



# Semantic processing impairment in individuals with schizotypal personality disorder features: A preliminary event-related potential study

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## ABSTRACT

**Objective:** This study aimed to examine semantic processing features in individuals with and without schizotypal personality disorder (SPD) features.

**Methods:** An implicit semantic task was used to examine the automatic spreading semantic activation process which is relatively free from the influence of attention. An explicit semantic task was used to examine the controlled semantic processing which requires high involvement of attention. Individuals with stable SPD features ( $n=17$ ) were those who scored higher than 36 on the schizotypal personality questionnaire (SPQ) at two time points. Individuals with unstable SPD features ( $n=15$ ) were defined as participants who scored higher than 36 at the baseline time point but lower than 36 at the second time point. Their performances in the two semantic tasks were then compared to 17 individuals without SPD features (scoring below 36 at both time points). Event-related potentials (ERP) were recorded when participants were performing the two tasks.

**Results:** Behavioral data, early ERP components and N400s were analyzed in each experiment. No between-group difference was observed in the implicit semantic task. In the explicit semantic task, the differences involved only the N400 component. When compared to the group without SPD features, participants with stable and unstable SPD features showed enhanced N400 effects (difference wave), while there was no difference between the two groups with SPD features. Moreover, the larger N400 effects were found to be due to less negative N400 amplitudes to related target words.

**Conclusion:** These findings suggest that individuals with SPD features were impaired in processing of context-related stimuli. The inhibition function to contextually unrelated materials in participants with SPD features appeared intact.

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## 1. Introduction

Loose and aberrant associations are frequently observed in the speech of patients with schizophrenia (Andreasen and Grove, 1986). In order to understand the neurocognitive mechanism of the abnormal speech pattern, researchers frequently used semantic priming techniques to investigate the structure and function of semantic memory. Previous findings confirmed that patients with schizophrenia have problems with semantic processing, but the precise deficits are highly dependent on the specific experimental design. Under automatic

experimental conditions, patients with schizophrenia usually exhibit normal semantic priming effect (or increased semantic priming effect in patients with thought disorder), while under experimental conditions biasing towards controlled processing, a reduced semantic priming effect was instead found (Kuperberg et al., 2010). Healthy individuals with schizotypal personality features share many similar traits with patients with schizophrenia. Research on this special population is important, since it could offer insights for schizophrenia without contamination from the effects of medication and prolonged admission. Some recent studies also suggested that individuals with schizotypal personality disorder (SPD) features have impaired semantic processing (Johnston et al., 2008; Kiang and Kutas, 2005; Mohr et al., 2001; Voglmaier et al., 1997). However, the underlying mechanism is not fully understood (Kiang, 2010).

Behavioral priming effect refers to the phenomena that participants' response to a word (e.g., lion) would be faster and/or more accurate if it is preceded by a semantically congruent context (e.g. tiger) as opposed to a semantically incongruent one (e.g., bread). It has been suggested that different mechanisms could contribute to this effect (Neely,

Abbreviations: AC, alternate current; ANOVA, analysis of variance; DSM-III-R, Diagnostic Statistical Manual 3rd version, revised; EEG, electroencephalogram; ERP, event-related potential; Hz, Hertz; SART, sustained attention to response task; RMB, renminbin; SOA, stimulus onset asynchrony; SPD, schizotypal personality disorder; SPQ, schizotypal personality questionnaire; WAIS-R, Wechsler Adult Intelligence Scale—Revised.

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1991). The automatic semantic activation model, a model of semantic memory, posits that one's semantic knowledge is stored in a network, with each node representing a specific concept and links between nodes representing semantic relationships (Collins and Loftus, 1975). According to this model, activation of one node (prime, e.g., tiger) would automatically spread to linked nodes (target, e.g., lion), such that the processing of the target word would be quicker by partial preactivation from the prime, and as a result brings out the semantic priming effect in a semantic priming task. If participants are given enough time, they can employ strategies to facilitate the processing of target words (Neely, 1991). Expectancy generation and semantic matching are two examples. Expectancy generation refers to the situation when participants generate a set of lexical candidates (e.g., wolf, lion, cat) in response to a prime word (e.g., tiger), and their response to the target would be facilitated accordingly (Becker, 1980). Semantic matching refers to the condition in which participants use the combination of prime and target to bias decision-making (Neely et al., 1989). These two processes are controlled processes heavily influenced by attention.

The behavioral semantic priming effect has a counterpart in event-related potentials (ERPs). The target words which are semantically unrelated to previous context would elicit a negative component peaking at about 400 ms after stimulus onset. The context could be words, sentences or line drawings (Kutas and Federmeier, 2011). This negativity, labeled N400, has been found to be sensitive to the type of processes engaged: a larger N400 is observed in tasks involving attentive processing (e.g., in a semantic mapping task), while an attenuated N400 is often observed in tasks requiring automatic processing (e.g., when participants were asked to attend to filler material) (Holcomb, 1988).

With a relatively short stimulus onset asynchrony (SOA) (i.e., less than 400 ms) and a relatively small proportion of related prime-target pairs (less than about 33.3%), the priming effect is mainly attributed to automatic semantic activation (Neely, 1991). With a long SOA and a relatively large proportion of related prime-target pairs, the priming effect is mainly attributed to strategic processes (Neely, 1991). Additionally, it has been found that experimental task could also influence the attribution of semantic priming effect. For example, Kreher et al. (2009) adopted two semantic priming tasks with the same SOA of 350 ms and the same stimulus set in patients with schizophrenia. In the implicit semantic task favoring automatic spreading activation, participants were asked to monitor filler materials (kinds of food). In the explicit semantic task favoring controlled processes, the same participants were asked to judge whether the prime and target were semantically related. Although the two tasks used the same SOA and identical stimuli, different N400 patterns were observed in the two tasks. When compared to healthy controls, a relatively normal (or increased in positively thought-disordered patients) N400 effect was observed for the patient group in the implicit task, while a reduced N400 effect in the explicit task was observed instead. Therefore, a number of variables, namely SOA, the proportion of related prime-target pairs and the precise experimental task, have to be considered in experiments using the semantic priming paradigm.

