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Huili Wang*, Ling Meng and Shuo Cao

N400 Prediction Effects in Relative Constructions

An ERP Study of Chinese Relative Constructions

Abstract: When a context of a strongly constrained sentence structure is formed, N400 as the ERP component of the follow-up word of the structure will be reduced in amplitude. Two accounts can explain this: a passive activation account and a contextual-based prediction account. A dispute lies in the extent of how each of these accounts influences the N400 element reduction. This issue is addressed in the present paper in Chinese relative construction context by formatting semantically associated Chinese relative construction prime and word target pairs within an experimental context that encouraged prediction. The proportion of related pairs was used to modulate the predictive validity of the relative construction prime for the target while holding constant semantic association. A semantic category probe detection task was used to encourage subjects to process semantic meaning of these experimental pairs without their preferences to the trial content of interest. A larger N400 reduction to related targets was observed in the high-proportion block of relatedness than under the low condition. The results support the hypothesis that N400 effects emerge in the predictions of upcoming input. The results suggest that predictability modulates N400 amplitude in a dominant way in a constrained context like Chinese relative constructions.

Key Words: Chinese relative construction; N400; relatedness proportion; semantic prediction

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***Corresponding author: Huili Wang**, Institute for Language and Cognition, School of Foreign Languages, Dalian University of Technology, E-mail: huiliw@dlut.edu.cn
Ling Meng: Institute for Language and Cognition, School of Foreign Languages, Dalian University of Technology, E-mail: merlinmeng@live.cb
Shuo Cao: Institute for Language and Cognition, School of Foreign Languages, Dalian University of Technology, E-mail: 1244393617@qq.com

1.1 Introduction

Recent studies widely suggest that context-based prediction plays a central role in language comprehension (Dikker, Rabagliati and Pylkkänen 2009; Lau, Phillips and Poeppel 2008; Federmeier 2007; Staub and Clifton 2006; DeLong, Urbach and Kutas 2005; Van Berkum, Brown, Zwitserlood, Kooijman and Hagoort 2005). Linguistic input is often open, random and high-paced, but it is still bound to numerous deterministic and probabilistic constraints. Based on context constraints, processing via prediction could be particularly useful for facilitating computation and distinguishing open input during language comprehension.

Standing out as one of the most supportive indices of contextual semantic comprehension is the ERP (event-related potential) component known as N400. The ERP is the measured brain response that is the direct result of a specific sensory, cognitive or motor event. More formally, it is a stereotyped electrophysiological response to a stimulus. The study of the brain in this way provides a noninvasive means of taking a look at how the brain functions during various cognitive events. As one of its typical components, N400 is a negative going deflection peaking observed at about 400 msec in the ERP waveform in response to a wide range of visual and auditory stimuli. When a word is preceded by a strongly constrained context, whether a lexical associate or a predictive sentence or discourse frame, a reduction in the amplitude of the N400 deflection is reliably observed (Kutas and Federmeier 2011). Debate continues over whether this N400 reduction reflects contextually facilitated access to stored memory representations or whether it reflects reduced difficulty in integrating new input with prior context and real-world knowledge, but most accounts agree that the N400 effect is at least partially driven by the degree to which the context predicts the target (Federmeier 2007; Van Berkum, Brown, Zwitserlood, Kooijman and Hagoort 2005; Lau, Holcomb and Kuperberg 2013).

The current research is intended to bring the debate regarding N400 deduction into the context of the Chinese language and give an account from this new perspective and even shed some light on defining a key waypoint that drives the processing of Chinese relative construction. The approach taken in this study is to keep all of the semantic memory relationships between prime (Chinese relative construction) and target the same but to vary the predictive validity of the experimental environment. If contextual facilitation of the N400 amplitude is simply spreading activation and connection between memory representations, size of the N400 amplitude should not be changed through varying the global predictive validity. However, if the N400 contextual facilitation is partially due to specific predictions about stimulus input, then a greater N400 amplitude reduction would be expected as the subjects are encouraged to make more specific context-based predictions. The same would apply to incorrect predictions, as they may elicit extra cost in semantic comprehension.

1.2 N400 and Prediction

A simple approach to estimate how a given word "predicts" the following is stated in the following sentence: to provide the preceding words in the sentence and then ask test subjects for a completion. The probability of a certain completion can then be estimated based on the results. This is known as the cloze probability (Taylor 1953). If such a certain completion is proposed by nearly all test subjects, it might be reasonably considered as a "predictable" outcome of the given word. The cloze probability will then be considered high.

The first indication that the N400 effect might be closely tied to predictability came from the observation that N400 amplitude of a word in a sentence is directly related to the cloze probability of that word; higher cloze probability is associated with a reduction in N400 amplitude (Kutas and Hillyard 1984). Subsequent work showed that, as it becomes easier to predict the next word as a sentence progresses, N400 amplitude to words steadily declines across the course of a sentence presented in isolation (Van Petten and Kutas 1990; Van Petten and Kutas 1991). More recently, Federmeier and his colleagues have demonstrated that N400 amplitude reduction is observed even for low cloze-probability incongruous words (relative to an incongruous control condition) if they share semantic features with high cloze-probability words (Federmeier and Kutas 1999).

However, as Van Berkum (2009) points out, effects of cloze probability may be accounted for without appealing to the idea that comprehenders are using the context to guess ahead in this way (Van Berkum 2009). Research on the text processing literature has suggested that potentially relevant stored representations become activated through simple passive "resonance"-like mechanisms in long-term memory as a comprehender proceeds through a text (Gerrig and McKoon 1998; Myers and O'Brien 1998). Despite the complex message-level meaning, such resonance may occur between groups of semantically associated or related words or stored schemas. Previous ERP research, however, has shown that, at least under some circumstances, simple lexical associations, schema-based relationships, or other types of simple semantic relationships between words cannot fully account for the N400 effects observed in sentences or discourse (Kuperberg, Paczynski and Ditman 2011; Nieuwland and Kuperberg 2008; Otten and Van Berkum 2007; Coulson, Federmeier, Van Petten and Kutas 2005; Van Petten 1993). Nonetheless, it is still possible that more complex conceptual stored representations, such as those associated with common events or states, are activated by the sentence-level or discourse-level message and, in turn, spread activation to associated semantic features of the upcoming word (Paczynski and Kuperberg 2012; Sanford, Leuthold, Bohan, and Sanford 2011). What has been concluded so far is that access to a high cloze-probability word may be facilitated not because the word is anticipated to come but because the word itself or its corresponding concept is simply associated with stored information in human memory. Such information is passively activated along with context progress.

To briefly conclude, two current accounts have been described that both explain why access to a high cloze-probability word is facilitated during sentence processing. Both assume that through structured combination of stored representations combination of context-level words could result in higher-level representations. For example, such representations of messages the speaker has expressed at sentence- and discourse-level would be included in sentence comprehension. However, differences exist at how these higher-level representations get decoded and both accounts provide their own explanations. One of the accounts states that this higher-level representation activates stored material, which then initiates a passive spread of activation that facilitates processing of upcoming input. The other one states that this conceptual representation is used to predict and affirm specific upcoming items. Such predictions could involve pre-activating the conceptual, phonological, and orthographic representations of the most likely upcoming word or word group. Although both accounts of processing mechanisms are backed with extensive research and likely to play a role in certain processing, this study is aimed at clearing out their respective contributions.

