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The impact of variety of episodic contexts on the integration of novel words into semantic network

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ABSTRACT
The current study examined whether and how the variety of episodic contexts influences the integration of novel words into semantic network via thematic and taxonomic relations in a semantic priming task with event-related potential (ERP) technique. The novel words were acquired from discourses containing either single or multiple episodes. We found that corresponding concepts, targets thematic-related to learning episodes (Experiment 1) and taxonomic-related targets (Experiment 2) elicited semantic-priming N400s/LPCs effects compared to the unrelated targets in both conditions, whereas the targets thematic-related to unlearned episodes (Experiment 1) and feature-related targets (Experiment 2) elicited semantic-priming N400s/LPCs effects only in the multiple episodic condition. These results indicated that only the novel words learned from variable episodes could successfully prime thematically related words in unlearned episodes and feature-related words. Our findings suggest that the variety of episodic contexts contributes to establishing more stable and richer semantic representations of the novel words.

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Novel word learning; semantic integration; variety of episodic contexts; ERP

Introduction

The human brain can infer the meaning of novel words from contexts and store the acquired information rapidly into semantic memory (Borovsky, Elman, & Kutas, 2012; Borovsky, Kutas, & Elman, 2010; Chen, Wang, & Yang, 2014; Mestres-Missé, Rodriguez-Fornells, & Münte, 2007, 2010; Zhang, Chen, Wang, Yang, & Yang, 2017). The processes are so rapid that even one exposure to a novel word in a meaningful context suffices for a learner to infer its meaning (Borovsky et al., 2012; Carey & Bartlett, 1978; Heibeck & Markman, 1987), and to understand its appropriate usage in context (Borovsky et al., 2010). Previous studies have found that novel words can evoke neural activation similar to that evoked by semantic integration and processing (Borovsky et al., 2010; 2012; Chen et al., 2014; Ding, Chen, Wang, & Yang, 2017; Zhang et al., 2017). Accordingly, the meaning of novel words could not only be immediately extracted from contexts, but also interact with the preexisting concepts in the semantic network. How a novel word is integrated into semantic memory is an essential question in language acquisition and development.

Concepts in semantic memory are related to each other via various semantic relations (Arias-Trejo & Plunkett, 2013; Chen et al., 2014; Ding et al., 2017; Zhang et al., 2017). Taxonomic and thematic relations are two important features of conceptual organisation (Borghi & Caramelli, 2003; Estes, Golonka, & Jones, 2011; Yee, Chrysikou, Hoffman, & Thompson-Schill, 2013). Taxonomic relations could be depicted as a hierarchical structure of concepts connected by semantic similarities that are based on shared features (Hashimoto, McGregor, & Graham, 2007; Murphy, 2010; Springer & Keil, 1991). That is, concepts belonging to the same taxonomic category, such as animals, fruits or tools, have more common features (e.g. *dog* and *wolf* both belonging to the animal category share features such as having fur and four legs, while *dog* and *banana* belonging to different categories have no common features, Rogers & McClelland, 2004). Differing from taxonomic relations, thematic relations are based on extrinsic relations between concepts, such as temporal, spatial, causal, or functional relations (Estes et al., 2011). Thematically related words usually participate in the same episodes or events and play complementary roles (e.g. *candles* and *matches* are thematically related based on their *frequent appearance in the same episode*, while *candles* and *cars* are thematically unrelated as they rarely appear in the same event or scenario, Estes et al., 2011; Goldwater, Markman, & Stilwell, 2011; Mirman & Graziano, 2012a, 2012b).