The current study aimed to examine the neural mechanisms of semantic processing in individuals with SPD features. It has been observed that SPD features fluctuate with time (Raine, 2006). It would therefore be interesting to examine whether semantic processing features would also vary according to the stability of SPD features. Similar to the experimental design used by Kreher et al. (2009), we adopted an implicit task to investigate the automatic semantic activation processes and an explicit task to investigate the controlled processes. We were particularly interested in whether automatic semantic activation or controlled processes or both are impaired in individuals with SPD features. Based on previous studies in patients with schizophrenia, we hypothesized that implicit semantic processing is relatively intact in individuals with schizotypal personality disorder features, and that their controlled processing may be abnormal.

## 2. Methods

### 2.1. Participants

All participants were selected from an extensive sample pool of individuals with SPD features from a previous study (Zong et al., 2010). As reported in the said study, 55% of the subjects with a score in the top 10% of the SPQ distribution could be diagnosed as SPD according to DSM-III-R (Raine, 1991). Based on a large scale screening among Chinese university students, we found that individuals scoring higher than or equal to 36 on the SPQ made up the top 10th percentile (Zong et al., 2010). Therefore in the current study, 36 was taken as the cutoff point. Altogether 35 participants with a SPQ score higher than or equal to 36 points and 18 participants with a SPQ score lower than 36 agreed to participate this study with a payment of 20 RMB per hour. They came to the laboratory individually and completed the SPQ for a second time. Among the 35 participants with high SPD scores in the first time point, 20 (10 female) of them scored higher than or equal to 36 in the second time point. They were designated as having stable SPD features. The remaining 15 (eight female) who scored lower than the 36 in the second time point were designated as having unstable SPD features. No one in the third group (18 participants; 11 female) scored higher than or equal to 36 in the second time point and they were designated as having no SPD features.

The exclusion criteria for each group of participants were 1) neurological and psychiatric illness in themselves or their first-degree relatives; 2) history of traumatic brain injury; 3) history of substance abuse; 4) hearing, vision, or upper body motor impairment. All participants were right-handed according to the Annett handedness questionnaire (Annett, 1976) and all were native Chinese speakers.

Data of four additional participants (three with stable SPD features, one without SPD features) were discarded due to overwhelming  $\alpha$ -wave in the ERP data. The final dataset contained 17 individuals with stable SPD features, 15 individuals with unstable SPD features and 17 individuals without SPD features (Table 1). The three groups did not differ significantly with respect to age and gender.

### 2.2. Measures

#### 2.2.1. Schizotypal personality questionnaire (SPQ)

The original SPQ (Raine, 1991) consists of a 74-item questionnaire assessing all nine symptoms of SPD, including ideas of reference, excessive social anxiety, odd beliefs or magical thinking, unusual perceptual experiences, odd or eccentric behavior, absence of friends, odd speech, constricted affect, and suspiciousness or paranoid ideation. The total internal reliability of the scale is high (0.91), while the internal reliabilities of the nine SPQ subscales are adequate (Cronbach's alpha ranges from 0.71 to 0.78, with a mean of 0.74). The test-retest reliability for the scale at a two-month interval was 0.82 (Raine, 1991, 2006; Raine et al., 1994). The present study used the Chinese version of the SPQ (Chen et al., 1997). This version has satisfactory psychometric properties, including a high internal consistency of the total SPQ score in both adults (0.90) and adolescents (0.93). Coefficient alpha for the nine subscales of the SPQ ranged from 0.58 to 0.79 in adults and 0.44 to 0.79 in adolescents (Chen et al., 1997).

#### 2.2.2. Neuropsychological measures

A set of comprehensive neuropsychological tests was also administered to all participants. Intellectual functioning was estimated by the short form (information, arithmetic, similarity, and digit span subtests) of the Chinese version of the Wechsler Adult Intelligence Scale—Revised (WAIS-R) (Gong, 1992). This method of prorating has been used previously to estimate IQ in schizophrenia (Allen et al., 1997; Blyler et al., 2000; Gong et al., 1989). Sustained attention was assessed by the sustained attention to response task (SART) (Robertson et al., 1997), which is a computer test requiring the

**Table 1**

Demographic and neuropsychological characteristics of each group.

	Participants with stable SPD features	Participants with unstable SPD features	Participants without SPD features	F	P
Age	21.24 ± 1.85	20.00 ± 1.71	20.47 ± 1.95	1.79	0.18
Gender (F/M)	10/7	8/7	11/6	0.42*	0.81
SPQ (Time 1)	45.81 ± 6.17	40.64 ± 5.00	15.56 ± 6.83	112.39	<0.001
SPQ (Time 2)	46.06 ± 7.61	27.53 ± 8.40	14.17 ± 7.16	77.36	<0.001
IQ estimates	127 ± 8	126 ± 7	128 ± 11	0.09	0.92
Logic memory (in time)	15.53 ± 3.83	17.00 ± 3.23	15.35 ± 4.16	0.83	0.44
Logic memory (delayed)	13.80 ± 3.03	15.50 ± 4.15	13.29 ± 4.55	1.25	0.30
Visual memory (in time)	23.33 ± 1.18	23.29 ± 1.98	23.35 ± 1.22	0.01	0.99
Visual memory (delayed)	23.33 ± 1.76	23.07 ± 1.59	22.29 ± 1.79	1.81	0.18
Text 1 back reaction time	518 ± 217	536 ± 167	500 ± 250	0.10	0.90
Symbol 1 back reaction time	639 ± 202	526 ± 107	611 ± 122	2.17	0.13
SART efficiency	0.88 ± 0.14	0.92 ± 0.14	0.90 ± 0.11	0.29	0.75
Total number of correct items in verbal fluency task	24.35 ± 5.87	23.93 ± 4.63	25.52 ± 6.05	0.35	0.71

Note: \*: by Chi-square test. SPQ, schizotypal personality questionnaire. SART, sustained attention to response task.

participant to respond to the occurrence of a target stimulus (digit) while inhibiting/withholding the response to a non-target. Working memory was assessed by the Chinese version of letter–number span test (Chan et al., 2008) and n-back test (1-back data were used in the present study). Verbal memory and visual memory were assessed by the logical memory and visual reproduction subscales of the Wechsler Memory Scale–Revised Chinese version (Gong et al., 1989). Executive function was evaluated by the animal name semantic verbal fluency test (Spreen and Strauss, 1998).

