Subliminal Auditory Priming Effect in Chinese: Evidence from the Auditory Masking Priming Paradigm

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Date: 2022-11-07T00:00:00+00:00

Abstract

Using Chinese disyllabic words as experimental materials and employing an auditory masking priming paradigm, three experiments were conducted to investigate subliminal auditory priming effects in Chinese. The results revealed that subliminal auditory repetition priming effects for real words were significant, and such effects were not influenced by the consistency of speaker gender between prime and target. However, subliminal phonological, morphological, and semantic priming effects for real words, as well as subliminal repetition and first-character priming effects for pseudo-words, were not significant. These findings suggest that lexical-level information of Chinese disyllabic words presented subliminally through the auditory modality can be processed unconsciously. Subliminal auditory priming effects for Chinese disyllabic words may be based on the unconscious activation of the whole-word representation of the prime.

Full Text

Subliminal Auditory Priming Effects in Mandarin Chinese: Evidence from the Auditory Masked Priming Paradigm

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Abstract

Using two-character Chinese words as experimental materials and employing the auditory masked priming paradigm, this study investigated subliminal auditory priming effects in Mandarin Chinese through three experiments. The results revealed significant subliminal auditory repetition priming effects for

real words, which were not influenced by the consistency of speaker gender between prime and target. However, subliminal phonological, morphological, and semantic priming effects for real words, as well as subliminal repetition and first-character priming effects for pseudo-words, were all non-significant. These findings demonstrate that lexical-level information of subliminally presented two-character Chinese words can be processed unconsciously. The auditory subliminal priming effect for two-character Chinese words may be based on the unconscious activation of the prime' s whole-word representation.

Keywords: two-character words, auditory masked priming paradigm, subliminal priming effect, unconscious processing
Classification Number: B842

Introduction

Subliminal priming refers to the facilitative effect of a subliminally presented prime stimulus on the cognitive processing of a subsequently presented related target stimulus (Ma & Zhang, 2011; Wang & Lu, 2005; Elgendi et al., 2018). Since the prime stimulus is presented below the conscious threshold, subliminal priming effects reflect unconscious processing of the prime (Song & Lv, 2015). The masked priming paradigm is one of the most commonly used methods in subliminal priming research. In this paradigm, a masked prime stimulus is briefly presented (typically for less than 50 ms) before a supraliminal target stimulus. The level of processing of the subliminal prime can be inferred from its influence on the cognitive processing of the target (Kouider & Dehaene, 2007). For example, if a prime facilitates semantic processing of a semantically related target, this indicates that semantic information of the subliminal prime can be unconsciously processed (Kiefer, 2002; Kouider & Dehaene, 2007).

Repetition priming is the most frequently used priming type in subliminal priming research (e.g., Ferrand, 1996; Forster & Davis, 1984). In repetition priming, the prime and target are identical in the related condition (e.g., contract—contract), while in the unrelated condition they are different and share no phonological, morphological, or semantic associations (e.g., ocean—contract). Because the related and unrelated conditions differ in orthography, phonology, and semantics, repetition priming effects alone cannot reveal the underlying mechanism of subliminal priming—for instance, whether it is based on activation of phonological or semantic representations of the prime word. Therefore, researchers have manipulated the relationship between prime and target to examine phonological, morphological, and semantic priming effects, thereby investigating the mechanisms of subliminal priming. In phonological priming, the prime and target share only partial phonology (e.g., red flag—flood). A significant subliminal phonological priming effect indicates that unconscious activation of shared phonological information between prime and target influences target processing (e.g., Ferrand & Grainger, 1992; Shen & Forster, 1999). In morphological prim-

ing, prime and target share the same root morpheme (e.g., water pump—water valve). Subliminal morphological priming effects can provide experimental evidence for morphological decomposition in early lexical processing (e.g., Grainger et al., 1991; Rastle et al., 2000). In semantic priming, prime and target are only semantically related (e.g., soldier—army). Significant subliminal semantic priming effects reflect unconscious spreading activation within the semantic network related to the prime (e.g., Greenwald et al., 1996; Marcel, 1983).

Early masked priming studies predominantly used words from Indo-European languages such as English and French (e.g., Dehaene et al., 2004; Dupoux et al., 2003; Greenwald et al., 1996). Later research found similar masked priming effects in Chinese, where masked primes not only influenced recognition of related target words (Shen et al., 2004; Zhao et al., 2017; Weekes et al., 1998) but also facilitated speech production (Jiang et al., 2020; Zhang & Damian, 2019). Wang et al. (2014) found that when masked primes were stroke-neighbor characters (e.g., 勺—习), target identification was slowed, suggesting that orthographic information of masked primes was processed in detail and interfered with processing of related targets. Additional studies indicate that subliminal priming effects in Chinese may occur at levels higher than orthography (perceptual features). For instance, significant translation priming effects have been found between Chinese and languages from different families such as English and Japanese (Wang & Zhang, 2013, 2014; Zhang et al., 2019), implying that unconscious processing of the prime activates lexical representations shared with the target (Davis & Kim, 2021), thereby facilitating lexical decision processes. Other studies using two-character Chinese words found that subliminally presented primes semantically related to targets facilitated semantic processing of the targets (Shui et al., 2003; Wang & Lu, 2005; Wu et al., 2020).

