive phenotypes.

The finding, in the present study and others (Kiang and Kutas, 2005; Kimble et al., 2000; Niznikiewicz et al., 2004, 1999), of an association between schizotypy and smaller N400 relatedness priming effects parallels reports of decreased N400 priming effects in schizophrenia (Condray et al., 2003; Ditman and Kuperberg, 2007; Kiang et al., 2008; Kostova et al., 2005; Ohta et al., 1999; Strandburg et al., 1997). Thus, at least under certain experimental conditions, schizophrenia and schizotypy may share a reduced difference in the degree to which a meaningful contextual stimulus facilitates processing of concepts that are normatively related versus unrelated to it. In schizophrenia, such deficits in using context to guide subsequent processing have been hypothesized to result from prefrontal dopaminergic deficiency (Cohen et al., 1999). It has further been proposed that a diminution in prefrontal dopaminergic activity could result from a neurodevelopmental lesion (Weinberger, 1987) which might lead to either schizophrenia or schizotypy depending on other genetic or environmental factors (Siever and Davis, 2004). There is in fact indirect evidence that schizotypy is associated with differences in levels of dopaminergic activity (Avramopoulos et al., 2002; Siever et al., 1993; Stefanis et al., 2004). Thus, further research is warranted to investigate whether semantic processing differences in schizotypy are mediated by variation in dopaminergic function.

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