As the stored knowledge that would give rise to either prediction or spreading activation is largely the same, in order to distinguish between these two mechanisms, some form of working memory needs to exist to hold higher-level representation online (Jonides, Lewis, Nee, Lustig, Berman and

Moore 2007). Here prediction is specifically referred to mechanisms of memory-held higher-level representation being updated ahead of actual input. For example, along with processing the fragment "During rush-hour the city metro is ...," the lexical representation of "crowded" is predictively added to the working memory representation of the message, which then the speaker will propose. Contrary to that, the passive resonance/spreading activation account states only the activation level of stored representations in long-term memory needs reference. Thus, after processing the fragment "During rush-hour ...," "crowded" may be activated within long-term memory (along with other related words and semantic features), but it is unlikely that "crowded" will be served as a continuation, that is to say, "crowded" is not actually added to the higher-level representation within working memory before its onset. Although predictions have been distinguished as dedicated to the working memory representation, such dedications could also influence the activation level of long-term memory representations. For instance, potentially adding a lexical representation to working memory could result in additional activation of the long-term memory representation. The boundary of what would be expected before now broadens through more passive spreading activation. In this sense, both predictive and spreading activation mechanisms may exert effects on long-term memory representations activation via different routes.

Convincing evidence has been raised for facilitating effects of lexical prediction with a different kind of paradigm from previous sentence-level studies. In the studies, the form of a functional element is dependent on a subsequent predicted content word (DeLong, Urbach and Kutas 2005; Van Berkum, Brown, Zwitserlood, Kooijman and Hagoort 2005; Wicha, Moreno and Kutas 2004). For example, DeLong, Urbach and Kutas (2005) showed that, when the context strongly predicts a noun beginning with a consonant, such as "kite" ("The day was breezy so the boy went out to fly ..."), a smaller negativity is observed for the article "a" relative to the article "an," which can only occur before words starting with a vowel and which is thus inconsistent with the predicted noun. Because the predicted word itself is not targeted for ERP in those studies, the results these studies provide are evidence strong enough to prove lexical prediction does occur in certain situations. However, these studies are less conclusive about identifying the degree to which classic N400 contextual effects are facilitated because of prediction rather than passive resonance, as the effects in these studies are often observed smaller than those at the predicted noun.

1.3 Relative Constructions with Chinese Contexts

Served as one of the most common linguistic phenomena, relative clauses have been extensively discussed and studied in major languages around the world. In the field of psycholinguistics, the processing advantage of either Subject Relative Clause or Object Relative Clause still lies on heated debate for Asian languages. As the most spoken language around the world, Chinese has also been subjected to this debate and studies have shown results that support processing advantage of either relative clause. The Chinese Object Relative Clause was first proved of processing advantage using a self-paced reading experiment (Hsiao and Gibson 2003). This finding was later rebutted through a redesigned self-paced reading experiment that proved processing advantage of Subject Relative Clause (Lin and Bever 2006). Both findings were later supported by other studies. For instance, aphasia and ERP have been regarded as new fields for Object Relative Clause processing advantage study (Packard, Ye and Zhou 2011; Zhou, Zheng, Shu and Yang 2010), while renewed self-paced reading experiment still proves to be crucial to that theory (Chen and Ning 2008). For processing advantage of Subject Relative Clause, the property of animacy has also been taken into consideration and found quite helpful (Wu, Kaiser and Andersen 2012). To summarize, the problem of processing advantage of Chinese relative clauses is still far from drawing a conclusion.

Compared to the ongoing research of relative clause, relative construction (Rel-Con) studies were much limited in the field. Although relative construction shares an inner connection with relative clause, it is still studied as a grammatical phenomenon. Related studies of English Relative Construction have focused on characterizing the various types of constructions to follow from more generalized properties of language in the field of generative grammar (Culicover 2011; Sag 1997). However, Chinese Relative Construction studies have discussed mostly the issue of infiniteness (Lin 2003; Zhang 2001; Tsai 1994; Tsao 1986), as the complexity of Chinese language hinders systematic study towards itself and leaves open areas for many other issues (Chen 2007).

1.4 The Current Study: Relatedness Proportion in Semantic Priming

The aim of the current study is to observe ERP signals of context-based prediction using a different approach. Rather than following the common measures of reading sentences or discourse, a relatedness proportion semantic priming manipulation was specifically used in which the proportion of semantically associated prime-target pairs varied under different experimental conditions. As these pairs were composed of Chinese relative constructions and words, they should still be considered as part of our natural sentence or discourse and not cause much unfamiliar feeling to test subjects. Moreover, the benefit of this approach is that rather than a naturalistic design, the current design will allow keeping the immediately preceding semantic content exactly identical across conditions.

It is challenging to try to differentiate between passive resonance activation facilitation and sentence/discourse comprehension prediction because of no established way of quantifying complex memory associations of stored scenarios and schemas. Thus, to construct stimuli that need to change itself in context predictability while fitting exactly to a target item for semantic association is difficult in a certain sense. Furthermore, extensive norming is required to develop either strongly or weakly constrained sentence structures, and ambiguities can arise from the weakly constraining contexts—for instance, whether such contexts predict some equally high probability endings or numerous low probability endings. The current study is able to avoid mentioned problems by keeping constant semantic content. At the same time, the probability of prediction can be modulated through changing larger experimental context. Many behavioral studies have demonstrated that increasing relatedness proportion facilitates semantic priming on related trials, as well as measurable costs on processing of unrelated trials (Hutchison, Neely and Johnson 2001; Neely, Keefe and Ross 1989; de Groot 1984; den Heyer, Briand and Dannenbring 1983; Posner and Snyder 1975). Several aspects of these results support the hypothesis that the effects of relatedness proportion are mediated by a predictive process (Becker 1980; Neely 1977). First, relatedness proportion often does not affect processing time in short stimulus-onset asynchrony (SOA) paradigms, where automatic spreading activation is thought to support priming effects, and the effect size seems to increase with longer SOAs, where there is more time between prime and target to generate an expectancy set (Posner and Snyder

1975). Second, Hutchison (2007) shows that the effect of relatedness proportion on priming is correlated across individuals with measures of working memory and attentional control, such as operation span and the Stroop task. From the previous discussions, it is clear that predictive mechanisms require expectancy generation from higher-level representations in working memory. Retrospective strategies like semantic matching (explicitly assessing the semantic match between prime and target) have also been shown to modulate priming effects in lexical decision paradigms, but factors that increase semantic matching result in a different profile of effects that is observed in relatedness proportion manipulations (Neely 1991).