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The extensive research has focused on the developmental stages of these semantic relationships during the language acquisition. It has been found that children could successfully group objects both thematically and taxonomically by the age of 3 years (Nguyen & Murphy, 2003; S. Waxman & Gelman, 1986). However, there is a predominate tendency to focus on thematic and functional relations which becomes increasingly stronger with age during early childhood (Greenfield & Scott, 1986; Smiley & Brown, 1979; Ware, 2017). By the age of 8 years and into adulthood, taxonomic relations are preferred, leading to the hypothesis that conceptual development is characterised by a thematic-to-taxonomic shift (for a review see Lin & Murphy, 2001; Markman, 1981, 1989). The trajectory of this development is not absolute, however, because these preferences can change based on the instructions, the type of stimuli, and the cognitive demands of the tasks (Hashimoto et al., 2007; Lin & Murphy, 2001; Markman & Hutchinson, 1984; Murphy, 2001; Nguyen & Murphy, 2003; S. R. Waxman & Namy, 1997). Nevertheless, that the experimental variations creates a bias in the preference of thematic or taxonomic choice illustrates the nature and cognitive difference of these two semantic relationships. In addition, previous studies also have revealed different cognitive and neural bases for taxonomic and thematic systems in semantic memory (for a review see Mirman, Landrigan, & Britt, 2017). There are consistent findings that anterior temporal lobes are particularly important for the processing of taxonomic relations, while the temporo-parietal cortex are particularly essential for the processing of thematic relations (Bedny, Dravida, & Saxe, 2014; de Zubicaray, Hansen, & McMahon, 2013; Geng & Schnur, 2016; Kalénine et al., 2009; Mirman & Graziano, 2012a; Schwartz et al., 2011). The different neural processing bases between the taxonomic and thematic relations further indicate that semantic memory is organised into distinct taxonomic and thematic systems (Mirman et al., 2017).

Contextual learning has been widely used in previous studies as a research paradigm to study word acquisition (Batterink & Neville, 2011; Nagy, Herman, & Anderson, 1985; Swanborn & De Glopper, 1999), which is an explicit learning with promotion of the acquisition of novel words (Ellis, 2015). For the words implicitly learned from narrative context without any overt instruction about the presence of novel words, no behavioural or electrophysiological evidence for semantic priming was found for the novel words in the lexical decision task (Batterink & Neville, 2011). However, in the studies used contextual learning, participants were asked to read and comprehend sentences or discourses to infer the meaning of novel words, and then performed a lexical decision task in the semantic priming paradigms to detect the learning effects (Borovsky et al., 2012; Borovsky, Kutas, & Elman, 2013; Mestres-Missé et al., 2007, 2010). In this paradigm, the learned novel words (e.g. "*yerge*" whose corresponding concept is "*magazine*") served as prime words, and their real-word counterparts (e.g. "*magazine*"), semantically related words (e.g. "*novel*"), and semantically unrelated words (e.g. "*accident*") served as target words. It was found that the novel words showed priming effects on the corresponding concepts and semantically related words as reflected by the smaller N400s elicited by the two types of the targets relative to the semantically unrelated words (Batterink & Neville, 2011; Chen et al., 2014; Ding et al., 2017; Mestres-Missé et al., 2007; Zhang et al., 2017). The N400 amplitude is a particularly sensitive indicator of semantic integration of the novel words as it is reduced when a word is predictable or semantically related to the preceding stimulus (Kutas & Federmeier, 2000; Kutas & Hillyard, 1980; Kutas & Van Petten, 1994). The N400 effects indicated that the meaning of novel words could be successfully acquired via contextual learning and integrated into semantic memory. In addition, a late positive component (LPC) is usually observed in the semantic priming lexical decision task, with targets preceded by semantically related words eliciting larger LPCs than those preceded by semantically unrelated words. The LPC effect has been proposed to reflect conscious awareness of semantic relations between primes and targets at a late processing stage (Bouaffre & Faita-Ainseba, 2007). It can be seen that the N400 and LPC effects that indicate different facets of semantic priming could be both the indicators of semantic integration.

Ample evidence has shown that the novel words learned from contexts could be integrated into the preexisting semantic networks via taxonomic relations (e.g. Borovsky et al., 2012; Ding et al., 2017; Tamminen & Gaskell, 2013). For instance, Ding et al. (2017) embedded novel words (e.g. *miaodi*) in discourses describing the semantic features (e.g. *a pair of big horns on its head, four legs with hard hooves*, etc.) of the corresponding concepts (e.g. *buffalo*). After a short learning phase, participants completed a lexical decision task in which the novel words served as primes. It was found that the corresponding concepts and the taxonomically related words (e.g. *reindeer*) elicited smaller N400s than the unrelated words. These results suggest that the novel words learned from sentence or discourse contexts could be related to known words through taxonomic relations (Borovsky et al., 2012; Chen et al., 2014; Tamminen & Gaskell, 2013).