These studies have advanced our understanding of the psychological mechanisms of unconscious processing in Chinese. However, they all used visually presented words, and thus cannot reveal whether similar subliminal priming effects exist in the auditory modality. The auditory modality plays a crucial role in daily communication, and for individuals without literacy skills (such as children and illiterate adults), it is the only pathway for language communication (Kouider & Dupoux, 2005). Moreover, the auditory modality has higher temporal resolution than vision (Pasinski et al., 2016). Given the substantial differences in cognitive processing between visual and auditory modalities, findings from visual subliminal priming cannot be directly applied to explain unconscious processing of auditory linguistic information. Extending Chinese subliminal priming research from visual to auditory modalities can broaden our understanding of unconscious processing in the auditory domain, clarify differences between visual and auditory unconscious processing of Chinese, and promote a comprehensive understanding of unconscious processing in Chinese. However, no studies have examined auditory subliminal priming effects in Chinese. Therefore, the present study aims to investigate auditory subliminal priming effects in Chinese using two-character words.

The auditory masked priming paradigm is commonly used to study subliminal auditory priming effects in non-Sino-Tibetan languages such as Indo-European and Semito-Hamitic languages. Kouider and Dupoux (2005) first applied this paradigm to study subliminal auditory priming effects. Using French words as materials and reversed words as masks, they presented masked primes before supraliminal target words. In addition to interference from masking stimuli, they reduced prime detectability by temporally compressing the primes. They used four compression rates: 35%, 40%, 50%, and 70%. Results showed that at 35% compression, participants could not detect the primes, and response times to targets were significantly shorter when prime and target were identical than when they were different, demonstrating a significant subliminal repetition priming effect. Subsequent studies using this paradigm with Indo-European languages such as English (Davis et al., 2010) and German (Degner, 2011), as well as Semito-Hamitic languages (Schluter, 2013; Ussishkin et al., 2015), also found significant subliminal auditory repetition priming effects.

Although studies across different language families have found auditory subliminal repetition priming effects, results differ across language families. Kouider and Dupoux' s (2005) study with French found significant auditory subliminal repetition priming but non-significant morphological, phonological, and semantic priming effects. Other studies with Indo-European languages also observed only subliminal repetition priming (Bermeitinger et al., 2012; Davis et al., 2010; Kopeikina et al., 2015). In contrast, studies with Semito-Hamitic languages found not only significant auditory subliminal repetition priming but also significant auditory subliminal morphological priming effects (Geary & Ussishkin, 2019; Schluter, 2013; Ussishkin et al., 2015). This discrepancy may be because Indo-European languages like French and English have more complex morphological changes, while Semito-Hamitic languages (e.g., Maltese) have root morphemes containing more information sufficient to elicit masked priming effects (Ussishkin et al., 2015). This suggests that morphological characteristics of different language families are important factors influencing auditory subliminal priming effects.

Chinese word formation and morphological changes differ from alphabetic languages such as Indo-European and Semito-Hamitic languages. Derivation, where root morphemes combine with affixes to form new words, is the main word formation method in most alphabetic languages, whereas over 70% of Chinese words are compound words formed by parallel arrangement of root morphemes (Zou & Shu, 2013; Zhou & Marslen-Wilson, 1995; Zhou et al., 1999). Indo-European and Semito-Hamitic languages often use inflectional changes to represent grammatical functions (e.g., number, tense, aspect), which are uncommon in Chinese. Additionally, Chinese has more homophonic heterographs compared to Indo-European and Semito-Hamitic languages. Based on these differences, auditory subliminal priming effects in Chinese may exhibit characteristics different from those in Indo-European and Semito-Hamitic languages. Therefore, the present study employed the auditory masked priming paradigm to investigate auditory subliminal priming effects in two-character

Chinese words.

Dupoux et al. (2008) examined the effect of interstimulus interval (ISI) between prime and target on auditory subliminal priming and found that the magnitude of auditory subliminal priming decreased as ISI increased, becoming non-significant when ISI exceeded 400 ms. This ISI effect reflects the duration of unconscious activation of subliminal prime words. However, existing research has only examined the duration of unconscious activation for French words in the auditory modality. Whether the modulation of auditory subliminal priming effects by ISI is universal across languages requires further verification. Therefore, Experiment 3 of this study investigated the duration of unconscious activation of two-character Chinese words in the auditory modality by examining the effect of ISI between prime and target on auditory subliminal priming effects.

In summary, to explore unconscious processing of auditory linguistic information in Chinese, the present study used the auditory masked priming paradigm with two-character Chinese words to investigate auditory subliminal priming effects in Chinese. The study comprised three experiments. Experiment 1 examined repetition, morphological, phonological, and semantic priming effects for two-character Chinese words to determine the level of unconscious processing of subliminally presented Chinese words in the auditory modality. Experiment 2 manipulated the consistency of speaker gender between prime and target to examine whether acoustic feature similarity between prime and target influences subliminal repetition priming effects in Chinese, thereby investigating the contribution of low-level (non-lexical) perceptual processing to auditory subliminal priming effects in Chinese. Experiment 3 manipulated the ISI between prime and target to investigate the duration of unconscious activation of subliminally presented two-character Chinese words in the auditory modality.

