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Research Report

Semantic illusion depends on information structure: ERP evidence

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ABSTRACT

Next to propositional content, speakers distribute information in their utterances in such a way that listeners can make a distinction between new (focused) and given (non-focused) information. This is referred to as information structure. We measured event-related potentials (ERPs) to explore the role of information structure in semantic processing. Following different questions in wh-question–answer pairs *(e.g. What kind of vegetable did Ming buy for cooking today? / Who bought the vegetables for cooking today?)*, the answer sentences *(e.g., Ming bought eggplant/beef to cook today.)* contained a critical word, which was either semantically appropriate *(eggplant)* or inappropriate *(beef)*, and either focus or non-focus. The results showed a full N400 effect only when the critical words were in focus position. In non-focus position a strongly reduced N400 effect was observed, in line with the well-known semantic illusion effect. The results suggest that information structure facilitates semantic processing by devoting more resources to focused information.

1. Introduction

When people communicate what they believe to be new or important, most of them do not realize that they arrange the information in a highly structured manner. For example, in the conversation *What did you eat for dinner? / I ate* **beef** *for dinner*, the *wh*-phrase in the question indicates what information the requester expects. In the answer, the *beef* is a newly supplied information, which is the focus of the sentence, whereas the remaining part of the sentence is associated with the previous context, which is the common background shared by the speaker and listener. This way of connecting new information (focus) with previously given information (background) during communication is part of information structure (IS) (Jackendoff, 2002). As described in the example, IS usually consists of two elements: background and focus. Background refers to the information that is already available in the mind of the listener/reader, while focus refers to the part of utterance that represents the new or contrastive information (Gűnther et al., 1999). There are several approaches to realize IS, such as position in question–answer pairs (as in the example, focus is in bold), syntactic constructions like it-cleft sentence (*It is* **beef** *that I ate for dinner.*), and accentuation in spoken language (*I ate* **BEEF** *for dinner*. The accented word is marked in capitals).

Several behavioral studies suggest that the focused information receives more attention and attains deeper processing than non-focused information (Cutler and Fodor, 1979; Birch and Rayner, 1997; Ward and Sturt, 2007; Sanford et al., 2006). In a recent ERP study, Li et al. (2008a) found that more resources

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were devoted to information that was marked as new (focus) by accentuation. These results suggest that not all information in utterances is processed to the same degree. The focused information gains more attention and is thus processed deeply, while non-focused information receives less attention, and might be processed to a lesser extent. To test to which extent the focus and attention are related in language processing, we made use of a phenomenon called the semantic illusion.

The semantic illusion was first reported by Erickson and Matteson (1981). It is an indication that listeners may indeed fail to represent particular information from the input. For example, participants did not notice that it was Noah rather than Moses who should be identified in the sentence *How many animals of each kind did Moses take on the ark?* (Erikson and Matteson, 1981). The probability of a semantic illusion is affected by a number of factors, such as word similarity (Van Oostendorp and De Mul, 1990; Shafto and Mackay, 2000), processing difficulty (Barton and Sanford, 1996), surrounding context (Hannon and Daneman, 2001) and syntactic form (Büttner, 2007). The semantic illusion reflects the depth of semantic processing, and can be modulated by allocation of attention (for reviews see Sanford, 2002; Sanford and Sturt, 2002).

To investigate the influence of the focus status on the detection of semantic illusion, Bredart and Modolo (1998) instructed participants to evaluate the truth of two statements such as "*Moses put two of each kind of animal on the ark*." And "*It was Moses who put two of each kind of animal on the ark*." They found that the detection rate was higher when the critical word was focused in the cleft sentence, indicating that the focus status of *Moses* triggers a fuller and more elaborate analysis. However, the detection rate is a relatively indirect index for studying the underlying cognitive process, and the task itself might make the semantic illusions more salient.