### 2.3. Word stimuli and experimental task in semantic tasks

One-hundred-and-twenty-two triplets of words with neutral emotional valence were developed (e.g., window-door-money). Each prime (e.g., window) was paired with a semantically related target (e.g., door) and a semantically unrelated target (e.g., money). Each prime and two corresponding target words had no orthographical or phonological similarity. The average semantic relationship strength was 4.45 between prime and related target, and 1.24 between prime and unrelated target, as judged by 24 native Chinese readers who did not participate in the ERP experiments on a five-point Likert scale. The average frequency of usage was 98,944 (per million) for related target words according to an on-line Modern Chinese Character Frequency List,<sup>1</sup> and 95,557 for unrelated target words. The mean number of strokes was 8.36 for related target words and 8.15 for unrelated target words. There was no significant difference with regard to mean frequency of usage between related and unrelated target words or average number of strokes.

The 122 triplets or words were then separated into two halves. The prime-related word pairs in the first half and the prime-unrelated word pairs in the second half were used for materials in the explicit semantic priming task. The prime-unrelated target word pairs in the first half and the prime-related target word pairs in the second half were used for the implicit semantic priming task. For the implicit priming task, another 121 word pairs with animal names as target words were developed as filler materials (e.g., book-dog).

#### 2.3.1. Implicit semantic priming task

Trials began with a central fixation (500 ms), followed by a 500 ms blank screen. A prime word then appeared in the center of the screen for 100 ms. After a 200 ms blank screen (SOA = 300 ms), a target word presented in the same place as the prime word appeared for 2000 ms. The participant was instructed to judge whether the target word was a kind of animal or not by pressing two designated keys on a computer

keyboard. Such animal words were introduced as filler probes; no animal name appeared in the prime-target pairs of interest.

#### 2.3.2. Explicit semantic priming task

The stimulus presenting procedure used for the explicit semantic priming task was identical to the implicit semantic priming task, with the exception that the prime presented for 500 ms, followed by a blank screen for 200 ms (SOA = 700 ms). The participants were instructed to judge whether the prime and target words were semantically related or not with index finger on two hands.

### 2.4. ERP recording and data processing

Scalp electroencephalogram (EEG) was recorded from an array of 59 silver/silver-chloride electrodes embedded in a Neuroscan electrocap (El Paso, Tex.), and amplified from AC to 100 Hz at a sampling rate of 500 Hz. The EEG was acquired referenced to the left mastoid and re-referenced off-line to linked mastoids. Further off-line data processing included a digital low-pass filter set to 40 Hz. Then the EEG was edited offline with the Semlitsch correction algorithm to remove contamination from eye movements (Semlitsch et al., 1986). After correcting for eye-movement, single sweeps were rejected if the amplitude at any of the electrodes exceeded  $\pm 75 \mu\text{V}$ . In the implicit semantic task, continuous EEG data were separated into 1500 ms epochs, commencing 200 ms prior to prime onset taken as baseline. In the explicit semantic task, continuous EEG data were separated into 1200 ms epochs, commencing 200 ms prior to target onset taken as baseline. Separate average waveforms were constructed for each target stimulus type (related, unrelated, or animal in the implicit semantic task, and related or unrelated in the explicit semantic task). Group grand averages were made on the basis of individual participant's averages.

### 2.5. Procedure

This study was approved by the ethics committees of the Institute of Psychology, Chinese Academy of Sciences. Informed consent was obtained from all participants before the testing session. Participant was asked to take part in an implicit semantic priming task and then explicit semantic priming task while EEG was recorded. After a 10-min break, they were then administered the set of neuropsychological tests and the SPQ.

### 2.6. Data analyses

For reaction time data and ERP data, only trials with correct responses were used for statistical analyses. Trials with reaction times under 200 ms or above 2000 ms were also excluded in the analyses.

<sup>1</sup> <http://lingua.mtsu.edu/chinese-computing>.

In the ERP data, electrodes over the whole scalp were blocked into 11 regions, frontal pole: FP1, FP2, FPZ, AF3, AF4; left frontal: F3, F5, F7, FC3, FC5, FT7; middle frontal: F1, F2, FZ, FC1, FC2, FCZ; right frontal: F4, F6, F8, FC4, FC6, FT8; left central: C3, C5, T7, CP3, CP5, TP7; middle central: C1, C2, CZ, CP1, CP2, CPZ; right central: C4, C6, T8, CP4, CP6, TP8; left parietal: P3, P5, P7, PO3, PO5, PO7; middle parietal: P1, P2, PZ, POZ; right parietal: P4, P6, P8, PO4, PO6, PO8; and occipital: O1, O2, OZ.

In the implicit semantic task, the prime elicited the N1 and P2 components which were followed and overlapped by the N1, P2, and N4 elicited by the target. To exclude the possibility that any potential between-group difference in the N400 was contributed by the early components elicited by prime or target words, N1s and P2s elicited by prime and target stimuli were also quantified and analyzed. Mean amplitudes over the 0–130 ms time window after prime onset were quantified for the prime N1, over the 130–300 ms time window after prime onset for prime P2, over the 0–160 ms after target onset for target N1, over the 160–260 ms after target onset for target P2, and over the 260–460 ms after target onset time window for N400. By visual inspection, the N1s and P2s were most salient over the anterior and frontal regions, and the N4 was clear over the whole scalp region. Therefore mean amplitudes over the anterior (frontal pole) and frontal regions (left, middle, and right frontal) were used for the analyses of N1s and P2s, and the mean amplitudes over the whole scalp were used for the analyses of N400.

In the explicit task, there was also clear N1 and P2 preceding the N400. As seen from Fig. 3, the P2 and N400 were inseparable. As a result, we only took N1 and N400 for analyses. The mean amplitudes over the 0–160 ms time interval were retrieved for quantification of N1, and those over the 300–450 ms time interval were retrieved for quantification of N400. As in the implicit task, only data over the four anterior regions were used for the quantification of N1, and data over the whole scalp were used for the analyses of N400.