An intriguing question is whether the novel words could be integrated into semantic memory via thematic relations. The abovementioned study of Ding et al. (2017) found that the novel words learned from descriptive actions or perceptual features only showed a priming effect (i.e. a reduced N400) for the taxonomically related words but not for the thematically related words, indicating that it is difficult for novel words to establish thematic relations from the features-related describing discourses. This might be attributed to the mismatch between the information for the establishment of thematic relations and that provided in the contexts. According to the definitions of taxonomic and thematic relations, semantic features are particularly important for taxonomic relations and the co-occurrence in the same event or scenario is particularly important for thematic relations. Hence, we hypothesised that encountering novel words in events or episodes would facilitate the integration of novel words into semantic memory via thematic relations. To test this assumption, we embedded novel words in discourse contexts describing events or episodes to induce learners' attention to the external structure of concepts (Zhang et al., 2017). The ERP data showed that the learned novel words could be associated with words thematically related to the learned episodes, but not to words thematically related to the unlearned scenarios. These results suggest that the integration of novel words into the thematic system is constrained by the learning episodes. How the novel words could establish extensive thematic relations in semantic memory remains to be explored.

Previous studies have found that the variety of contexts is an important factor in word learning. The meaning of novel words was acquired more rapidly and accurately when the novel words appeared in various contexts than those in the same repeated context (Bolger, Balass, Landen, & Perfetti, 2008; Hills, Maouene, Riordan, & Smith, 2010). This might be attributed to more information provided by variable contexts for novel words, which facilitated the emergence of comprehensive semantic knowledge for novel words (Beck, McKeown, & McCaslin, 1983). It has been suggested that encountering a word across a variety of contexts may promote a rich set of semantic associations, including connotative as well as denotative understanding (Beck, McKeown, & Kucan, 2013). In addition, words with more associates are recognised faster than words with few associates in lexical decision tasks (Buchanan, Westbury, & Burgess, 2001). Because when more semantic units are involved in a semantic representation, the system is able to build stronger attractors for those concepts in semantic space, which allows for more efficient semantic processing (Pexman, Hargreaves, Edwards, Henry, & Goodyear, 2007). All the aforementioned results suggest that the cumulative exposures in variable contexts result in an efficient acquisition of word meaning (Horst & Samuelson, 2008; McMurray, Horst, & Samuelson, 2012; Yu & Smith, 2007).

The current study aimed to further explore the impact of variety of episodic contexts on the integration of novel words into thematic and taxonomic systems in semantic memory. The variety of episodic contexts is the number of diverse episodes appearing in the learning discourses. The novel words were learned from either single or multiple episodic contexts, in which each novel word appeared twice (see Table 1 for an example). The single episodic context described only one learning episode; while the multiple episodic contexts described two learning episodes, the first one was the same as that in the single episodic condition. After the learning phase, a semantic priming task was used to detect the semantic priming effects of the learned novel words on target words. Given the role of episodic contexts in building thematic relations of novel words (Zhang et al., 2017), the current study firstly examined the impact of the variety of episodic contexts on the integration of novel words into thematic system in semantic memory. As the cumulative occurrences across variable contexts could facilitate the establishment of semantic association and efficient acquisition of word meaning (Beck et al., 2013; Yu & Smith, 2007), Experiment 1 mainly focused on exploring whether the novel words learned in multiple episodic contexts could establish extensive thematic associations with thematically related words in unlearned episodes.

A further question is whether the variety of episodic contexts will influence the novel words' extension to the taxonomic system in semantic memory. The answer to this question seems to be unclear since the thematic and taxonomic relations are two distinct semantic systems as mentioned above. Previous studies have shown that the novel words learned from sentences or discourses describing semantic features could be integrated into the taxonomic system instead of the thematic system (Borovsky et al., 2012; Ding et al., 2017; Tamminen & Gaskell, 2013), while the novel words learned from discourses describing episodes or events could be integrated into the thematic system (Zhang et al., 2017). These results suggest that the acquisition of thematic relations of novel words is constrained by the information type provided by the learning sentences or discourses. Differing from the thematic relations, the establishment of taxonomic relations depends on the semantic similarities of concepts, such as the shared features (Hashimoto et al., 2007; Murphy, 2010; Springer & Keil, 1991). Given the learning episodes mainly induce the learner's attention on the external relations of the concepts, whether the learner can

Table 1. Examples of the learning discourses and the testing targets.