In this study, we aim to investigate whether IS modulates the semantic illusion effect in on-line processing. If IS influences the depth of processing, the semantic illusion might only occur when information is not in focus, but less often occur with focused information. This hypothesis was tested using a well-known ERP component, the N400. The N400 is a negativity that peaks around 400 ms after stimulus onset, with a centro-parietal maximum distribution (Kutas and Hillyard, 1980). The N400 amplitude varies as a function of how easily a word is integrated into or activated by the previous context. For instance, words that are semantically anomalous in the sentence context elicit a larger N400 than semantically coherent words, which is classified as an N400 effect (Kutas and Federmeier, 2000; Hagoort et al., 2004). Moreover, the N400 is also sensitive to the constraints provided by a single open class word or a wider discourse (see Kutas et al., 2006 for a review). An ERP study on the semantic illusion by Nieuwland and Van Berkum (2005) found no N400 difference between anomalous and normal words when listeners failed to notice the anomaly immediately, whereas they found a late positive effect which indicated that the listeners ultimately detected the semantic anomaly. Consequently, we can interpret the absence of a regular N400 effect to a semantic anomaly as the on-line manifestation of a temporary semantic illusion.

To investigate whether the IS plays a role in the occurrence of a semantic illusion, we manipulated IS by using wh-question–answer pairs. The constituent of the answer corresponding to the wh-word in the question usually conveys important and/or new information and thus has a focus status, while the part of the answer referring to information stated in the question has a non-focus status (Jasinskaja et al., 2004). Additionally, the semantic appropriateness (appropriate vs. inappropriate) of focused and non-focused constituents in the answer sentence was manipulated. The N400 effect to the semantic anomaly was used to indicate the depth of semantic processing. We hypothesized that readers allocate more attention to focused words, and process them more deeply than non-focused words. Consequently, we expected inappropriate words to show an N400 effect when in focus position, but a smaller or no N400 effect in non-focus position.

2. Results

2.1. *Behavioral results*

On average, participants gave a correct response to 97% of the statements, indicating that they did attend to the materials.

2.2. *ERP results*

Fig. 1 displays the grand average waveforms elicited by the four different conditions at nine representative electrodes (F3/C3/P3, FZ/CZ/PZ, F4/C4/P4). (Note that we only displayed the ERPs in the time window between −200 and 700 ms rather than the entire preprocessed time window between −200 and 1200 ms, because we did not find any significant effects for IS or any interactions in the later time window.) In view of the effects revealed by the grand averages, two time windows were selected for the statistical analysis: (a) The standard N400 in the time window 300–500 ms; (b) The late positivity between 500–650 ms. Using mean amplitude values computed for each participant, each condition and each time window, analyses of variance (ANOVAs) were conducted to four factors: IS (focus, non-focus), Appropriateness (appropriate, inappropriate), Region (anterior, central, posterior) and Hemisphere (left, midline, right). When the degree of freedom in the numerator was larger than one, Greenhouse–Geisser correction was applied.

2.2.1. *300–500 ms*

The results revealed a significant main effect for Appropriateness ($F_{(1, 17)}=21.47$, $p<.001$), with semantically inappropriate words eliciting a larger negativity than appropriate words. In addition, there were main effects for Region ($F_{(2, 34)}=4.89$, $p<.05$) and Hemisphere ($F_{(2, 34)}=3.91$, $p<.05$). As can be seen in Fig. 2, importantly there was a significant interaction between Appropriateness and IS ($F_{(1, 17)}=4.72$, $p<.05$). A further simple-effect test showed a significant N400 difference between semantically appropriate and inappropriate words in focus position ($F_{(1, 17)}=29.66$, $p<.001$), but not in non-focus position ($F_{(1, 17)}=1.76$, $p=.20$). (Note that in the non-focus condition, the interaction between Appropriateness and Region was not significant ($F_{(2, 34)}=2.46$, $p=.10$), although the visual observation of the waveforms shows different patterns at frontal, central and posterior areas.) Comparing the amplitudes in the semantically appropriate conditions, we can see that the N400