Although a number of different processes are involved in sentence comprehension rather than relatedness proportion paradigm alone, the key process of lexical prediction supported by the relatedness proportion effect seems to be similar to the lexical prediction that is presumed to occur during sentence and context comprehension. Once the subjects realize the fact that many of the prime-target pairs do have a close forward relationship, they begin to try to predict the pair itself as a representation in working memory. That is to say, after the presence of relative construction as prime, a strongly associated target word is predictively added to a working memory representation of the prime-target pair—the higher-level representation. This predictive process is thought to occur only when subjects expect word pairs to be associated—as hinted above that a high-proportion associated pairs exist; if on the contrary few pairs are associated, lexical facilitation for related targets should only be the other account—because of passive priming of representations stored within long-term semantic memory.

Previous behavioral response observations of relatedness proportion effects are suggestive to some extent. However, they still do not present clear evidence on whether lexical processing is facilitated by prediction. This is because behavioral responses sum up the effects of multiple processing stages. Therefore, these effects could be limited to differences in much later stages as in decision processes of lexical decision task. These results also do not address the more specific question of whether N400 amplitude is modulated by prediction over and above the effect of spreading activation, as the N400 does not always track behavioral responses (Holcomb, Grainger and O'Rourke 2002).

Several previous ERP studies have provided important preliminary data that address the above-mentioned questions. Using a lexical decision task with a long SOA (1150 msec), Holcomb (1988) showed that the N400 priming effect was larger for targets in a high relatedness proportion block in which participants were instructed to pay attention to prime-target relationships than in a low relatedness proportion block when they were instructed to ignore such relationships. The increased priming effect was caused by a reduction in N400 amplitude for related targets rather than an increased N400 amplitude for unrelated targets, consistent with the predictive facilitation (Kutas and Van Petten 1988; Kutas and Van Petten 1994). Holcomb also found evidence for a larger late positivity to unrelated targets relative to related or neutral targets, which could be interpreted as reflecting the cost of making an incorrect prediction (Holcomb 1988). In a between-subject design, Brown, Hagoort, and Chwilla (2000) showed that a higher relatedness proportion led to an increased N400 priming effect in a lexical decision paradigm, even when participants were not explicitly instructed to attend to prime-target relationships. Brown and colleagues also showed that the effect of relatedness proportion was not significant in a second experiment in which participants had no explicit task and interpreted this as evidence that predictive mechanisms are not a part of normal language processing but are rather because of the lexical decision task itself (Brown, Hagoort and Chwilla 2000). Finally, Grossi (2006) showed that relatedness proportion did not modulate the size of behavioral or N400 priming effects in lexical decision when the SOA was only 50 msec, which is consistent with the idea that the effect of relatedness proportion on the N400 reflects top-down predictions that take time to generate (Grossi 2006).

Although these findings are suggestive, to better isolate lexical-semantic processing prediction effect, current properties of these studies are still far from being ideal. For instance, semantic-level processing may not be fully engaged with the lexical decision task and additional strategies that are unlikely to occur in common comprehension, for example, semantic matching may be engaged with the task instead. In another instance, motor response, which is typically required by intended targets in a lexical decision task, might disturb the ERP effect. For example, if a prime relative construction in the high-proportion condition leads to an expectation of a particular related target while an unrelated word target is presented instead, the response to the particular target may be kept until the correct representation can be retrieved, and this unfulfilled expectation might thus lead to a temporary response conflict besides lexical level conflict of representation. Although the silent reading task used by Brown and his colleagues (2000) has the advantage that it does not require an unnatural lexicality decision, reading a long series of word pairs without any task may be less well-matched to natural comprehension on other properties such as attention to meaning (Brown, Hagoort and Chwilla 2000). Low-level semantic processing would tend to reduce lexical-semantic prediction and thus result in a smaller relatedness proportion effect. It is true that although relatedness proportion on the priming effect is not significant in the silent reading experiment, the N400 priming effect was larger in number in the high-proportion condition (Brown, Hagoort and Chwilla 2000).

In this study, a semantic probe detection task was adopted. This task requires the subjects to react to certain defined categorical items. This design in the study has several advantages. First, this task requires access to lexical semantics, compared to the lexical decision task to which in principle requires only word form have access. Therefore it may elicit minor semantic processing. Second, this task eliminates much of the potential benefit of a so-called retrospective semantic matching strategy. This strategy accesses target semantics and assesses the matching degree of the prime word. It may be an intelligent shortcut in a lexical decision task where it costs much to directly determine whether the target is an infrequent real word or a non-word. However, it is not such an obvious shortcut in the semantic probe detection task where a decision can be made immediately upon accessing the target word semantics. Third, this task requires no explicit response on the critical targets, which means that response-related ERP time window interference is not a problem.

Compared to the study by Holcomb (1988), the discussion of prime-target relationships was not included in this study, nor was the existence of two separate blocks indicated in the experiment instructions (Holcomb 1988). In this way, different responses across relatedness proportion can be explained only by assuming that the subjects implicitly noticed the change in predictive validity over time. The low-proportion block was also presented first to all the subjects. If however, the high-proportion block was first presented, it may bring significant carryover effects to the low-proportion block. This is because subjects may continue to assume that the prime still predicts the target to some extent until enough information is presented to disrupt this process. Because of this, the low-proportion block was always first to be presented in the experiment such that in the low-proportion block, subjects would have the least evidence to assume prediction of the target on the basis of the relative construction prime. Although throughout the entire experiment there remain factors such as attention and fatigue, these kinds of changes that relate to the status of the subjects would be most likely to reduce the N400 effect size over time, which would go contrary to the main hypothesis that increased facilitation effects is bound up with prediction.

In this study the following hypotheses is discussed. First, semantic priming should result in a dominant relatedness effect, which means targets related to their Chinese relative construction primes elicit a reduced N400 amplitude than unrelated targets, as shown in many previous studies. Second, if increased relatedness proportion calls on test subjects to predict upcoming target using the relative construction prime and if one outcome of such prediction is to further facilitate lexical processing, a quantitative difference in the relatedness proportion effect will be available: a greater reduction in N400 amplitude for related targets of the high-proportion block than that of the low-proportion block.

2 Methodology

2.1 Materials

Table 2.1 summarizes arrangements of the material set used in this study. This experiment followed a 2 × 2 matrix design (Low-/High-Proportion × Related/Unrelated). The materials were thus divided into two blocks—a low-proportion block and a high-proportion block. 10% of relative constructions were set related in the low-proportion block whereas 50% in the high-proportion block. A set of designed and balanced test pairs was chosen for the examination of the effect of the experimental factors. Proportion manipulation was then achieved by inserting related and unrelated filler pairs of different proportions to mix with these test pairs. Finally, a set of animal items was included in each block as the probe detection task. Each block then contained altogether 200 relative constructions pairs, with a total of 400 test pairs per experiment.