In both tasks the N400 peak latencies were quantified by the most negative point for unrelated target words in 250–500 ms at CZ where the N400 effects were most salient. Individual peak latency data were visually inspected for each participant.

For ANOVA, the Greenhouse–Geisser correction for nonsphericity was used when the assumption of sphericity was violated. Epsilon-corrected *p*-values are reported together with uncorrected degrees of freedom.

### 3. Results

Demographic and neuropsychological characteristics of the three groups are presented in Table 1. The three groups were well matched in age, gender, IQ, logical and visual memory function, sustained attention efficiency, working memory capacity and verbal fluency ability. The three groups were only different on the SPQ scores at the second test point. Post hoc analyses indicated that at both time points the group with stable SPD features had higher SPQ score than the group with unstable SPD features, while the latter had higher SPD score than the group without SPD features.

#### 3.1. Implicit semantic task

##### 3.1.1. Behavioral data

The behavioral data are presented in Table 2. An ANOVA for mean accuracy with group (stable SPD features vs. unstable SPD features vs. without SPD features) and relatedness (related vs. unrelated vs. animal) showed no significant main effect or interactions (*p*-values>0.1). The same ANOVA was launched for mean reaction times data. Only a main effect for relatedness was significant ( $F(2,92)=29.90, p<0.0001, \epsilon=0.7647$ ). No other effect reached statistical significance (*p*-values>0.1). Further analysis of the target effect revealed that the mean reaction times for unrelated targets were longer than those for related targets

**Table 2**

Mean reaction times (in ms) and accuracy for all stimulus types in implicit semantic task, with standard deviations in parentheses.

		Participants with stable SPD features	Participants with unstable SPD features	Participants without SPD features
Reaction times	Related	630 (100)	633 (85)	635 (107)
	Unrelated	639 (97)	641 (96)	661 (131)
	Animal	595 (66)	607 (82)	611 (104)
Accuracy	Related	0.98 (0.02)	0.98 (0.02)	0.99 (0.01)
	Unrelated	0.96 (0.04)	0.97 (0.03)	0.98 (0.01)
	Animal	0.97 (0.03)	0.98 (0.02)	0.97 (0.02)

Note: SPD, schizotypal personality disorder.

( $F(1,46)=22.88, p<0.001$ ), and the latter was longer than those for animal words ( $F(1,46)=14.17, p<0.001$ ).

#### 3.1.2. ERP data

**3.1.2.1. Prime N1, P2, target N1 and P2.** An ANOVA between group (stable SPD features vs. unstable SPD features vs. without SPD features), relatedness (related vs. unrelated), and region was launched. There were no main effect for group ( $F<1$ ) and relatedness ( $p>0.05$ ). The interactions between group and relatedness were not significant ( $F<1$ ), neither were the interactions related to the two factors ( $p>0.05$ ).

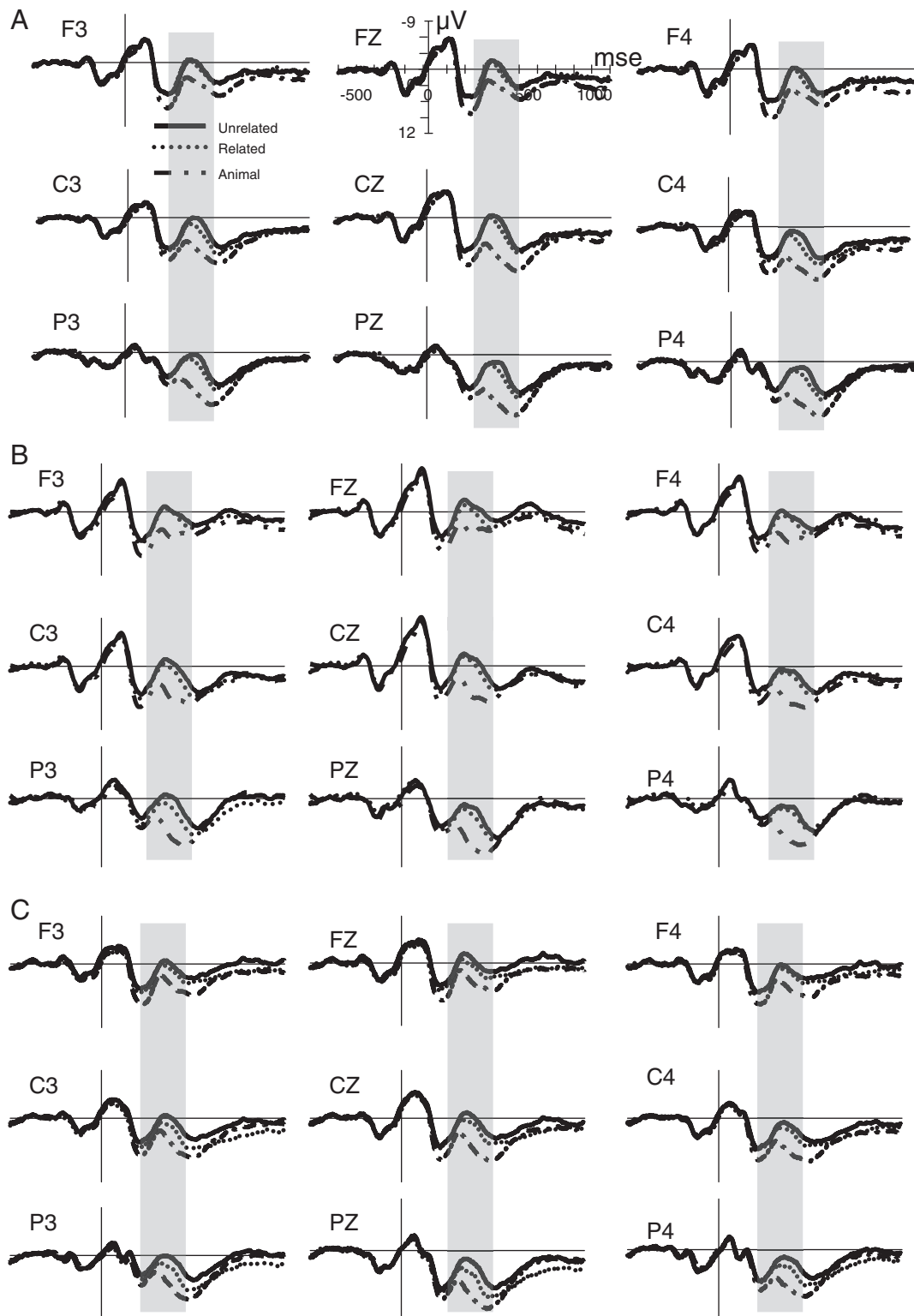
**3.1.2.2. N400.** Across three groups the mean N400 peak latency for unrelated target words was 364 ms (SD = 36 ms). One-way ANOVA with group as between-group factors indicated no group effect ( $F<1$ ).