Experiment 1

The purpose of Experiment 1 was to examine the level of unconscious processing of two-character Chinese words in the auditory modality and to determine the optimal compression rate for primes in Chinese auditory masked priming experiments. Experiment 1 manipulated the relationship between prime and target to create six priming conditions: real-word repetition priming, morphological priming, phonological priming, semantic priming, and pseudo-word repetition and first-character priming. By examining whether different types of subliminal priming effects were significant and comparing their magnitudes, we could infer the mechanism of auditory subliminal priming effects. Based on previous research (e.g., Davis et al., 2010; Kouider & Dupoux, 2005), Experiment 1 hypothesized that subliminal repetition priming effects for real words would be significant, while other types of priming effects for real words and subliminal repetition and first-character priming effects for pseudo-words would be non-significant.

A second purpose of Experiment 1 was to determine the optimal compression rate for primes in Chinese auditory masked priming experiments. Following Kouider and Dupoux (2005), Experiment 1 included three compression rate conditions: 40%, 50%, and 60%. Experiment 1 combined subjective reports and objective detection tasks to determine whether processing of the primes was unconscious. We hypothesized that processing of primes at 40% compression would be unconscious, while processing of primes at 60% compression would be conscious.

Method

Participants We used G*Power 3.1 software to estimate the required sample size (Faul et al., 2007). Referencing classic studies of auditory subliminal priming effects (Kouider & Dupoux, 2005), the effect size for subliminal repetition priming was $^{2} = 0.24$ (f = 0.56). We set the effect size at f = 0.56. With power (1 -β) = 0.95 and $\alpha = 0.05$, at least 13 participants were needed per between-subject condition. We recruited 72 undergraduate and graduate students (24 per compression rate condition), including 22 males, aged 19–26 years (M = 22.14, SD = 2.21). All participants had normal hearing and were native Chinese speakers. Participants received appropriate compensation after the experiment.

Design Experiment 1 used a mixed design with three factors: time compression rate of the prime (40%, 50%, 60%) as a between-subjects variable, and prime-target relatedness (related, unrelated) and prime type (repetition, morphological, phonological, and semantic priming for real words; repetition and first-character priming for pseudo-words) as within-subjects variables. The dependent variable was participants' reaction time in making lexical decisions about target stimuli.

Materials Experimental materials consisted of auditory stimuli of two-character Chinese real words and pseudo-words. All words had a disyllabic CV-CV structure. Sound stimuli were audio files generated using speech synthesis technology provided by Baidu Cloud Computing (https://cloud.baidu.com/). All stimuli were spoken by a male voice. Sound editing was performed using the Python-based pysox audio editor (Bittner et al., 2016). Temporal compression was applied using the WSOLA algorithm to preserve spectral information while compressing the time domain (Verhelst & Roelands, 1993). Target stimuli had a duration of 522 ms. Based on previous research and pilot studies, Experiment 1 compressed primes to 40% (208 ms), 50% (261 ms), and 60% (313 ms) of the target duration. Masking stimuli were reversed versions of the primes. The volume of primes and masks was 15 dB lower than that of targets.

Real words included four priming types: repetition priming (prime and target identical), morphological priming (prime and target shared the first morpheme), phonological priming (prime and target shared the first syllable but were dif-

ferent morphemes), and semantic priming (prime and target had no phonological or morphological association but were semantically related). Pseudowords included two priming types: repetition priming (e.g., sahe—sahe) and first-character priming (prime and target shared the first character, e.g., sahe—saqing).

We selected 192 real words and 192 pseudo-words as target stimuli. In the related conditions, each priming type for real words included 48 target stimuli, and each priming type for pseudo-words included 96 target stimuli. Word frequencies for target real words in each priming type are shown in Table 1 . Word frequencies did not differ significantly across the four priming types, $F(3, 188) = 0.36$, $p = 0.785$, $^2 = 0.01$, 90% CI = [0.00, 0.02]. Word frequency data were obtained from Corpus Online (Computational Linguistics Laboratory, Institute of Applied Linguistics, Ministry of Education, 2011). The same target stimuli were used in both related and unrelated conditions. According to the definitions of each priming type, corresponding primes were selected and paired with targets to create priming condition word lists. Unrelated condition word lists were created by pairing targets with primes that had no phonological or semantic association.

Each word list was divided into two halves to balance the related/unrelated condition assignment across blocks.

Apparatus The experiment was conducted in a closed, soundproof laboratory. Auditory stimuli were presented through headphones connected to a computer. Stimulus presentation and response recording were controlled using PsychoPy 3 (Peirce, 2007).

Procedure The stimulus presentation sequence for Experiment 1 is shown in Figure 1 [Figure 1: see original paper]. Each trial began with a mask, followed immediately by the prime, then the target (ISI = 0 ms). While the target was playing, three additional masks were presented sequentially. The trial ended 1500 ms after target onset, followed immediately by a 500 ms tone (“beep”) signaling the start of the next trial. Participants were instructed to respond as quickly and accurately as possible using the “F” and “J” keys to make lexical decisions about the clearly audible target words. The mapping of keys to word/pseudo-word responses was counterbalanced across participants.

The experiment consisted of 192 trials: 24 trials for each real-word priming type (12 related, 12 unrelated) and 48 trials for each pseudo-word priming type (24 related, 24 unrelated). The assignment of stimuli to related/unrelated conditions was balanced across blocks: if a stimulus was in the related condition in the first (or second) two blocks, it was in the unrelated condition in the second (or first) two blocks. Whether a stimulus was related in the first or second two blocks was counterbalanced across participants. Within each block, stimuli were presented in pseudo-random order such that no more than four consecutive trials contained stimuli of the same type (real word or pseudo-word) or the same

priming condition. Participants completed 20 practice trials before the formal experiment. They could rest between blocks for a self-determined duration not exceeding 3 minutes.