Table 2.1 Item design of the two proportion blocks

Low-proportion Block	High-proportion Block
20 related targets	20 related targets
20 unrelated targets	20 unrelated targets

Low-proportion Block	High-proportion Block
20 animal probes	20 animal probes
140 unrelated fillers	60 unrelated fillers 80 related fillers

Table 2.2 Examples from the low-proportion block

Low-proportion Block
Related target:
hu zeng li wu de lang man/ai qin
(romance/love caused by mutual gift-giving)
Unrelated target:
zheng zai xiu jian de ma tou/mu qin
(the dock/mother under construction)
Animal probe:
da pian shang ying de ying yuan/yanshu
(the blockbuster/mole showed in the cinema)
Unrelated filler:
zong tong qian shu de zhi piao/mei guo
(the check signed by the president/America)

Table 2.3 Examples from the high-proportion block

High-proportion Block
Related target:
fa biao yan jiang de guo wang/huang hou
(the king/queen who delivered the speech)
Unrelated target:
mu shi zhu chi de zang li/wai tao
(the funeral/coat chaired by the priest/coat)
Animal probe:
lv shi chu shi de zheng ju/xi niu
(the evidence/rhinoceros presented by the lawyer
Unrelated filler:
you ke san bu de hai an/cai liao
(the beach/material the tourists are taking a walk)
Related Fillers:
yao qing qian wang de ju hui/yin yue
(the party/music being invited)

To create such a set of related and unrelated test pairs, 80 highly associated prime-target pairs were selected from the University of South

Florida Association Norms. This database is the largest database of free association ever collected in the United States. More than 6,000 participants produced nearly three-quarters of a million responses to 5,019 stimulus words. Participants were asked to write the first word that came to mind that was meaningfully related or strongly associated to the presented word on the blank shown next to each item. In this database free association was used as the means for identifying the strength, number and direction of connections because first, using free association as a procedure for measuring connection strengths has a long history as a reliable technique. Second, compared to rating pairs of words for "relatedness" free association has a number of advantages. Having concluded that free association is likely to be better than rating procedures, it is important to note that free association suffers shortcomings as well, which may limit the use of this index in some situations but two important factors would ease the concern. First, as noted earlier, free association norms are reliable. Second, free association norms have strong predictive relationships to cued recall, feelings of knowing, priming and to other types of performance that rely on memory. Despite the absence of a measure of dispersion, the strength index has proven useful in predicting and controlling performance in psychologically important tasks (Nelson, McEvoy and Schreiber 2004).

During materials selection in the current study, one of the criteria—forward association strength of all pairs was looked into and kept above 0.5 (meaning when presented with the prime word, 50% of participants responded with the target word), while the mean forward association strength was over 0.6. All associated pairs had been previously normed by at least 100 participants. Pairs with morphological overlap in English were not included. As the probe task was set to respond to animal words, all pairs had been filtered of animal words.

The 80 highly associated prime-target pairs were then formed into Chinese relative constructions. After a careful formation of following a "7 Chinese characters for relative construction and 2 Chinese characters for target word" pattern to keep consistency, the Chinese pairs then went through the process of balancing the number within kinds of relative constructions and filtering off exact Chinese words. A final check was in place to correct unintended animal characters in Chinese even though they formed words that were anything but animals.

Forty unrelated test pairs in the set were then created by randomly redistributing the Chinese relative constructions across the target words and checking by hand to confirm that no associated pairs were accidentally formed during this process. The 80 related and unrelated pairs were created into two lists in a Latin Square design, such that no list contained the same construction or target twice. These lists were then again divided in two, such that 20 related and 20 unrelated pairs were assigned to each block.

Twenty probe trials and the rest filler pairs for each block were formed afterwards. The probe trials consisted of a randomly selected and formed Chinese relative construction followed by an animal word target. The constructions in the probe trials were never related to the targets. The animal words were selected from the Encyclopedia of China online version (http://ecph.cnki.net) and also limited to the 2-Chinese-characters pattern. To achieve the desired relatedness proportion in each block, 140 unrelated filler trials were included in the low-proportion block to create 10% ratio of the related trials, while 120 unrelated filler trials and 160 related filler trials were included in the high-proportion block to create 50% ratio. The related filler pairs were also selected and formed from the South Florida Association Norms and again, no words or constructions were ever repeated in these pairs.

2.2 Subjects

Subjects were selected from graduate students of Dalian University of Technology with a total of 20 participants (12 men and 8 women). Their ages range from 20 to 26 years old with a mean age of 23.4 years. All selected subjects were raised in China and have been native speakers of Chinese. They were consulted as right-handed and had normal or corrected-to-normal vision. None of the subjects had history of reading disability or neurological disorders. Informed consent was obtained from all participants in written or digital forms before experiment under the existing guidelines of Dalian University of Technology in China.

2.3 Stimulus Presentation

Experimental materials were then designed to present in a preset sequence. This sequence was designed using the psychology software tool E-Prime. E-Prime is a visualized programming language platform that makes the psychological experiment computerized and a packaged application for data collection and analysis within millisecond. Its functions are as follows: experimental design, generation, operation, data collection, editing, pre-processing and so on.

Its advantages are as follows: the presentation of E-prime can be in the form of text, picture and sound or any combination of two of these three forms at one time. It can provide detailed information of time and event, including presentation time and response time, for further analysis, facilitating to understand problems about the operation time of the real experiment. E-prime is psychological-experiment-oriented and the time of psychological experiment is optimized. Stimuli presentation is synchronized with the screen refreshment with the accuracy of up to milliseconds.

During the experiment process subjects were individually tested. They were seated in a comfortable chair in a dimly lit and soundproof room. Stimuli were visually presented on a 1920×1080 resolution LED monitor of 60 Hz refreshing rate. They were set to display in yellow 24 Song font on a black background. Each trial of the experiment began with a fixation cross, presented at the center of the screen for 700 msec and a 100-msec black screen to follow. The prime word then was presented for 500 msec followed by a 100-msec black screen. After that, the target word was presented for 900 msec. A 100-msec black screen was put as the end of each trial. Subjects were instructed in advance to use their right index finger and press "J" on the keyboard whenever they noticed an animal name. Figure 2.1 was prepared as a flow diagram of a single trial. The experiment process was divided into 2 sessions (of 2 blocks) and always started from the low-proportion block, with 200 trials of about 8 minutes each. To better acquaint subjects with the ongoing process, all of them were given a practice of 5 trials at the beginning of the experiment.

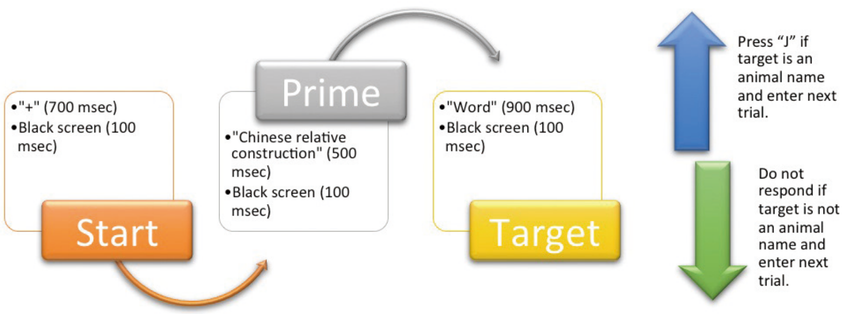

Figure 2.1: Flow chart of single trial in the experiment

2.4 Electrophysiological Recording

To begin with, the electrode position Cz, Fpz, and Oz were measured and labeled on the head of test subjects with measurement tape in advance. Then thirty-six tin electrode caps were put on by subjects sitting still, while its Cz electrode was precisely placed on the previously labeled position. The cap would later be adjusted once more.