A clear N400 was elicited by related and unrelated target words in comparison with animal words, and the N400 to unrelated target words was more negative than the N400 to related target words. Here we focused only on the ERP waves between related and unrelated targets words for analysis (Fig. 1). An ANOVA between group (stable SPD features vs. unstable SPD features vs. without SPD features), relatedness (related vs. unrelated), and region, revealed a main effect for relatedness ( $F(1,46)=8.29, p<0.01$ ), indicating that unrelated target words elicited a more negative N400 as compared to related target words. The main effect of group was not significant ( $F<1$ ), neither was the interaction between group and relatedness ( $F<1$ ) nor the three way interaction between group, relatedness, and region ( $F<1$ ).

It could be observed from the figure that the N400 effect in the upslope stage (360–460 ms) was more salient than in the onset stage (260–360 ms). To exclude the possibility that the three groups might be different in either of the two stages, a fine-grained analysis of N400 mean amplitudes was carried out for both stages. In the onset stage, we found a marginally non-significant main effect for relatedness ( $F(1,46)=2.85, p=0.09$ ), while the main effect of group or any other interactions with relatedness was not significant. In the upslope stage, there was a significant main effect for relatedness ( $F(1,46)=13.98, p<0.01$ ) and an interaction between relatedness and region ( $F(10,460)=3.75, p=0.01, \epsilon=0.3046$ ). Further analysis of the interaction indicated that the relatedness effect was significant over the whole scalp ( $F>3.69, p<0.06$ ), except the frontal pole ( $F<1$ ) and the left frontal region ( $p>0.05$ ). Therefore the analysis confirmed that the N400 effect was more robust in the upslope stage than the onset stage. The results thus resembled the findings when taking the whole 260–460 ms time window for analysis, and showed no difference among the three groups regarding N400 mean amplitudes.

The topographic maps of the voltage amplitudes for difference waves (unrelated minus related) in the 360–460 ms window (the upslope stage of N400) are shown in Fig. 2. It could be observed that the N400 effect, although small in effect size, was evident over the whole scalp.





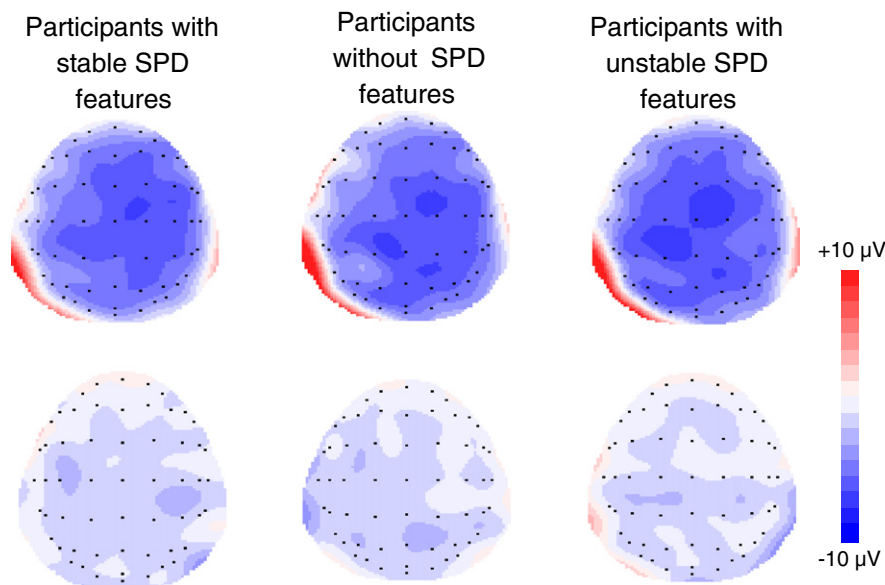
**Fig. 1.** Grand-average ERPs at nine representative electrodes for animal (dash dotted), related (dash), and unrelated (bold) target words in the implicit semantic task. A: Participants with stable SPD features; B: participants with unstable SPD features; C: participants without SPD features.

### 3.2. Explicit semantic task

#### 3.2.1. Behavioral data

The behavioral data are shown in Table 3. An ANOVA for mean accuracy with group (stable SPD features vs. unstable SPD features vs. without SPD features) and target (related vs. unrelated) revealed a

significant main effect for relatedness ( $F(1,46)=24.63$ ,  $p<0.001$ ). The participants made more correct responses for related than for unrelated targets. The same ANOVA for mean reaction times data revealed also a main effect for relatedness ( $F(1,46)=72.93$ ,  $p<0.001$ ), indicating longer reaction times for unrelated target words than for related target words.



**Fig. 2.** Topographic maps of the voltage amplitudes for difference waves (unrelated minus related) in the 360–460 ms in the explicit task (upper panel) and 300–450 ms in the implicit task (lower panel) for participants with stable SPD features (left), participants with unstable SPD features (middle) and participants without SPD features (right).

### 3.2.2. ERP data

**3.2.2.1. N1.** ERPs at nine representative recording sites in the three experimental conditions are shown in Fig. 3. An ANOVA between group (stable SPD features vs. unstable SPD features vs. without SPD features), relatedness (related vs. unrelated), and region revealed no main effect for group ( $p > 0.05$ ) and relatedness ( $F < 1$ ). The interactions between group and relatedness were not significant ( $p > 0.05$ ), neither were the interactions related to the two factors ( $p > 0.05$ ).