After the experiment, we assessed participants' awareness of the primes using both subjective reports and an objective detection task. For the subjective report, after explaining the existence of the primes, we asked participants whether they had heard any masked words during the experiment. The objective detection task differed from the formal experiment in two ways: (1) target stimuli were removed, and (2) participants were informed about the primes and asked to make lexical decisions about them (or guess if they could not hear them). The objective detection task included 192 trials (96 words, 96 pseudo-words). Participants completed 20 practice trials before this task. The masked priming experiment and awareness detection together lasted approximately 45 minutes.

Results

Prime Awareness Level We used a combination of subjective and objective measures to determine whether processing of the primes was unconscious (Sweeny et al., 2009). Processing was considered unconscious only if participants reported no awareness of the primes and could not distinguish between word and pseudo-word primes in the objective detection task. If either condition was not met, processing was considered conscious.

Subjective reports indicated that participants in the 40% and 50% compression conditions reported hearing no words before the target. In the 60% compression condition, 23 out of 24 participants reported hearing the prime on some trials.

We conducted one-sample t-tests comparing accuracy in the objective detection task against chance level (0.5) for each compression rate. Results showed that accuracy in the 40% compression condition ($M = 0.51$, $SD = 0.03$) did not differ significantly from chance, $t(23) = 0.94$, $p = 0.36$, $d = 0.19$, 95% CI = [-0.21, 0.59]. Accuracy in the 50% and 60% compression conditions ($M = 0.55$, $SD = 0.04$ and $M = 0.67$, $SD = 0.11$, respectively) was significantly above chance, $t(23) = 5.44$, $p < 0.001$, $d = 1.11$, 95% CI = [0.59, 1.62]; $t(23) = 7.28$, $p < 0.001$, $d = 1.49$, 95% CI = [0.89, 2.06]. This indicates that at 40% compression, discrimination accuracy was at chance level.

Treating real words as signals and pseudo-words as noise, we calculated participants' discrimination sensitivity d' (40%: $M = 0.07$, $SD = 0.21$; 50%: $M = 0.29$, $SD = 0.23$; 60%: $M = 1.00$, $SD = 0.66$). One-sample t-tests comparing d' against 0 showed that d' in the 40% compression condition did not differ significantly from 0, $t(23) = 1.47$, $p = 0.16$, $d = 0.30$, 95% CI = [-0.11, 0.71]. d' in the 50% compression condition was significantly greater than 0, $t(23) = 5.92$, $p < 0.001$, $d = 1.21$, 95% CI = [0.67, 1.73]. d' in the 60% compression condition was also significantly greater than 0, $t(23) = 7.30$, $p < 0.001$, $d = 1.49$, 95% CI = [0.90, 2.07].

Subjective and objective results indicated that processing of primes at 40% compression was unconscious, while processing at 60% compression was conscious. Therefore, we designated priming effects at 40% compression as subliminal and those at 60% compression as supraliminal.

Priming Effects For analysis of subliminal priming effects, only correct-response trials were included, and trials with reaction times more than 2.5 standard deviations above or below the mean were excluded (Finkbeiner & Palermo, 2009). Excluded trials accounted for 1.70% of total trials. Reaction times for real-word and pseudo-word conditions are shown in Table 2 and Table 3 , respectively.

A 4 (priming type: repetition, morphological, phonological, semantic) × 2 (prime-target relatedness: related, unrelated) × 3 (prime compression rate: 40%, 50%, 60%) repeated-measures ANOVA on real-word reaction times revealed a significant three-way interaction, $F(6, 207) = 6.49$, $p < 0.001$, $^2 = 0.16$, 90% CI = [0.07, 0.22]. We therefore analyzed each compression rate separately.

At 40% compression, repetition priming was significant, $F(1, 23) = 6.63$, $p = 0.017$, $^2 = 0.22$, 90% CI = [0.03, 0.45], with shorter reaction times in the related than unrelated condition. Phonological, morphological, and semantic priming effects were all non-significant (ps > 0.05). At 50% compression, repetition priming was significant, $F(1, 23) = 112.43$, $p < 0.001$, $^2 = 0.83$, 90% CI = [0.71, 0.89], while phonological, morphological, and semantic priming effects were non-significant (ps > 0.05). At 60% compression, repetition priming ($F(1, 23) = 117.85$, $p < 0.001$, $^2 = 0.84$, 90% CI = [0.72, 0.89]), morphological priming ($F(1, 23) = 31.50$, $p < 0.001$, $^2 = 0.58$, 90% CI = [0.34, 0.72]), and semantic priming ($F(1, 23) = 23.67$, $p < 0.001$, $^2 = 0.51$, 90% CI = [0.26, 0.67]) were all significant, with shorter reaction times in related than unrelated conditions. Phonological priming remained non-significant, $F(1, 23) = 0.46$, $p = 0.504$, $^2 = 0.02$, 90% CI = [0.00, 0.19].