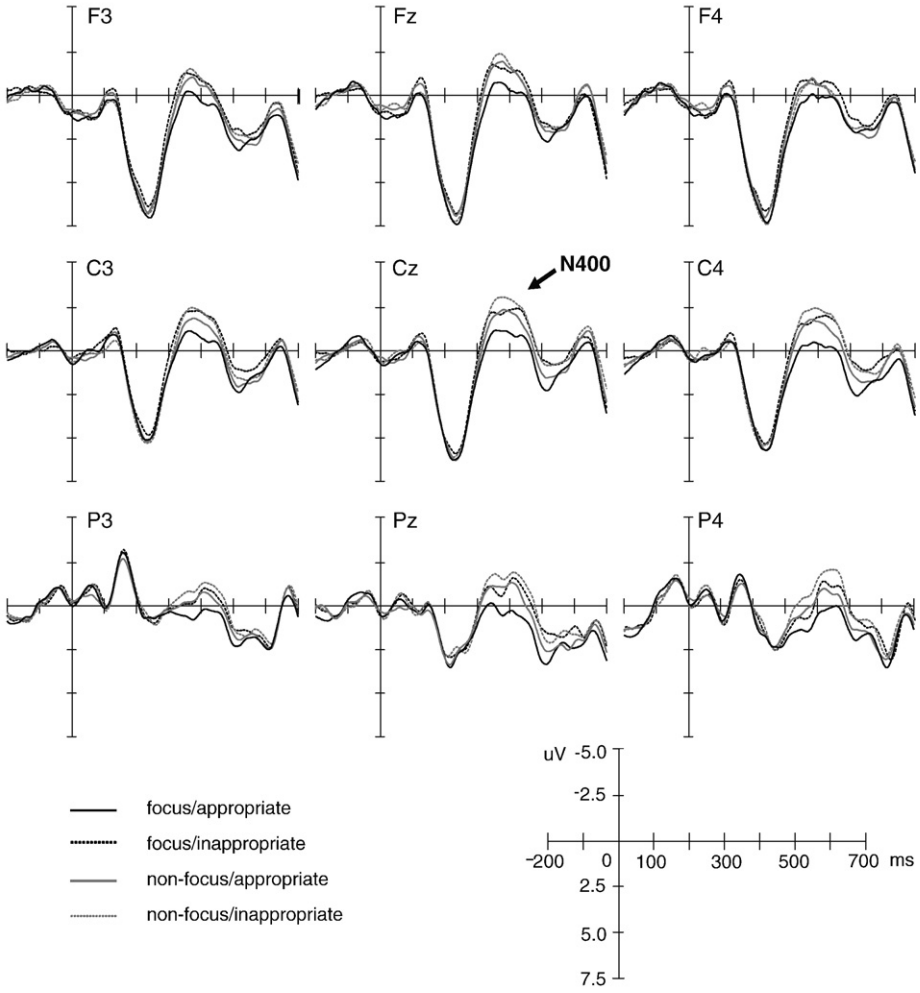

Fig. 1 – Grand average waveforms ($N = 18$) evoked by the critical words as a function of IS status and semantic appropriateness at 9 selected electrode positions. Waveforms are time-locked to the onset of the critical words and negative amplitude is plotted up. Note that the waveforms were smoothed for illustrative purpose only.