The electrode cap of 10/20 configuration was connected to the Neuroscan Nuamps Amplifier, Model 7181 (Compumedics Neuroscan, El Paso, TX) linked to a computer used to collect the amplified EEG signal with a USB cable. On the computer the software Scan 4.3 would need to be installed and configured for monitoring the acquisition process. Press the “Acquire” button on the left side panel of Scan interface would open the acquisition program. Then execute “File” → “Load Setup” command from the menu panel to load electrode position configuration file. Further parameters would need to be set by executing “Edit”→ “Overall Parameters” command from menu panel to set sample rate as 250Hz and bandpass of 0.1–40 Hz. Finally, to help the computer understand that additional electrodes were also placed over the left and right mastoids for reference, execute “Edit”→ “Nuamps Setup” command from the menu panel to set reference electrode option as (A1+A2)/2.

The electrode jelly was then accordingly injected into respective electrodes to achieve under 5 kΩ impedance for all scalp electrodes, mastoid and eye electrodes sites for signal reception. First execute “Impedance” command from the menu panel on the computer to monitor instant impedance status of each connected electrode. The electrode of GND was then firstly injected. After cleaning cuticle of head skin with facial scrub, paste the reference electrodes A1 and A2 full of electrode jelly with adhesive tape to both of the mastoid sides below subjects’ ears. With the previously mentioned method, electrode jelly was also injected into electrodes HEOR (outer canthus of the right eye) and VEOL (1 cm below the left eye). During this step the connection wires of amplifier should not be turned over and block the view of subjects. The rest of electrodes were eventually injected respectively with electrode jelly. When all of the process was completed, the computer monitor would show that except for electrode A2, instant impedance status of other connected electrodes would be well below 5 kΩ, which indicated that good connection had been established between subject and computer and data collection could start in any moment.

When the subjects feel ready, press the green “Start” button on the toolbar and start an instant presentation of current EEG signal. Then before setting up and starting the presentation sequence of experimental materials at the side of E-Prime, press the red round-shaped “Record” button on the toolbar to start signal recording. During experiment process, while subjects focus on their monitor for any timely reactions, a second 1280×1024 resolution LED monitor that was previously connected to the computer would be used to track ongoing process of EEG signal recording. Calibration pulses were also recorded for offline recalibration of the EEG signal later.

During the experiment, room lights were completely turned off and all mobile devices were also switched off, eliminating possible radio interference towards both the computer and amplifier and helping test subjects focus on the material presentation on screen in a dimly lighted environment. The test chamber was also kept from unauthorized personnel entry to make sure that no potential noise would occur to hinder subjects to achieve natural performance of experiment task.

2.5 Data Analysis

After filtering ocular and muscular artifacts using preprocessing functions provided by the EEGLAB toolbox (Delorme and Makeig 2004) and its automatic identification add-on MARA (Winkler, Haufe and Tangermann 2011), averaged ERPs time-locked to target words could be formed offline. EEGLAB is an interactive Matlab toolbox for processing continuous and event-related EEG, MEG and other electrophysiological data incorporating independent component analysis (ICA), time/frequency analysis, artifact rejection, event-related statistics, and several useful modes of visualization of the averaged and single-trial data. EEGLAB provides an interactive graphic user interface (GUI) allowing users to flexibly and interactively process their high-density EEG and other dynamic brain data using independent component analysis (ICA) and/or time/frequency analysis (TFA), as well as standard averaging methods (Delorme and Makeig 2004). MARA (“Multiple Artifact Rejection Algorithm”) is an open-source EEGLAB plug-in which automatizes the process of hand-labeling independent components for artifact rejection. The core of MARA is a supervised machine-learning algorithm that learns from expert ratings of 1290 components by extracting six features from the spatial, the spectral and the temporal domain. Features were optimized to solve the binary classification problem “reject vs. accept” (Winkler, Haufe and Tangermann 2011).

Only trials either responded or withheld a response correctly by subjects before the onset of the next trial were included in the target words processing. Across all 20 subjects included in the analysis, 6 were rejected because of over 50% artifact-affected trials. A 100-msec pre-stimulus baseline was subtracted from all waveforms for epoch reference before statistical analysis. A 15-Hz low-pass filter was applied to the data to create the figures.

To assess the hypotheses that high relatedness proportion would increase N400 priming, thus further indicate existence of N400 effects of prediction. IBM® SPSS® Statistics 21 was used to compute a repeated-measure Type III ANOVA on mean ERP amplitudes between 300- and 500-msec post-stimulus onset across all sites, with Relatedness and Proportion as the experimental factors of interest. IBM® SPSS® Statistics is statistical analysis software that delivers the core capabilities to take the analytical process from start to finish. It is easy to use and help survey authoring and deployment, data mining, text analytics, statistical analysis, collaboration and deployment. There should be no correction needed for violations of sphericity (Greenhouse and Geisser 1959), as ANOVAs conducted here included no more than 1 *df* in the numerator. The figures in the main text illustrate the response waveforms of only the representative site (Cz) in consideration of saving space. Waveforms across all sites are available in the follow-up supplementary chapter.

2.6 Results

2.6.1 Behavioral Results

Subjects were required to press the button only when they encountered an animal word from the probe category. Only responses within 900 msec of target presentation duration were considered. Accuracy in correct responding to non-probe targets was 99.1% among all conditions. Mean accuracy in identifying animal probe words in the low-proportion condition was 97.5% (*SD* = 3.3%) and in the high-proportion condition 97.5% (*SD* = 3.8%), thus showing no appreciable effects of proportion. Mean RTs of low-proportion block were 591 msec (*SD* = 69 msec) and the other block 634 msec (*SD* = 85 msec). A paired-sample *t* test showed that this RT difference was significant [*t*

(13) = 2.16, $p < 0.01$], indicating that participants were slower to act to animal words in the high-proportion block as prediction was suggested.

2.6.2 ERP Results

Figures 2.2 to 2.5 illustrate the N400 response to all the 4 conditions of low and high-proportion blocks (related high/unrelated high, related low/unrelated low, related low/related high and unrelated low/unrelated high). To begin with, a special N400 effect of semantic priming (unrelated target more negative than related target) was observed in both proportion blocks, but consistent with hypothesis, the N400 effect was larger in the high-proportion block than in the low-proportion block.