Combining these results with awareness level findings, we compared priming effect magnitudes (difference between unrelated and related conditions) between supraliminal (60% compression) and subliminal (40% compression) conditions using independent-samples t-tests. Supraliminal repetition priming ($M = 100.46$, $SD = 45.34$) was significantly larger than subliminal repetition priming ($M = 16.09$, $SD = 30.62$), $t(46) = 7.56$, $p < 0.001$, $d = 2.18$, 95% CI = [1.60, 2.76]. Supraliminal morphological priming ($M = 28.69$, $SD = 25.05$) was significantly larger than subliminal morphological priming ($M = 10.68$, $SD = 33.07$), $t(46) = 2.13$, $p = 0.039$, $d = 0.61$, 95% CI = [0.03, 1.20]. Supraliminal ($M = 6.38$, $SD = 46.07$) and subliminal ($M = 9.18$, $SD = 29.11$) phonological priming did not differ significantly, $t(46) = 0.25$, $p = 0.802$, $d = 0.073$, 95% CI = [-0.49, 0.64]. Supraliminal semantic priming ($M = 30.27$, $SD = 30.48$) was significantly larger than subliminal semantic priming ($M = 0.11$, $SD = 37.42$), $t(46) = 3.06$, $p = 0.004$, $d = 0.88$, 95% CI = [0.30, 1.46].

A 2 (priming type: repetition, first-character) × 2 (prime-target relatedness: related, unrelated) × 3 (prime compression rate: 40%, 50%, 60%) repeated-measures ANOVA on pseudo-word reaction times showed a marginally significant three-way interaction, $F(2, 69) = 2.79$, $p = 0.069$, $^2 = 0.08$, 90% CI = [0.00, 0.18]. Separate analyses for each compression rate revealed that at 40% and 50% compression, neither repetition nor first-character priming effects were significant (ps > 0.05). At 60% compression, repetition priming was significant, $F(1, 69) = 47.09$, $p < 0.001$, $^2 = 0.41$, 90% CI = [0.26, 0.53], with shorter reaction times in the related than unrelated condition, while first-character priming remained non-significant ($p > 0.05$).

Discussion

Analysis of prime awareness levels revealed that processing of primes at 40% compression was unconscious, while processing at 60% compression was conscious. Analysis of subliminal and supraliminal priming effects for real and pseudo-words showed that among various subliminal priming types for real words, only repetition priming was significant. Among supraliminal priming types for real words, only phonological priming was non-significant. For pseudo-words, only supraliminal repetition priming was significant.

Experiment 1 found significant subliminal repetition priming for real words but not for pseudo-words, consistent with previous research in other languages (e.g., Kouider & Dupoux, 2005; Ussishkin et al., 2015). The difference between real and pseudo-words is that only real words have corresponding lexical representations in the mental lexicon, and some real words can activate representations of specific objects. Although the similarity of low-level acoustic features between prime and target was identical in both real-word and pseudo-word subliminal repetition priming conditions, only real words could activate lexical-level or higher-level semantic representations. Therefore, the finding that only real words showed significant subliminal repetition priming suggests that auditory subliminal priming effects are not based on unconscious activation of low-level acoustic features of prime words.

Experiment 1 found no significant subliminal morphological or phonological priming effects, consistent with previous research on Indo-European languages (e.g., Kouider & Dupoux, 2005). The Multi-Level Cluster Representation Model (MCRM) for Chinese compound words proposes that the mental lexicon contains three representation levels: syllable, morpheme, and whole-word. After phonological input, all three levels are activated simultaneously and interact to complete lexical access (Zhou & Marslen-Wilson, 1994, 1995). Zhou and Marslen-Wilson (1995) argued that two-character Chinese words have morpheme and whole-word representation levels in the mental lexicon. Words sharing a morpheme are not directly connected at the whole-word level but are linked through morpheme nodes at the morpheme level. Therefore, significant morphological priming effects are based on activation of shared morpheme representations. The finding that morphological priming was significant supraliminally

but not subliminally suggests that activation of morpheme representations for two-character Chinese words in the auditory modality may require conscious awareness. At the morpheme level, nodes for homophonic morphemes form a morpheme set, and morphemes within the same set compete during lexical processing. Therefore, phonologically related primes should hinder processing of targets sharing the first syllable. The non-significant subliminal phonological priming effect indicates that the first character of subliminal primes did not activate its corresponding homophonic morpheme set. Since repetition priming involves identical whole-word and morpheme representations for prime and target, the non-significant subliminal morphological and phonological priming effects suggest that auditory subliminal priming effects may be based on unconscious activation of whole-word representations of prime words.

Consistent with previous research (Kouider & Dupoux, 2005), Experiment 1 also found no significant auditory subliminal semantic priming effect. Semantic priming was significant only at 60% compression. According to spreading activation models, semantic priming effects result from activation of the prime' s semantic representation spreading through the semantic network to facilitate activation of semantically related targets (Greenwald et al., 1996; Marcel, 1983). Significant subliminal semantic priming effects are typically considered evidence that semantic information of the prime can be unconsciously activated (Wu et al., 2013). Therefore, the non-significant subliminal semantic priming effect in this study cannot provide evidence for unconscious activation of semantic information of the prime. However, this result does not rule out the possibility that semantic information of the prime could be unconsciously activated. Activation of semantic information from subliminal primes may be too weak for reaction time measures (or task types) to detect its influence on target processing.

Based on analysis of subliminal priming results, we can infer that the auditory subliminal repetition priming effect for real words is based on unconscious activation of whole-word representations of subliminal primes. However, because Experiment 1 did not compare subliminal repetition priming effects for real words under conditions of similar versus dissimilar acoustic features between prime and target, the results cannot rule out the possibility that acoustic similarity contributed to the real-word subliminal repetition priming effect. Therefore, Experiment 2 further examined this issue.