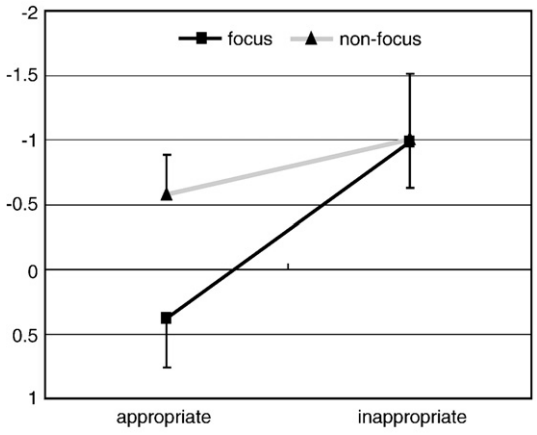

Fig. 2 – Mean N400 amplitudes (μV) and standard error across the 9 selected electrodes. The semantic anomaly caused an N400 effect for focused information, while no reliable N400 effects was observed for non-focused information.

amplitude of non-focus was significantly larger than focus ($F_{(1, 17)} = 10.88$, $p < .01$), while there was no significant difference between the N400 amplitudes in the inappropriate condition ($F_{(1, 17)} < 1$, $p = .95$).

Visual inspection of Fig. 1 suggests that at the central and posterior electrodes, the semantically inappropriate words in the non-focus condition also elicited an N400 effect. Because the N400 is typically centrally or posteriorly distributed, we performed separate ANOVAs for the central (C3/CZ/C4) and posterior (P3/PZ/P4) electrodes, despite the absence of a significant interaction between IS, Appropriateness and Region ($F_{(2, 34)} = 1.62$, $p = .21$). First, for the central electrodes (C3/CZ/C4), the simple-effect test showed similar results as the overall analysis; that is, a significant N400 effect was only found for focus ($F_{(1, 17)} = 34.58$, $p < .001$) but not for non-focus ($F_{(1, 17)} = 2.28$, $p = .15$). Second, for the posterior electrodes (P3/PZ/P4), the simple-effect test revealed that the N400 effect was elicited for focused words ($F_{(1, 17)} = 14.45$, $p < .01$); for non-focused words, a marginally significant effect was obtained ($F_{(1, 17)} = 4.28$, $p = .054$).

These results demonstrate that IS can modulate the occurrence of a semantic illusion. The N400 effect elicited by a semantic inappropriateness was reliably observed for

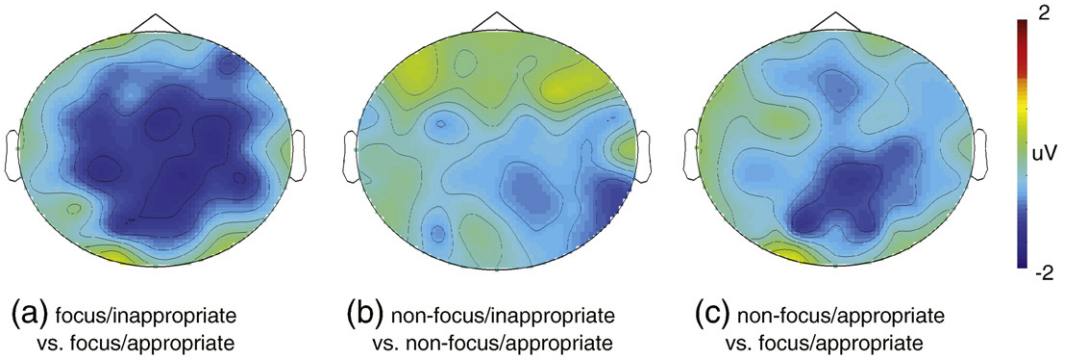

Fig. 3 – Topographies were computed from values resulting from the subtractions of ERPs for focus/appropriate from that for focus/inappropriate (a), ERPs for non-focus/appropriate from that for non-focus/inappropriate (b) and ERPs for focus/appropriate from that for non-focus/appropriate (c) in the N400 time window between 300 and 500 ms.

focused information, but sharply reduced and restricted for non-focused information.