**3.2.2.2. N400.** The N400 effects were observed over the whole scalp, with a maximum over centro-parietal regions (Fig. 2). Taking all the participants as a whole, the mean N400 peak latency for unrelated target words was 373 ms ( $SD = 42$  ms). One-way ANOVA with group as between-group measures indicated no group effect for the N400 peak latency measure ( $F < 1$ ).

An ANOVA between group (stable SPD features vs. unstable SPD features vs. without SPD features), target (related vs. unrelated) and region (eleven regions) was calculated for the mean amplitude data. Taking the three groups as a whole, there were clear N400 effects, as indicated by the significant main effect of relatedness ( $F(1,46) = 373.70$ ,  $p < 0.0001$ ). The interaction between relatedness and region was also significant ( $F(10,460) = 35.54$ ,  $p = 0.0001$ ,  $\epsilon = 0.3042$ ). Further analysis of this effect indicated that the relatedness effect was significant in each region ( $F \geq 45.80$ ,  $p < 0.0001$ ), but most salient over the central and posterior regions.

The ANOVA procedure also yielded a significant interaction between relatedness and group ( $F(2,46) = 7.97$ ,  $p = 0.001$ ). Following the interaction we found that there were significant N400 effects in each of the three groups ( $F \geq 63.92$ ,  $p < 0.0001$ ). However, the group effects were not significant for either the related or unrelated target condition ( $p > 0.10$ ). To further examine the interaction between relatedness and group, we used three ANOVAs between group (stable SPD features vs. unstable SPD features; stable SPD features vs. without SPD features; and unstable SPD features vs. without SPD features) and relatedness (related vs. unrelated), and found that the interactions between group and relatedness existed only when comparing the two groups with SPD features with the group without SPD features ( $F \geq 45.80$ ,  $p \leq 0.0001$ ). Moreover, there was no group effect, or any interaction between group and other factors when comparing the two groups with SPD features. Therefore we combined the data from the two groups with SPD features into one group, and compared the mean amplitudes between the combined groups (with SPD features) with the group without SPD features. A trend group effect for related conditions was found ( $F(1,48) = 2.79$ ,  $p = 0.10$ ), indicating a less negative N400 for related target conditions in participants with SPD traits. More evidence for the decreased N400 effects in the two groups with SPD features could be found in Fig. 4, where only the difference wave between related and unrelated target words is presented.

## 4. Discussion

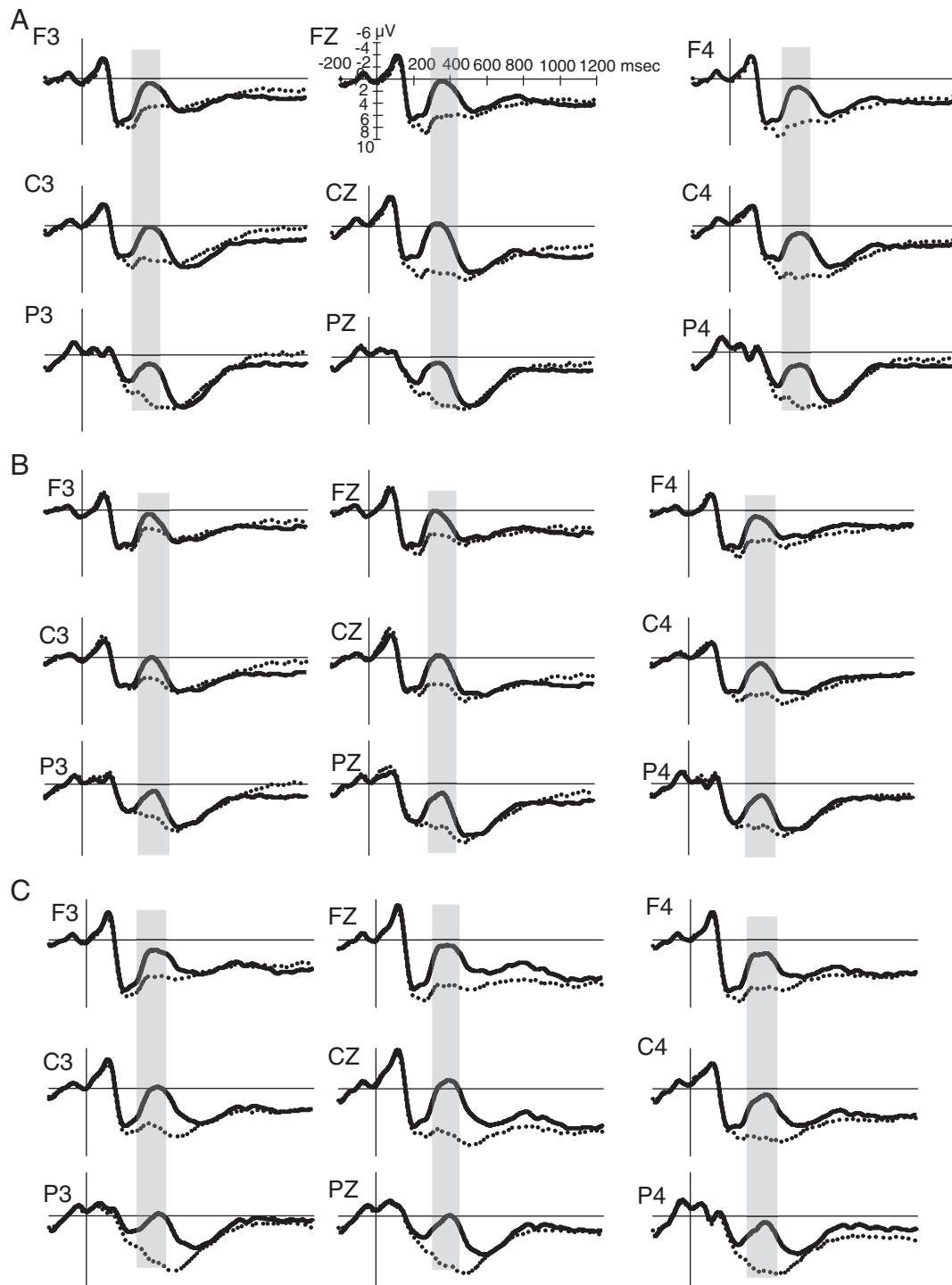
In this study, the three groups of participants recruited were well matched in demographic and neuropsychological characteristics. We found longer reaction times for unrelated target words in both semantic tasks in each group. In the ERP data in both tasks, unrelated target words elicited a larger N400 as compared to related target words. Semantic priming effects, behaviorally and in the ERP data, were much larger in the explicit semantic task than in the implicit semantic task. Given that many previous studies had shown a larger semantic priming effect in tasks favoring controlled process than in tasks favoring automatic processes (Kutas and Federmeier, 2011), we believed that the two tasks chosen were suitable for studying automatic processes and controlled processes separately.