Repeated-measures ANOVA in the 300–500 msec time window across all sites demonstrated a main effect of relatedness [$F(1, 13) = 8.06$, $p < 0.01$] and a significant interaction between relatedness and proportion [$F(1, 13) = 9.92$, $p < 0.01$]. This interaction was because of a larger effect of relatedness in the high-proportion condition than in the low-proportion condition (0.98 μV of related low-proportion, 1.23 μV of unrelated low-proportion, 4.79 μV of related high-proportion, and 2.25 μV of unrelated high-proportion). Pair-sampled t-tests for both proportion blocks showed that the effect of relatedness was significant in both the low-proportion [$t(13) = 3.13$, $p < 0.01$] and high-proportion [$t(13) = 2.07$, $p = 0.049$] blocks. This indicates that it was amplitude difference of the priming effect over 2 blocks that caused interaction between relatedness and proportion rather than an absence of priming effect in the low-proportion block.

It is hypothesized that the facilitative effects of fulfilled prediction and conflict effects of unfulfilled prediction would be observed at the N400 in sequence, and yet the interaction between relatedness proportion and priming at the N400 could also reflect an increase in N400 amplitude for high-proportion unrelated targets. However, from the results shown in Figure 2.5 it is clearly indicated that there exist matched N400 amplitudes of unrelated targets for both high- and low-proportion blocks at centro-parietal electrodes.

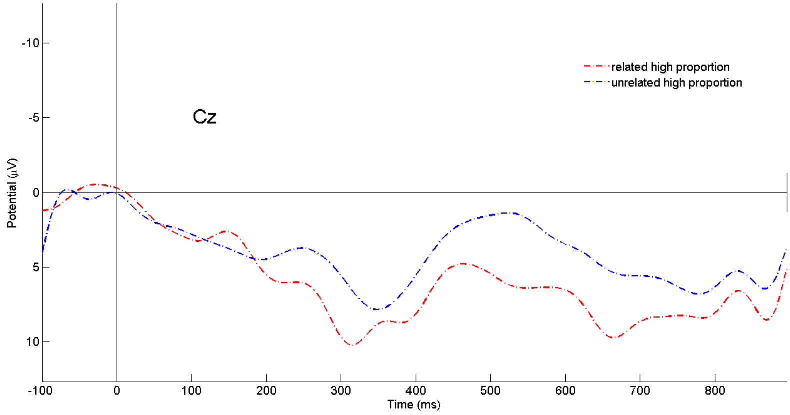

Figure 2.2: Grand-averaged waveforms to target words following related and unrelated primes of high relatedness proportion at site Cz.

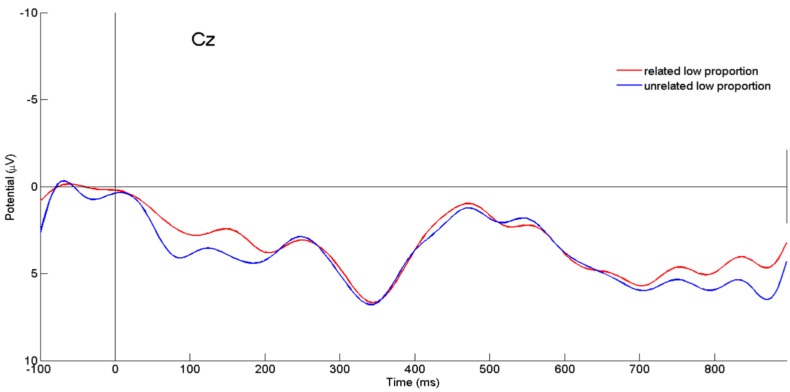

Figure 2.3: Grand-averaged waveforms to target words following related and unrelated primes of low relatedness proportion at site Cz.

On the contrary, a reduced N400 amplitude was elicited in the high-proportion block to the related targets. Pair-sampled t-test results at each level of relatedness were consistent with this visual presentation and demonstrated that proportion (low/high) had a significant effect on the response to related targets [$t(13) = 4.78$, $p < 0.01$], whereas the effect of proportion on the unrelated targets was not significant [$t(13) = 1.53$, $p = 0.15$].

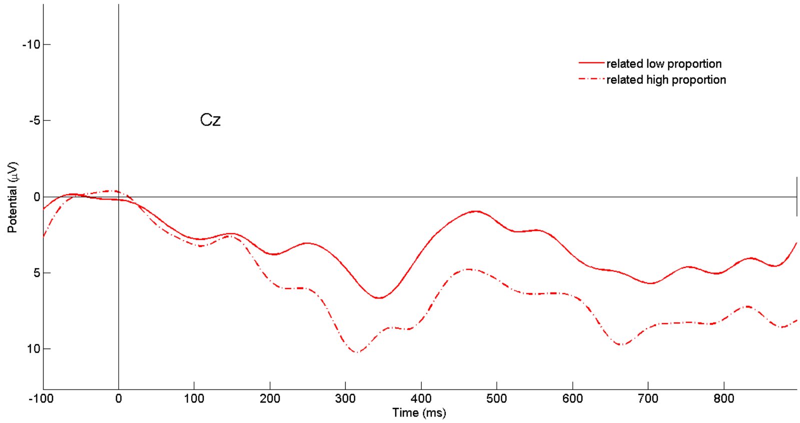

Figure 2.4: Grand-averaged waveforms to target words following related primes of low and high relatedness proportion at site Cz.

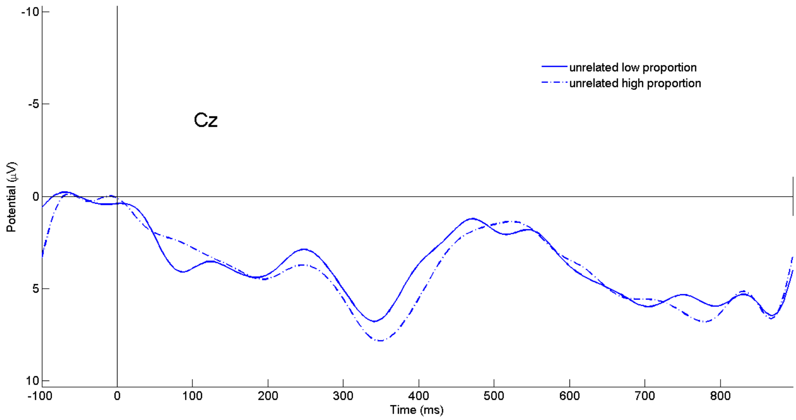

Figure 2.5: Grand-averaged waveforms to target words following unrelated primes of low and high relatedness proportion at site Cz.

3 Discussion

In this experiment, a relatedness proportion paradigm was used to manipulate the predictive validity of the prime Chinese relative constructions while keep the constant local context. A semantic category probe task was used to encourage target meaning processing without requiring test subjects to execute motor responses on trials of interest. The results show that as relatedness proportion increases—a manipulation previously argued to encourage predictive processing (Neely 1977)—N400 effect is substantially reduced for related targets. These results are consistent with previous ERP studies demonstrating increased N400 facilitation with increased relatedness proportion (Holcomb 1988).[53] The N400 effect latency was also found under all experimental conditions with an average timeframe of 472 msec for maximum N400 effect which is consistent with previous study that onset and peak of the N400 effect are delayed because of rapid presentation of experiment materials (Kutas 1993).