In order to better illustrate the overall N400 effect, Fig. 3 shows the scalp topographies of different contrast conditions. Fig. 3a was calculated by subtracting the ERPs for the semantically appropriate words from that for the inappropriate words in focus position, revealing the distribution of semantic inappropriateness effect for focused words. Fig. 3b was obtained by subtracting the ERPs for the semantically appropriate words from that for the inappropriate words in non-focus position, showing the distribution of semantic inappropriateness effect for non-focused words. Fig. 3c was derived from subtraction of ERPs for the focused words from that for the non-focused words in the semantically appropriate condition, reflecting the topographic feature of focus processing. The comparison between Figs. 3a and b confirmed our results that the N400 effect of focused information was larger than non-focused information. Meanwhile, Figs. 3a and c were both consistent with the classical N400 distribution, with a broader distribution for the semantic inappropriateness effect than for focus processing.

2.2.2. *500–650 ms*

The ANOVA analysis in time window 500–650 ms only showed main effects for Appropriateness ($F_{(1, 17)}=6.14$, $p<.05$) and Region ($F_{(1, 17)}=3.93$, $p<.05$), but no significant main effect for IS or any interactions. The semantically appropriate words elicited a significantly larger positivity than inappropriate words, whose trend was similar to the preceding N400. Therefore, we can interpret it as an aftereffect of N400 due to overlapping components.

3. Discussion

The main purpose of the present study was to investigate how IS influences on-line semantic processing. We found that both focused and non-focused words elicited the N400 during semantic processing. Whereas the semantic inappropriateness of focused words generated an N400 effect, the processing of non-focused words showed a very reduced N400 difference between the semantically appropriate and inappropriate conditions. These results indicate that people were able to rapidly discriminate the information with different IS status. We will discuss the results in more detail below.

3.1. *The natural mechanism of IS in semantic integration*

The present results revealed that the N400 effects caused by a semantic inappropriateness were different for the focused and non-focused information. If the information is in focus position, the inappropriateness induced a classical N400 effect. A sharply reduced N400 effect was found with the same information in non-focus position. The N400 effect for contextually marked focus was also recently observed by Li et al. (2008b). These results confirmed our hypothesis that the focused information gained more resources and was thus processed thoroughly, while non-focused information received reduced resources, resulting in the semantic illusion.

The role of IS in modulating processing resources has been studied in several papers. Using a phoneme monitoring task, Cutler and Fodor (1979) showed that the detection of target phonemes was quicker when they belonged to focused phrases, which suggested that the focused words received more attention. Additionally, Birch and Rayner (1997) found that readers looked longer at focused than non-focused words, which led to enhanced representations for focused information. In line with this, Sanford et al. (2006) used a text-change procedure in which texts were repeated with some changes to a word on the second display. They found that change detection increased when the written words were italicized or the spoken words were accented. This was interpreted as a clear indication that stressed words captured more attention and increased depth of processing. In accordance with these findings, the N400 effect elicited by focused information in our study indicated that elaborative processing took place and thus that the semantic inappropriateness was successfully detected. On the contrary, the illusion phenomenon observed for non-focused information implied that non-focused words were less elaborately processed, which might lead to a failure in detecting the semantic inappropriateness. The dissociation of N400 effects for focused and non-focused information demonstrates the role of IS in modulating processing resources for semantic analysis.

Moreover, we found that non-focused information elicited a larger N400 than focused information in the semantically

appropriate condition, which provides further evidence for the role of IS in manipulating processing resources. In our study, people have clear expectations as to where the demanded information would be provided in the answer, namely in the focus position, and they therefore allocate more processing resources to focused information. Consequently, people could immediately associate the information provided in the answers with what was expected in the question. Conversely, fewer resources are allocated to non-focused information, and accordingly the extra information in non-focus position might be harder to integrate or activate. Numerous studies have reported that the processing of content words elicits an N400 component (Van Petten and Kutas, 1991; Münte et al., 2001; Guo et al., 2008). It has also been shown that the easier the integration, the smaller N400 amplitude (Kutas and Federmeier, 2000; Hagoort et al., 2004). Therefore, the non-focused words elicited a larger N400 than focused words, whose N400 was reduced due to easier integration.