Experiment 2

The results of Experiment 1 indicated that auditory subliminal priming effects in Chinese are based on unconscious activation of lexical-level representations, but could not determine whether low-level acoustic similarity between prime and target influences subliminal priming effects. The purpose of Experiment 2 was to examine the influence of acoustic feature similarity between prime and target on subliminal repetition priming effects in Chinese. Experiment 2 manipulated the consistency of speaker gender between prime and target to control acoustic feature similarity. When speaker gender was consistent, acoustic features of prime

and target were similar; when inconsistent, they differed substantially in frequency, timbre, and other acoustic features. Comparing sublimimal repetition priming effects across these conditions allowed us to examine the contribution of acoustic feature similarity to auditory subliminal repetition priming effects. Experiment 2 hypothesized that acoustic feature similarity between prime and target would not influence auditory subliminal repetition priming effects.

Method

Participants Sample size estimation followed Experiment 1. We recruited 36 undergraduate and graduate students. One participant was excluded due to incorrect button presses, leaving 35 valid participants (9 males), aged 19–26 years (M = 20.92, SD = 1.98). All had normal hearing and were native Chinese speakers. Participants received appropriate compensation after the experiment.

Design Experiment 2 used a three-factor within-subjects design: prime-target speaker gender consistency (consistent, inconsistent) × prime-target relatedness (related, unrelated) × stimulus type (real word, pseudo-word).

We selected 64 real words and 64 pseudo-words as target stimuli. Consistent and inconsistent speaker gender conditions each included 32 real words and 32 pseudo-words. Word frequencies for real words did not differ between consistent (M = 146.50 per million, SD = 77.12) and inconsistent (M = 144.31 per million, SD = 76.54) conditions, t(62) = -0.11, p = 0.91, d = 0.03, 95% CI = [-0.46, 0.52]. An additional 64 real words and 64 pseudo-words were selected as primes for unrelated conditions. Audio file generation followed Experiment 1. Prime compression rate was 40%. Each word had both male and female versions.

Procedure Stimulus presentation and task were identical to Experiment 1. The experiment consisted of two blocks of 128 trials each (16 trials per condition). The two blocks used identical target stimuli but with opposite relatedness assignments (e.g., if target A was related to its prime in block 1, it was unrelated in block 2). Target speaker gender differed across the two blocks. The matching of target speaker gender to blocks was counterbalanced across participants. Stimuli were presented in pseudo-random order with no more than four consecutive trials of the same condition or stimulus type. Participants completed 24 practice trials before the formal experiment.

After the experiment, we assessed awareness of masked primes using the same subjective report and objective detection methods as Experiment 1. The objective detection task included 96 trials (half with male-voiced primes, half with female-voiced). Participants completed 20 practice trials before this task. Experiment 2 and awareness detection lasted approximately 15 minutes.

Results

Prime Awareness Level Subjective reports indicated that all participants reported no awareness of primes before target stimuli. Accuracy in the objective detection task (M = 0.50, SD = 0.07) did not differ from chance level (0.5), t(34) = -0.34, p = 0.73, d = -0.06, 95% CI = [-0.38, 0.27]. Discrimination sensitivity d' was calculated (M = 0.031, SD = 0.19). Both subjective and objective results indicated that participants could not detect the masked primes, confirming that primes were presented subliminally.

Subliminal Priming Effects For analysis of subliminal priming effects, only correct-response trials were included, and trials with reaction times more than 2.5 standard deviations from the mean were excluded (Finkbeiner & Palermo, 2009), accounting for 1.43% of trials. Reaction times for each condition are shown in Table 4 .

Separate 2 (prime-target relatedness: related, unrelated) × 2 (prime-target speaker gender consistency: consistent, inconsistent) repeated-measures ANOVAs were conducted for real-word and pseudo-word conditions. For real words, the main effect of prime-target relatedness was significant, F(1, 34) = 6.81, p = 0.013, ^{2} = 0.17, 90% CI = [0.02, 0.35], with shorter reaction times in related than unrelated conditions. Critically, the interaction between relatedness and speaker gender consistency was not significant, F(1, 34) = 0.07, p = 0.79, ^{2} = 0.002, 90% CI = [0.00, 0.08]. For pseudo-words, neither the main effect of relatedness nor the interaction between relatedness and speaker gender consistency was significant (ps > 0.05).

Discussion

The results of Experiment 2 showed that only for real words did participants respond faster to related than unrelated trials, replicating Experiment 1' s finding that auditory subliminal repetition priming effects in Chinese exist only for real words. Moreover, the interaction between prime-target relatedness and speaker gender consistency was not significant, indicating that auditory subliminal repetition priming effects in Chinese are not influenced by speaker gender consistency between prime and target. Since acoustic features of prime and target are more similar when speaker gender is consistent than when it is inconsistent (Latinus & Belin, 2011), these results demonstrate that acoustic similarity between prime and target does not influence auditory subliminal repetition priming effects in Chinese. This suggests that auditory subliminal repetition priming effects are not based on unconscious processing of surface perceptual features of prime words, but rather on unconscious processing of lexical-level information (Kouider & Dupoux, 2005).

Experiment 3

The purpose of Experiment 3 was to examine the modulation of interstimulus interval (ISI) on auditory subliminal repetition priming effects and to investigate the duration of unconscious activation of two-character Chinese words in the auditory modality. Experiment 3 included five ISI conditions: 0 ms, 208 ms, 416 ms, 624 ms, and 832 ms. We hypothesized that auditory subliminal repetition priming effects in Chinese would decrease gradually as ISI increased.