3.1 Various Accounts Concerning Relatedness Proportion Paradigm

As argued in the Introduction, using sentence- or discourse-level stimuli to distinguish between the two accounts of the N400 effect facilitation is difficult. Differences in association between the context of relative construction and the target item might easily be seen through any manipulation in contextual constraint or word predictability. This study has come to an important understanding that without changing content of the immediate context the N400 effect can be modulated with the only factor of prediction strength. This indicates that the N400 priming effect does not trigger the spreading resonance between stored long-term memory items only. Moreover, it also appears to be closely related to the extent of how the reader predicts about the relatedness from the existing context to the target item.

The relative positioning in the experiment may be an alternative explanation for the observed N400 effects of relatedness proportion. Following previous studies, we found the high-proportion block was always second to present to ensure that subjects were unaware of the relative construction serving as valid prediction for the target during the low-proportion block. Still, one might argue that the differences between blocks were caused by some primitive property associated with their presentation sequence rather than the relatedness proportion manipulation itself. Although in the current paradigm it is not possible to separate the conditions of trial order from relatedness proportion, it is also believed that the trial order alone cannot provide a good account for the observed results. As low-level variables such as lower attention and motivation would normally be associated with trial order, such variables would seem to produce reduced effect sizes for a manipulation that is irrelevant to the tasks as the experiment proceeds. Despite that, bigger priming effect was indeed witnessed in the second half of the experiment, which receives a natural explanation through the change in the proportion of related relative constructions.

A more plausible account on the trial order is that the modulation of N400 priming is indeed driven by increased prediction but that it is the number of related prime-target pairs encountered by test subjects rather than the block proportion that drives them to predict. In this way, once enough time was provided in a low-proportion block subjects would still begin to use relative construction prime to predict the target. This is a possibility that relates to the broader question of how prior input properties modulate predictive strategies in general. It would not affect the central conclusion of this study if being correct, that modulation of prediction strength then further modulates of the N400 effect.

3.2 Realization of N400 Prediction Effect

The N400 prediction effect could be realized in the following ways. First, in strongly predictive contexts, subjects may hold the prime in working memory and use this representation to directly pre-activate lexical representations of strong associates, which are added to working memory before the appearance of the target. As a result, lexical processing as reflected by N400 amplitude would be easier when one of those associates is actually presented. This account is consistent with work suggesting that the N400 effect is at least partially because of facilitated activation of lexical-conceptual information in long-term memory (Lau, Phillips and Poeppel 2008; Kutas and Hillyard 1984; Kutas and Federmeier 2000).

However, there exists the possibility that the current priming effects of contextual predictability can be elicited by subjects pre-activating the target words (or their semantic features) long before relative construction primes are presented. For example, initial activation of the target could be purely based on bottom-up information, but in an environment with high predictive validity, participants might be more likely to bring prior context into a later stage of processing (Marslen-Wilson 1987). Another possibility is that, subjects tend to further process the prime which has more predictive validity so that it is able to passively spread more activation to associated memory representations (though for this account, greater absolute N400 amplitude might be expected for high-proportion primes, whereas current results show the opposite).

Although these mentioned alternative hypotheses could explain the observed N400 modulation pattern, current results are showing the preference towards the predictive account, as the effect of the prime context was observed to begin earlier under the high-proportion condition. These results will be further discussed and can be directly used to explain if predictive mechanisms are selectively invoked under this condition. However, they are still far from answering questions including whether context is used in a later stage or an increase of the same spreading activation mechanism is caused only by the change from low-to high-proportion. As discussed in the Introduction, there is also evidence from sentence-level studies for lexical prediction effects before the onset of critical words (DeLong, Urbach and Kutas 2005; Van Berkum, Brown, Zwitserlood, Kooijman and Hagoort 2005; Wicha, Moreno and Kutas 2004). Finally, if the relatedness proportion effects were simply because of further processing of the prime, it would seem to predict that accuracy of detecting an animal probe in the prime position would also be higher, but in a similar study that included animal probes in both prime and target position, no difference was found in the rate of detection across high- and low-proportion blocks although the overall detection rate was well below ceiling (Lau, Gramfort, Burns, Delaney-Busch, Fields, Fanucci, et al. 2012).

The fact that N400 priming effect was even observed in the low-proportion condition suggests that effect of N400 facilitation may not be completely concluded as predictive processes. This is consistent with the previous work demonstrating N400 priming effects under conditions thought to elicit more automatic processing, such as N400 semantic priming at short SOAs (Franklin, Dien, Neely, Huber and Waterson 2007; Deacon, Uhm, Ritter, Hewitt, and Dynowska 1999; Anderson and Holcomb 1995), priming of targets that are only indirectly associated with their primes (Kreher, Holcomb and Kuperberg 2006; Chwilla, Kolk, and Mulder 2000), and at least semiconscious masked semantic priming (Grossi 2006; Holcomb, Reder, Misra and Grainger 2005; Kiefer 2002). Retrospective semantic processes such as semantic matching have also been shown to elicit N400 effects (Chwilla, Hagoort and Brown 1998) and thus could also have contributed to the low-proportion N400 effect here, although the use of a semantic probe task may have made this less likely. The presence of an N400 priming effect in the absence of prediction is regarded to be consistent with more recent work at the sentence and discourse level showing N400 facilitation for targets that are not predictable and are not necessarily semantically related to the predicted item but are plausibly associated with other individual words in the context (Boudewyn, Gordon, Long, Polse and Swaab 2012; Camblin, Gordon and Swaab 2007; Ditman, Holcomb and Kuperberg 2007) or related to the overall stored schema activated by the context (Paczynski and Kuperberg 2012; Sanford, Leuthold, Bohan, and Sanford 2011). Because semantic relatedness between relative constructions and words in context is unlikely to be predictive of upcoming material in actual comprehension, sentences or discourses containing such associations resembles more to the low-proportion condition rather than high-proportion condition. Effects of both conditions may be mediated through more passive resonance mechanisms. This may also account for the fact that in sentence and discourse paradigms, effects of lexical association independent of the message-level representation have tended to be relatively smaller and more variable Boudewyn, Gordon, Long, Polse and Swaab 2012; Camblin, Gordon and Swaab 2007; Traxler, Foss, Seely, Kaup and Morris 2000; Morris and Folk 1998; Van Petten, Weckerly, McIsaac and Kutas 1997; Morris 1994; Carroll and Slowiaczek 1986).

In summary, these results suggest that spreading activation and prediction may have a complementary effect for people to prepare for upcoming sentence or discourse. Even though spreading activation serves as a less decisive effect less than prediction, it can still provide processing benefit of certain degrees even when specific predictions are unavailable for the context.