There are two possible reasons why people may allocate fewer resources to the non-focused information. One explanation is that, the subjects expect a full noun-phrase anaphor ("the vegetable") or a pronoun ("them") in non-focus position, so that they tend to partly skip the extra information once they have encountered the requested information (the agent) in the answer sentence. Another interpretation is related to the limitation of cognitive resources. People dedicate more resources to information that is thematically marked as new than to old or other information in the answer (i.e. agent or theme in our question–answer pairs). It is hard to distinguish between these two possibilities in the current study, but our results do provide insights into understanding how IS influences the allocation of processing resources.

3.2. *The immediacy of semantic integration in discourse*

Our results also support the view that people immediately integrate the incoming information into a prior context (George et al., 1994; Nieuwland and Van Berkum, 2006; Van Berkum et al., 2003; Otten and van Berkum, 2007). In the present study, the critical words were fully congruent with the local sentence but only sometimes inappropriate relative to the question context. If the reader would only attempt a local integration, all words could be integrated without any difficulty within the answer sentence and thus no N400 effect would be observed. However, the inappropriateness of focused information did elicit an N400 effect, which indicated that all information is integrated immediately within a broader context (George et al., 1994; Nieuwland and Van Berkum, 2006; Van Berkum et al., 2003; Otten and van Berkum, 2007). This kind of immediacy suggests that the IS modulates semantic integration very quickly. In addition, the focused information elicited a smaller N400 than the non-focused information, which suggests that people actively integrate information during language processing, since the context induced an expectation that new information would appear in a particular position, which helped the semantic processing of the critical noun.

Although the IS affects the semantic integration immediately and leads to a semantic illusion for the non-focused information, we could not verify whether the illusion is temporary or permanent. First, we did not find any positive effect, which indicated the resolution of the semantic illusion (Nieuwland and Van Berkum, 2005). Second, we did not measure the off-line detection of semantic anomaly. However, it is evident that IS rapidly modulates semantic integration in on-line processing of language.

4. Conclusions

The present study suggests that the IS affects semantic processing immediately, as reflected in the N400 response. The IS could lead people to quickly allocate more processing resources to the privileged focus, thereby facilitating its semantic integration, whereas non-focused information recruits less resources, which could lead to a semantic illusion.

5. Experimental procedures

5.1. *Participants*

Twenty-two university students (mean age 20 years, range 19–23; twelve males) served as paid volunteers. They were all native speakers of Mandarin Chinese with normal or corrected to normal vision, and without any neurological impairment. They signed the informed written consent form according to the local ethics committee and the declaration of Helsinki. The data of four participants (all were males) were excluded because of excessive artifacts.

5.2. *Materials*

The stimuli consisted of 200 experimental stimuli and 120 fillers in Chinese. In each experimental item, the wh-question established the context and projected the focus position in the answer. The semantic appropriateness of the critical word in the answer was manipulated accordingly. The critical word in the answer sentence was either in focus or non-focus position, and it was either semantically appropriate or inappropriate in relation to the wh-question context (see Table 1 for more details). The inappropriate words were semantically related to their appropriate counterparts, but unsuitable in the context (e.g. in the context *What kind of vegetable did Xiao Ming buy for cooking today?*, both *eggplant* and *beef* can be cooked and eaten, but *beef* is not a vegetable). Semantically appropriate and inappropriate words were matched on average frequency per million (mean ± SD = 160.70 ± 447.36; 232.66 ± 759.26 respectively) based on information provided by Beijing Institute of Language (1986). The difference in frequency was not significant ($t_{(199)} = -1.28$, $p > .01$). The critical words were all two-character words, and for each item, the words preceding and following the critical words in the answer sentences were identical for all four conditions. Critical words were never in sentence-initial or sentence-final position. The local congruency of the answers was not disrupted by the inappropriateness of the critical words.