**Table 3**

Mean reaction times (in ms) and accuracy for all stimulus types in the explicit semantic task with standard deviations in parentheses.

		Participants with stable SPD features	Participants with unstable SPD features	Participants without SPD features
Reaction times	Related	682 (98)	665 (96)	711 (124)
	Unrelated	622 (85)	610 (80)	666 (109)
Accuracy	Related	0.98 (0.02)	0.98 (0.02)	0.97 (0.04)
	Unrelated	0.96 (0.03)	0.94 (0.03)	0.95 (0.02)

Note: SPD, schizotypal personality disorder.



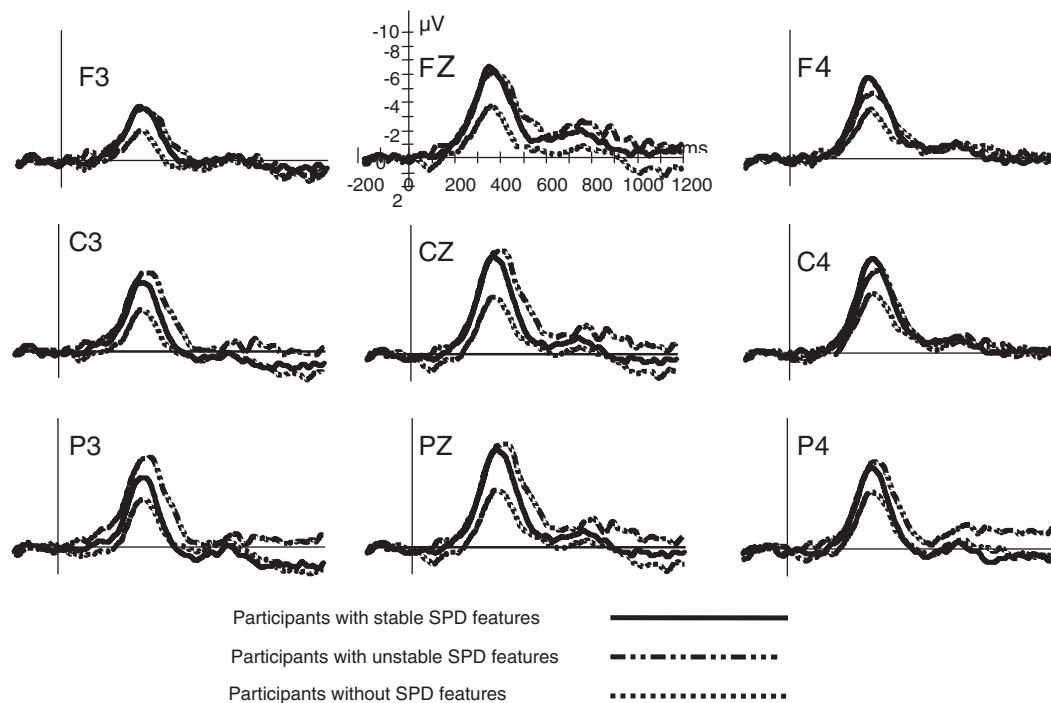
**Fig. 3.** Grand-average ERPs at nine representative electrodes for related (dash) and unrelated (bold) target words in the explicit semantic task. A: Participants with stable SPD features; B: participants without SPD features; C: participants with unstable SPD features.

#### 4.1. Automatic semantic spreading activation

Behaviorally, all three groups exhibited clear semantic priming effects in the implicit semantic task, while the semantic priming effects were quite similar among the three groups in the explicit semantic task. These findings thus indicated a relatively intact automatic semantic processing in individuals with SPD features. Similar findings have also been reported by previous behavioral studies (Kerns and Berenbaum, 2000; Moriz et al., 1999; Pizzagalli et al., 2001). For instance, Pizzagalli et al. (2001) investigated the influence of magical

ideation on the automatic semantic priming effect. Using a lexical decision tasks with a SOA of 200 ms, they found that individuals who had high and low magical ideation scores exhibited similar reaction times. To further examine this topic, we also recorded the ERP data in our study. The ERP data pattern was similar to the behavioral data pattern. Although a clear N400 was observed in each group, the N400 did not differ significantly between the three groups.

As compared to ERP studies investigating controlled semantic processing, relatively few studies had used ERP to investigate the automatic semantic processing, partly due to the short SOA. Using very



**Fig. 4.** Mean N400 difference waves between related and unrelated target words at nine representative electrodes in participants with stable SPD features (bold), participants with unstable SPD features (dash dot dot), and participants without SPD features (dot).

short SOA, ERPs elicited by target words are highly likely to overlap with ERPs elicited by prime words. It is then difficult to analyze the difference in ERPs for target words. To decrease the potential influence of ERPs elicited by prime words on the N400 elicited by target words, we carefully analyzed N1s and P2s elicited by prime and target words. The early components were not different, implying that although the ERPs elicited by prime words could have an influence on the N400, the influence should be similar for different conditions in different groups. Therefore we believed that we could compare N400 for different conditions among different group in our study.

The experimental paradigms in our study were similar to Kreher et al. (2009) who investigated the automatic semantic processing in patients with schizophrenia. Similar to their study, we observed a more salient N400 in the upslope stage than in the onset stage which supports the validity of the experimental paradigm we used.