Learning discourses in the learning phase

单情境: 今天晚上停电, 小明在家里点上狙辉写作业。有了狙辉的帮助, 他很快就完成了作业。
(Single episodic condition: Tonight the electricity was cut off, Xiaoming lit up a *Juhui* to do his homework. With the help of a *Juhui*, he finished his homework very quickly.)

多情境: 今天晚上停电, 小明在家里点上狙辉写作业。想起前天的生日宴会上, 他看到了很多狙辉。
(Multiple episodic condition: Tonight the electricity was cut off, Xiaoming lit up a *Juhui* to do his homework. He remembered, at the birthday party the day before yesterday, he saw a lot of *Juhui*.)

Primes and Targets in the testing phase

Target conditions	Primes		Targets
Corresponding concepts (CC):	狙辉 (*Juhui*)	–	蜡烛 (*candle*)
Words thematic-related to the shared episode in both learning conditions (THS-1):	狙辉 (*Juhui*)	–	火柴 (*match*)
Words thematic-related to the episode only in multiple episodic condition (THS-2):	狙辉 (*Juhui*)	–	蛋糕 (*cake*)
Words thematic-related to unlearned episodes (THD):	狙辉 (*Juhui*)	–	教堂 (*church*)
Unrelated words (NR):	狙辉 (*Juhui*)	–	相机 (*camera*)
Pseudoword:	狙辉 (*Juhui*)	–	浑坎 (*hunkan*)
Pseudoword:	狙辉 (*Juhui*)	–	秒底 (*miaodi*)
Pseudoword:	狙辉 (*Juhui*)	–	疤嘻 (*baxi*)
Pseudoword:	狙辉 (*Juhui*)	–	笔项 (*bixiang*)
Pseudoword:	狙辉 (*Juhui*)	–	睹迅 (*duxun*)

Note: The stimuli were originally in Chinese followed by English translations in parenthesis. The critical words in discourses are underlined.

acquire the taxonomic relations of novel words under this circumstance remains to be explored. Therefore, Experiment 2 was conducted to examine whether the novel words learned from the episodic contexts could be integrated into the taxonomic system.

Experiment 1

Experiment 1 investigated the influence of the variety of episodic contexts on the establishment of thematic relations of novel words. In the semantic priming task, the learned novel words served as the prime words. The target words were either the corresponding concepts of novel words (CC targets), words thematically related to the shared episode in both the single and multiple episodic conditions (THS-1 targets), words thematically related to the episode only in the multiple episodic condition (THS-2 targets), words thematically related to unlearned episodes (THD targets), or unrelated words (NR targets). For example, the novel word "*Juhui*" (corresponding to the concept "*candle*") related to "*match*" (THS-1 targets) in the episode of lighting in both the single and multiple episodic conditions, related to "*cake*" (THS-2 targets) in the episode of birthday party only in the multiple episodic condition, and related to "*church*" (THD targets) in the episode of praying which did not appear in both learning conditions.

Previous studies have shown that the meaning of novel words could be successfully inferred from contextual learning (Batterink & Neville, 2011; Chen et al., 2014; Ding et al., 2017; Mestres-Missé et al., 2007; Zhang et al., 2017), we therefore expected semantic priming effects for the CC targets (i.e. a reduced N400 and/or an enhanced LPC compared to the NR targets) in both learning conditions. The corresponding concepts of novel words were thematically connected to the THS-1 targets and THS-2 targets in the learning episodes, and to the THD targets in the unlearned episodes. According to the previous study (Zhang et al., 2017), the novel words could be linked to the words thematically related to the learned episodes after a short learning phase. Therefore, the THS-1 targets would elicit a smaller N400 and/or a larger LPC than the NR targets in the single episodic condition, and the THS-1 as well as the THS-2 targets would elicit smaller N400s and/or larger LPCs than the NR targets in the multiple episodic condition. Most importantly, the establishment of the thematic relation of the novel words might be facilitated by the multiple episodic contexts (Beck et al., 1983, 2013; Horst & Samuelson, 2008; McMurray et al., 2012; Yu & Smith, 2007). Thus, we expected a reduced N400 and/or an enhanced LPC for the THD targets compared to the NR targets in the multiple episodic condition but not in the single episodic condition.