The experimental design was fully factorial, combining all conditions of IS (focus, non-focus) and Appropriateness (appropriate, inappropriate). The four conditions of each experimental item were distributed among four lists, each containing an equal number of items (50 trials) per condition.

Table 1 – An example of all four conditions for one experimental item, with a statement requiring a response.

Focus/appropriate
What kind of vegetable did Xiao Ming buy for cooking today?
Today Xiao Ming bought eggplant to cook.
Focus/inappropriate
What kind of vegetable did Xiao Ming buy for cooking today?
Today Xiao Ming bought beef to cook.
Non-focus/appropriate
Who bought the vegetables for cooking today?
Today Xiao Ming bought eggplant to cook.
Non-focus/inappropriate
Who bought the vegetables for cooking today?
Today Xiao Ming bought beef to cook.
Statement
Xiao Ming did not cook today.

Notes. The example of materials was translated from the original Chinese materials, with the critical words underlined. This statement is incorrect, which requires the press of "F" on the keyboard.

In addition, there were another 120 wh-question–answer pairs serving as fillers (60 correct pairs, 30 pairs with a standard semantic violation and 30 pairs with a syntactic violation in the answer sentence).

5.3. *Procedure*

Participants read 320 wh-question–answer pairs in pseudo-random order (200 of which were critical for the current study). The stimuli were presented in font size 18 as white characters on a black background at the center of a computer screen, positioned approximately 80 cm away from the participants. A trial started with a fixation cross (duration 1000 ms) in the center of the screen, followed by a question that was presented as a whole sentence for 3000 ms. After a 1000 ms black screen, the answer was presented word by word, with each word appearing for 300 ms, and an interstimulus interval (ISI) of 200 ms. Participants were told not to move or blink when individual words appeared. To ensure that participants read for comprehension, they were required to judge a statement following the answer, or to make a response to "blank" within 3000 ms. The statement was related to the presented item but did not refer to the content of the semantic inappropriateness. The statements appeared following 67 experimental stimuli and 40 fillers, equally distributed among all conditions. The participants were instructed to press buttons on the keyboard: the letter symbol "J" for a correct statement with the right forefinger; the letter symbol "F" for an incorrect statement with the left forefinger; the space bar for a response to "blank" with the right thumb. The next trial began immediately after the response. Each participant began with a practice session consisting of eight trials; then all experimental trials were presented in four blocks (80 items per block) of about 15 min each, separated by brief rest periods.

5.4. *Electroencephalogram (EEG) recording and preprocessing*

The EEG was recorded by a NeuroScan system, with a cap containing 64 Ag/AgCl electrodes mounted according to the International 10–20 system. The left mastoid electrode served as the reference, and a forehead electrode served as the ground. The vertical eye movements and blinks were monitored via a supra- to suborbital bipolar montage. A right to left canthal bipolar montage was used to monitor the horizontal eye movements. All electrode impedances were kept below 5 kΩ during the experiment. Recording was done with a band pass filter of 0.05 Hz–100 Hz and a sampling frequency of 500 Hz.

The EEG data were re-referenced off-line to the linked mastoid. Electro-oculogram (EOG) artifacts were automatically corrected by NeuroScan software (Semlitsch et al., 1986). Data were filtered off-line with a 40 Hz low-pass filter. Critical epochs ranged from 200 ms before to 1200 ms after the onset of the critical word, with 200 ms before the onset serving as the baseline. The artifact rejection criterion was ±75 μV. Since there was much slow wave drift in the raw signal, we used linear detrend corrections (linear detrend module of Neuroscan 4.3 software) followed by baseline correction before artifact rejection to five participants. Four participants (all males) were excluded because the total rejection rate exceeded 30%. The averaged trial loss was 16% across all remaining participants, with the remainder evenly distributed among conditions. For each participant, remaining trials were averaged for each of the four conditions.

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