Method

Participants Sample size estimation followed Experiment 1. We recruited 38 undergraduate and graduate students (6 males), aged 18-23 years (M = 19.93, SD = 1.13). All had normal hearing and were native Chinese speakers. Participants received appropriate compensation after the experiment.

Design Experiment 3 used a three-factor within-subjects design: ISI (0 ms, 208 ms, 416 ms, 624 ms, 832 ms) × prime-target relatedness (related, unrelated) × stimulus type (real word, pseudo-word).

We selected 100 real words and 100 pseudo-words as target stimuli, with 20 real words and 20 pseudo-words per ISI level. Word frequencies for real-word targets across ISI levels are shown in Table 5 . Word frequencies did not differ significantly across ISI levels, $F(4, 95) = 0.14$, $p = 0.967$, $^{2} = 0.006$, 90% CI = [0.00, 0.01]. An additional 100 real words and 100 pseudo-words were selected as primes for unrelated conditions. Sound editing followed Experiment 1. Prime compression rate was 40%.

Procedure The stimulus presentation sequence was similar to Experiment 1, except that each trial in Experiment 3 included nine masks. The target was always presented after the sixth mask, while the prime' s position varied according to ISI condition. The masked priming experiment consisted of four blocks of 100 trials each, with 50 real words and 50 pseudo-words per block, 50 related and 50 unrelated trials, and 20 trials per ISI level. Each target stimulus appeared once in the first two blocks and once in the last two blocks, but with opposite relatedness assignments. Stimuli were presented in pseudo-random order with no more than four consecutive trials of the same condition or stimulus type. Participants completed 16 practice trials before the formal experiment.

After the masked priming experiment, we assessed awareness of the primes using the same subjective report and objective detection methods as previous experiments. The objective detection task included 100 trials (20 per ISI level). The entire experiment lasted approximately 25 minutes.

Results

Prime Awareness Level Subjective reports indicated that all participants reported no awareness of primes before target stimuli. Accuracy in the objective detection task (M = 0.49, SD = 0.06) did not differ from chance level (0.5), t(34) = -0.75, p = 0.46, d = -0.12, 95% CI = [-0.44, 0.20]. Discrimination sensitivity d' was calculated (M = 0.035, SD = 0.31). Both subjective and objective results confirmed that participants could not detect the masked primes.

Subliminal Priming Effects For analysis of subliminal priming effects, only correct-response trials were included, and trials with reaction times more than 2.5 standard deviations from the mean were excluded (Finkbeiner & Palermo, 2009), accounting for 1.01% of trials. Descriptive statistics for each condition are shown in Table 6 .

Separate 2 (prime-target relatedness: related, unrelated) × 5 (ISI: 0 ms, 208 ms, 416 ms, 624 ms, 832 ms) repeated-measures ANOVAs were conducted for real-word and pseudo-word conditions. For real words, the interaction between relatedness and ISI was significant, F(4, 148) = 2.49, p = 0.046, ^{2} = 0.06, 90% CI = [0.001, 0.12]. Simple effects analysis revealed that reaction times were significantly shorter in related than unrelated conditions at ISIs of 0 ms, F(1, 37) = 5.05, p = 0.031, ^{2} = 0.12, 90% CI = [0.01, 0.30]; 208 ms, F(1, 37) = 10.08, p = 0.003, ^{2} = 0.21, 90% CI = [0.05, 0.39]; and 416 ms, F(1, 37) = 4.44, p = 0.042, ^{2} = 0.11, 90% CI = [0.002, 0.28]. At ISIs of 624 ms and 832 ms, related and unrelated conditions did not differ significantly (ps > 0.05). For pseudo-words, neither the main effect of relatedness nor the interaction between relatedness and ISI was significant (ps > 0.05).

To further evaluate the duration of auditory subliminal priming effects in Chinese, we conducted a linear regression analysis with mean priming effect (difference between unrelated and related conditions) for real words as the dependent variable and ISI as the independent variable. The regression curve is shown in Figure 2 [Figure 2: see original paper]. The regression model was marginally significant, R = 0.88, F(1, 3) = 9.99, p = 0.051.

Discussion

Experiment 3 found that only for real words did participants respond faster to related than unrelated trials, and that this effect interacted significantly with ISI. This indicates that auditory subliminal repetition priming effects in Chinese are modulated by ISI. Further regression analysis showed that priming effect magnitude decreased as ISI increased, consistent with previous research using French (Dupoux et al., 2008). Specifically, auditory subliminal repetition priming was significant when ISI was less than 416 ms but non-significant when ISI exceeded 624 ms. This suggests that the duration of unconscious activation of subliminally presented two-character Chinese words likely falls between 416 ms and 624 ms, similar to findings for Indo-European languages (Dupoux et al.,

2008).

General Discussion

Three experiments systematically investigated auditory subliminal priming effects in Chinese. Experiment 1 examined auditory repetition, phonological, morphological, and semantic priming effects for two-character Chinese words at different compression rates, finding only significant auditory subliminal repetition priming. Experiment 2 investigated whether acoustic feature similarity between prime and target influences subliminal repetition priming, finding no such influence. Experiment 3 manipulated ISI to examine the duration of unconscious activation of subliminal primes, finding that auditory subliminal repetition priming decreased gradually with increasing ISI and was significant only at ISIs of 416 ms or less.