In addition, it was found that the words with a high number of semantic features or associates elicited a smaller P200 and a larger N400 compared to words with a low number of semantic features or associates during word recognition such as in lexical decision task (Amsel, 2011; Müller, Duñabeitia, & Carreiras, 2010; Rabovsky, Sommer, & Abdel Rahman, 2012a). The P200 may be the candidates for the initial influences of semantic richness as recent evidence suggested that the lexical semantic may start at the first 200 ms of semantic processing (e.g. Kiefer & Pulvermüller, 2012; Pulvermüller, Shtyrov, & Hauk, 2009; Segalowitz & Zheng, 2009). The larger N400 might reflect more activation of semantic information (Kounios & Holcomb, 1994). However, some studies found an opposite pattern for the N400 effect in concreteness judgment and semantic relatedness judgment tasks (Amsel & Cree, 2013; Kounios et al., 2009). The opposite direction of the N400 effect could be attributed to task requirements (Amsel & Cree, 2013). The concreteness judgment and semantic relatedness judgment tasks required explicit semantic access which might facilitate the semantic processing of the target words with higher semantic richness, resulting in smaller N400s for words with a high (vs. low) number of semantic features or associates. A recent study by Vergara-Martínez, Comesaña, and Perea (2017) also revealed that words appeared in different contexts showed larger early N400 (225–325 ms) than those appeared in few contexts. Therefore, if the establishment of thematic associations of novel words was modulated by the variety of episodic contexts, there would be difference in the semantic access of the novel words. In order to directly test this hypothesis, we would analyse the ERP data of the prime words (i.e. the learned novel words), which could give us an insight of the richness of semantic associations of novel words in different learning conditions. If the multiple episodes enable the novel words to build a rich set of thematic associations, we expected that the novel words learned in this condition would elicit a smaller P200 and a larger N400 than those learned in the single episodic condition in a lexical decision task.

Methods

Ethical approval

The study was approved by the Institutional Review Board of the Institute of Psychology, Chinese Academy of Sciences.

Participants

Twenty-one undergraduate students were recruited in this experiment (Mean age = 22.57 ± 1.89 years; 12 males). All were strongly right-handed, bilingual, native Mandarin speakers, and had normal or corrected-to-normal vision. None had any history of neurological impairment or psychoactive medication use. All provided informed consents and were paid for their participation.

Materials

Sixty-two two-character pseudowords (e.g. "*Juhui*" for "狙辉") served as the novel words to be learned through discourse reading. Each discourse consisted of two sentences, and the novel word appeared once in each sentence. In the single episodic condition, the two sentences described around the same episode. In the multiple episodic condition, the two sentences described two distinct episodes, with the first sentence describing the same episode as the single episodic condition. The 124 discourses were divided into two lists, with the discourses embedded the same novel word appearing in different learning condition lists. In order to ensure the validity of the manipulation of the variety of episodic context, twenty-two participants (mean age = 23.41, nine males, 11 participants per version) were asked to evaluate contextual status (single or multiple). We calculated the percentage of participants who accurately identified the contextual status for each learning discourse. The results showed that the contextual status of the learning discourses was highly accurately identified in both the single (Mean (SD) = .96 (.07)) and multiple episodic conditions (Mean (SD) = .96 (.07); $F(1,61) < 1$). In addition, twenty participants (mean age = 23.55, nine males, 10 participants per version) were asked to infer the meaning of novel words. We calculated the percentage of participants who accurately inferred the meaning of novel words for each learning discourse. The analysis showed that the inferring accuracies were equally high in both the single and multiple episodic conditions (Mean (SD) = .96 (.07) vs. .97 (.07) for the single and multiple episodic conditions, respectively, $F(1,61) < 1$).