Our results did not support the association between “odd speech” and an over-activated network in individuals with SPD features. With an over-activated semantic network, we would expect a less negative N400 for either unrelated or related target words in the SPD group in the implicit semantic priming task. Similar results have been reported in studies on patients with schizophrenia. An over-activated semantic network in patients with schizophrenia has often been proposed. However, in a systematic review, it was suggested that an over-activated semantic network might exist only in schizophrenia patients with thought disorder (Kuperberg et al., 2010). It is worthwhile to note that some studies also reported that an over-activated semantic network is only found in individuals with typical “positive schizotypal personality traits”, such as magical ideation, disorganization and so on (Johnston et al., 2008; Mohr et al., 2001). In this study, we chose individuals according to the total SPQ scores, and so we could not rule out the possibility that an over-activated semantic network might exist in some individuals with SPD features in our sample, such as those with predominantly “positive schizotypal traits.” Another version of the over-activated semantic network hypothesis proposed an increased activation of weakly related concepts (Kiang, 2010). We were unable to test this hypothesis since we did not use “intermediately” or “weakly” related word pairs. Further studies to clarify this issue are necessary.

To date, only one ERP study provided evidence for an over-activated semantic network in individuals with SPD features. In a lexical decision task with a SOA of 450 ms, Niznikiewicz et al. (2002) observed a less negative N400 with related word conditions in individuals with SPD. Their findings were similar to our results in the explicit semantic task investigating controlled semantic processing. However, the SOA they used might be too long for investigating automatic spreading semantic activation. It is possible that much attentional processes have been involved with the relatively long SOA. Moreover, in the study of Niznikiewicz et al. (2002), all participants were diagnosed with SPD, while individuals with stable or unstable SPD features in our study were university students with good social function.

#### 4.2. Controlled semantic processing

Similar to the situation with the implicit task, we observed clear behavioral semantic priming effect in the explicit semantic task, and the effects were not different among the three groups. Based on the behavioral data alone, we might conclude that controlled semantic processing was normal in individuals with SPD features. However, the enhanced N400 effect observed in this group was inconsistent with this conclusion. As compared to the group without clear SPD features, individuals with SPD features had a less negative N400 to related target words. In contrast, the N400 for unrelated target words was not different among the three groups. These results seemed to suggest that individuals with SPD features processed contextually unrelated stimuli in a similar way to normal individuals, but processed contextually related materials differently.

An abnormal N400 in semantic tasks favoring controlled process has previously been observed elsewhere. Niznikiewicz et al. (1999) presented sentences with either correct or incorrect final words to individuals with a DSM diagnosis of SPD. Instead of enhanced N400 effect, the authors observed a diminished N400 effect in the SPD group. However, similar to findings in our study, the abnormality was brought on by congruent conditions. Taken together, findings from our study and the study by Niznikiewicz et al. (1999) suggest that individuals with SPD or with SPD features might be impaired



in integrating related information to previous context. Their inhibition function to contextually unrelated materials might however be normal (based on the normal N400 to contextually unrelated conditions). Therefore, the impairments might reflect the inability to actively represent goal information in working memory, which is a central deficit in schizophrenia (Barch and Ceaser, 2012).

We noted that Niznikiewicz et al. (1999) observed diminished N400 effects (and prolonged N400 peak latency) in individuals with SPD, while we observed enhanced N400s effect in the SPD groups. Niznikiewicz et al. (1999) recruited DSM-diagnosed SPD, while our groups with stable or unstable SPD features were university students with higher IQ. Interestingly, in patients with schizophrenia, studies have consistently shown diminished N400 effects (and prolonged N400 peak latency). It is possible that, along the continuum of schizophrenia, the closer a group is to the illness, the more likely the group would show similar controlled semantic priming pattern to patients with schizophrenia. Moreover, we agreed with Niznikiewicz et al. (2002) that working memory load is essential to bring out semantic dysfunction in SPD. The enhanced N400 observed for individuals with SPD features might indicate that they could employ more resources, such as working memory to perform the task better. It has been found that in tasks with a low demand for working memory, diagnosed SPD group could also show normal controlled semantic processing. In a lexical decision task, under low working memory condition (SOA = 1000 ms), diagnosed SPD patients had a normal N400, while under high working memory load (SOA = 450 ms) the same group showed a diminished N400 (Niznikiewicz et al., 2002). In summary, although impaired, groups with different levels of risk to schizophrenia might exhibit different patterns in controlled semantic processing, and this might be partly explained by the difference in working memory load of the task and different working memory impairments of the participants.

#### 4.3. Implications for schizophrenia spectrum disorders

Few studies have examined the cognitive features of individuals with unstable SPD, although it has been observed that SPD features may fluctuate over time. In this study, individuals with unstable SPD features showed exactly the same pattern as those with stable SPD features in both semantic tasks. In the implicit task, they were not different from participants in the group without SPD features. In the explicit semantic task, they presented a larger N400 effect than participants without SPD features. In both tasks, they were not distinguishable from participants with stable SPD features. These observations suggest that even though the symptoms of SPD might fluctuate over time, features in semantic processing exhibit a trait-like pattern. In other words, semantic processing features might be an even more stable cognitive marker for SPD than symptoms per se.

Raine (2006) put forward a biosocial, neurodevelopmental model of two forms of SPD. In this model, he carefully separated pseudo-SPD from neuro-SPD. According to this model, individuals with pseudo-SPD have weaker genetic and neurobiological basis than neuron-SPD, and are less likely to develop schizophrenia. As compared to neuron-SPD, individuals with pseudo-SPD show symptoms fluctuation over time. In this conceptual model, he also predicted that individuals with pseudo-SPD will be predominantly or solely impaired in cognitive features. In terms of controlled semantic processing, data from our group with unstable SPD features seemed to support this model. Even when their SPQ scores decreased dramatically at the second time point, participants in the unstable SPD group still exhibited abnormal cognitive features.

## 5. Conclusion

In summary, findings from our study suggest that individuals with SPD features have normal automatic semantic processing and

impairments in controlled semantic processing. The abnormality remained stable even though the features of SPD might vary over time. One limitation of our study was that we did not examine working memory load in the tasks. Future studies may focus on the influence of working memory load on semantic processing features of individuals with stable and unstable SPD features. In addition, all participants were university students with good social functions and might present a source of bias. More studies on the normal population are necessary in future.

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