The auditory masked priming paradigm reduces prime detectability through temporal compression. However, if compression is too high, primes cannot be processed even unconsciously, while if compression is too low, primes cannot be rendered subliminal. Therefore, experiments must include multiple compression rates to identify an appropriate level. Previous research found that optimal compression rates differ across languages: 35% for French (Dupoux et al., 2008; Kouider & Dupoux, 2005) and 50% for German (Degner, 2011). To identify the optimal compression rate for two-character Chinese words, we included 40%, 50%, and 60% compression rates. All three experiments used combined subjective and objective measures to assess detectability of masked two-character words. Results consistently showed that at 40% compression, participants could not detect masked primes, confirming unconscious processing.

All three experiments observed significant subliminal repetition priming only for real words, consistent with previous research on Indo-European and Semito-Hamitic languages (Kouider & Dupoux, 2005; Ussishkin et al., 2015). Based on the Multi-Level Cluster Representation Model for Chinese compound words (Zhou & Marslen-Wilson, 1994, 1995) and our findings, we propose that auditory subliminal repetition priming effects for two-character Chinese words are based on unconscious activation of whole-word representations. Additionally, Experiment 2 and Kouider and Dupoux' s (2005) findings both show that auditory subliminal repetition priming effects are not influenced by acoustic similarity between prime and target, suggesting they are not based on unconscious activation of low-level auditory sensory impressions.

Although subliminal repetition priming was significant for real words, subliminal phonological, morphological, and semantic priming effects were all non-significant. According to the pre-activation model, pre-activation of masked primes increases the accessibility of their phonology, orthography, and semantics (Forbach et al., 1974). In repetition priming, where prime and target share all attributes, pre-activation facilitates target access. In phonological, morphological, and semantic priming, where only one attribute is shared, pre-activation

of that attribute may be offset by mismatches in other attributes, reducing overall accessibility of target lexical representations. Thus, our non-significant subliminal phonological, morphological, and semantic priming effects may reflect that phonological, orthographic, and semantic information of subliminal primes were all unconsciously processed, but reaction time measures lack the temporal resolution to determine the level of pre-activation. Future research could use event-related potentials with higher temporal resolution to examine pre-activation levels.

As discussed earlier, significant visual subliminal semantic priming effects have been found for Chinese, indicating that subliminal processing of visually presented two-character Chinese words can reach the semantic level (Shen et al., 2004; Shui et al., 2003). However, our study found no significant subliminal semantic priming, suggesting that subliminal processing of auditorily presented two-character Chinese words cannot facilitate identification of semantically related targets through automatic spreading activation in the semantic network. Previous auditory masked priming studies using Indo-European and Semito-Hamitic materials also failed to find significant auditory subliminal semantic priming (e.g., Lähteenmäki et al., 2019; Ussishkin et al., 2015), while visual masked priming studies using these materials found significant subliminal semantic priming (e.g., Greenwald et al., 1996). These differences suggest that the threshold for automatic semantic activation may be lower for visual than auditory words. However, these differences could also result from methodological variations between visual and auditory masked semantic priming studies. For example, some visual studies used semantic categorization tasks (e.g., Greenwald et al., 1996), while auditory studies used lexical decision tasks. Although our study found no significant auditory subliminal semantic priming, this does not preclude its existence. First, our study cannot determine whether other paradigms would reveal significant effects. Auditory masked priming uses temporally compressed speech, which is uncommon in daily life and may reduce depth of unconscious semantic processing, possibly explaining why this paradigm has not found significant auditory subliminal semantic priming (Daltrozzo et al., 2011). Future research should examine auditory subliminal semantic priming in Chinese using other paradigms. Second, our study and previous auditory masked priming research used lexical decision tasks, which may not require high-level semantic processing. Semantic priming effects may be more likely to emerge in tasks requiring deeper semantic processing, such as semantic categorization (Lupker, 1984; Shelton & Martin, 1992). Future research should use semantic categorization tasks to investigate auditory subliminal semantic priming in Chinese and compare effects across task types to examine how top-down task demands influence these effects.

Experiment 3 manipulated ISI to investigate the duration of unconscious activation of subliminal primes. Results showed that the magnitude of auditory subliminal repetition priming in Chinese decreased with increasing ISI and disappeared when ISI exceeded 416–624 ms, similar to findings with French (Dupoux et al., 2008). Visual masked priming research suggests that unconscious acti-

vation of visual subliminal primes lasts less than 200 ms (e.g., Ferrand, 1996; Greenwald et al., 1996), while unconscious activation of auditory subliminal primes may last longer (over 400 ms), possibly because iconic memory decays faster than echoic memory (Darwin et al., 1972; Sperling, 1960).

In conclusion, using two-character Chinese words and the auditory masked priming paradigm, this study investigated auditory subliminal priming effects in Chinese. Our findings are: (1) 40% compression is the appropriate rate for investigating unconscious processing of Chinese words using the auditory masked priming paradigm; (2) significant auditory subliminal repetition priming effects exist for Chinese real words and are independent of acoustic similarity between prime and target; (3) auditory subliminal repetition priming effects for two-character Chinese words are based on unconscious activation of whole-word representations; and (4) auditory subliminal priming effects in Chinese decrease as ISI between prime and target increases.

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Note: Figure translations are in progress. See original paper for figures.