3.3 Conclusion

The results of this study show that contextual prediction modulates the N400 amplitude facilitation and the degree to which context generates a prediction for the target directly impacts the facilitation effect. Although the Chinese relative construction prime and target word pair paradigm is still far away from a natural language comprehension situation, findings in this study suggest that theoretically under a content of constant context specific lexical-conceptual predictions can in a way affect N400 amplitude more than effects of passive spreading activation can. These results argue against previous studies and accounts of a long-term memory spreading activation model, which claims to solely account for N400 contextual modulation. On the other hand, the results support a model in which context is used for online generation of predictions for upcoming input during comprehension. The results also lay down the hints for one step of a possible processing mechanism for Chinese relative clauses. Thus future research could either continue to look into properties that distinguish the two standing accounts of N400 deduction brought by contextual facilitation in more paradigms that appeal to natural language, or further investigate the processing mechanism for Chinese relative clauses to provide enough support for a more conclusive understanding of the processing advantage.

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Bionotes

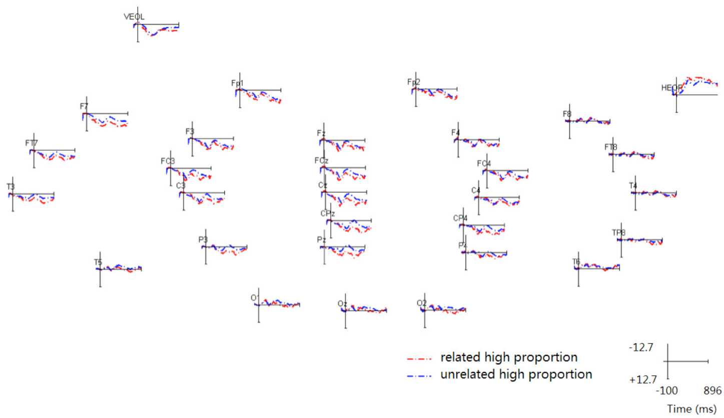
Huili Wang
Huili Wang (b. 1966) is the professor and director of the Institute for Language and Cognition in Dalian University of Technology. Her research interests include psycholinguistics, cognitive neurolinguistics and experimental philosophy. Her publications include: “Economy is an organism—a comparative study of metaphor in English and Russian economic discourse” (2013), “The role of preparation time length in asymmetrical switch cost: an ERP study based on overt picture naming” (2013).

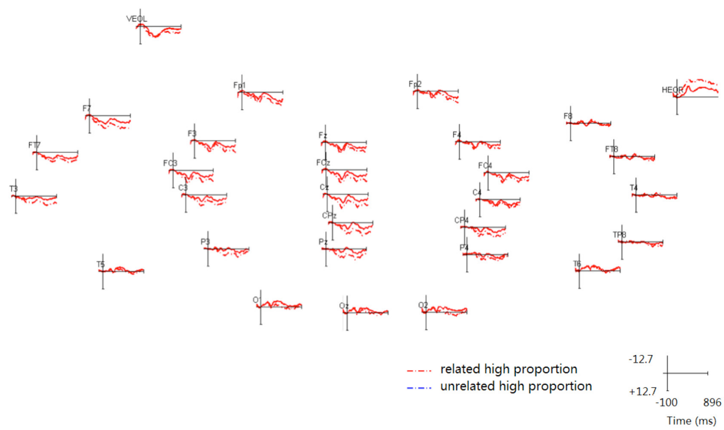
Meng Ling
Ling Meng (b. 1989) is a M.A. holder of the Institute for Language and Cognition in Dalian University of Technology. His research interests include psycholinguistics, cognitive linguistics and neurolinguistics. His publications include: Mind, language and world—review of the book “Louder Than Words: The new science of how the mind makes meaning” (2014).

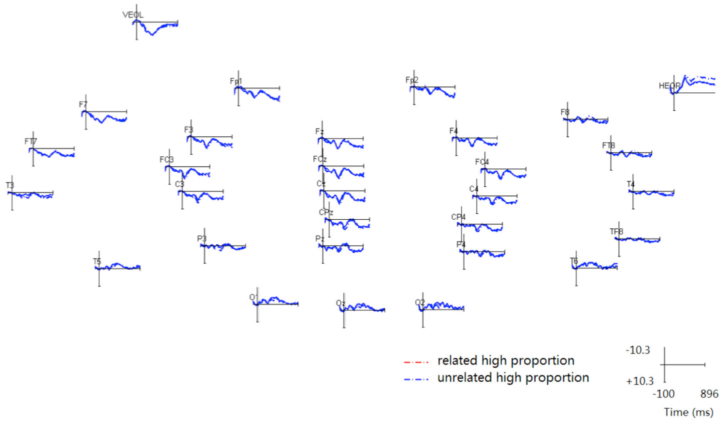
Cao Shuo
Cao Shuo (b. 1977) is the associate professor and number of the Institute for Language and Cognition in Dalian University of Technology. Her research interests include cognitive linguistics, discourse analysis and advertisement study. Her publications include: "Intertextuality and glocalization: A corpus-based analysis of advertisement texts of an international female magazine" (2014); "Move analysis of online shopping deals: a perspective of intertextuality"(2014).

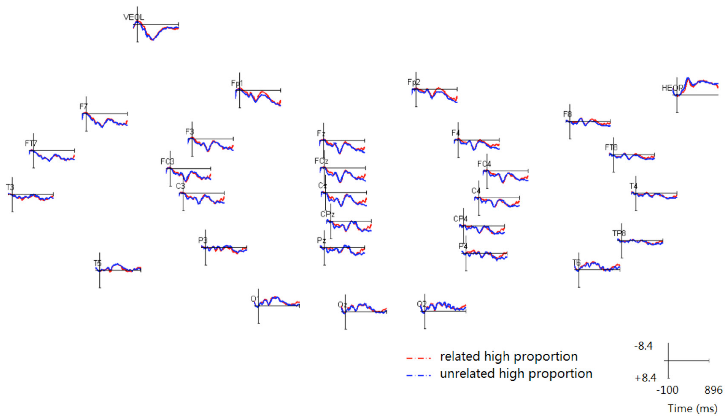
Appendix: Supplementary Figures

The following four figures provide a complete view of electrodes data for all the condition-based comparisons discussed in the paper. The figures illustrate the time-locked response to the target word in the prime-target pair (-100:900 ms).






VEOL
Fp1
Fp2
HEOR
F7
F3
Fz
F4
F8
FT7
FC3
FCz
FC4
FT8
T3
C3
Cz
C4
T4
CPz
CP4
TP8
P3
Pz
P4
T5
T6
O1
Oz
O2
related high proportion
unrelated high proportion
-10.3
+10.3
-100
896
Time (ms)


VEOL
Fp1
Fp2
HEOR
F7
F3
Fz
F4
F8
FT7
FC3
FCz
FC4
FT8
T3
C3
Cz
C4
T4
CPz
CP4
TP8
P3
Pz
P4
T5
T6
O1
Oz
O2
related high proportion
unrelated high proportion
-8.4
+8.4
-100
896
Time (ms)