In the lexical decision task, the novel words were used as prime words, followed by real-words or pseudowords as target words (see Table 1). Altogether, there were 310 novel word-target pairs and 310 novel word-pseudoword pairs. Another 34 participants (mean age = 23.23, 17 males) were asked to evaluate the thematic relatedness between the discourses and the related/unrelated target words (i.e. the THS-1, THS-2, THD, and NR target words), as well as the thematic relatedness between the corresponding concepts of the novel words (i.e. the CC targets) and the related/unrelated target words in 7-point Likert scales (7 indicates the most closely related and 1 indicates unrelated). Table 2 presents the relatedness rating results. For the relatedness between the targets and the learning discourses, repeated measures ANOVA revealed that the interaction between Episodic variety and Target condition was significant, $F(3,183) = 1354.58$, $MSE = .11$, $p < .001$, $\eta_p^2 = .95$. In the single episodic condition, the THS-1 targets were rated to be more related to the learning episodes than the THS-2, THD, and NR targets (THS-1 vs. THS-2: $t(61) = 61.39$, $p < .001$; THS-1 vs. THD: $t(61) = 70.21$, $p < .001$; THS-1 vs. NR: $t(61) = 112.98$, $p < .001$). There was no difference between the THS-2 and THD targets ($t(61) = 1.30$, $p \approx 1.0$). In the multiple episodic condition, the THS-1 and THS-2 targets were rated to be more related to the learning episodes than the THD and NR targets (THS-1 vs. THD: $t(61) = 58.68$, $p < .001$; THS-2 vs. THD: $t(61) = 53.65$, $p < .001$; THS-1 vs. NR: $t(61) = 80.95$,

Table 2. Linguistic properties of the stimuli ($M \pm$ SD).

		CC	THS-1	THS-2	THD	NR
Thematic-related to learning episodes	Single context	–	6.23 ± .37	1.56 ± .44	1.45 ± .44	1.03 ± .11
	Multiple context	–	6.15 ± .48	5.97 ± .51	1.52 ± .44	1.05 ± .16
Thematic relatedness		–	6.02 ± .45	5.84 ± .44	5.83 ± .55	1.75 ± .57
Word frequency		2.41 ± .76	2.33 ± .83	2.18 ± .81	2.31 ± .77	2.05 ± .68
Number of strokes		16.37 ± 4.84	16.52 ± 5.80	16.47 ± 4.50	16.45 ± 4.87	16.02 ± 3.96

Note: The data are expressed in Mean ± SD. CC = Corresponding concepts, THS-1 = Words thematic-related to the shared episode in both learning conditions, THS-2 = Words thematic-related to the episode only in multiple episodic condition, THD = Words thematic-related to unlearned episodes, and NR = Unrelated words.

$p < .001$; THS-2 vs. NR: $t(61) = 72.31$, $p < .001$). There was no difference between the THS-1 and THS-2 targets ($t(61) = 2.44$, $p = .11$). In addition, the ratings for the THS-1, THD, and NR targets were not significantly different between the single and multiple episodic conditions (THS-1: Single vs. Multiple: $t(61) = 1.60$, $p = .12$; THD: Single vs. Multiple: $t(61) = -1.03$, $p = .30$; NR: Single vs. Multiple: $t(61) = -.92$, $p = .35$), while the THS-2 targets were rated to be more related to the learning discourses in the multiple episodic condition than that in the single episodic condition ($t(61) = 51.87$, $p < .001$). For the relatedness between the novel words and the targets, an one factor (Target condition: THS-1, THS-2, THD, and NR) repeated measures ANOVA revealed a significant main effect of Target condition, $F(3,183) = 1189.68$, $MSE = .22$, $p < .001$, $\eta_p^2 = .95$. The THS-1, THS-2, and THD targets were judged as being more thematically related to the CC targets than the NR targets (THS-1 vs. NR: $t(61) = 47.40$, $p < .001$; THS-2 vs. NR: $t(61) = 53.14$, $p < .001$; THD vs. NR: $t(61) = 44.77$, $p < .001$), and the THS-1, THS-2, and THD were equally related to the CC targets (THS-1 vs. THS-2: $t(61) = 2.38$, $p = .12$; THS-1 vs. THD: $t(61) = 2.30$, $p = .15$; THS-2 vs. THD: $t(61) = .18$, $p \approx 1.0$). The target words in the five conditions were also matched for word frequency based on the corpus developed by Cai and Brysbaert (2010) ($F(4,212) = 1.76$, $MSE = .60$, $p = .14$, $\eta_p^2 = .03$), as well as number of strokes ($F < 1$).

Procedure

Participants were tested in a dimly lit, sound-attenuated room, and seated in a comfortable chair. The distance between participants and the screen was about 80 cm. All Chinese characters were presented in white colour on a black background, with a font size of 24 in Song typeface. In a learning trial, a fixation was presented for a random duration of 800–1200 ms in the centre of the screen, followed by a learning discourse presented one phrase at a time. Each phrase was presented for 500 ms except for the novel word (e.g. 狙辉), which appeared in isolation for 1000 ms. Two consequent phrases were separated by a 300-ms blank. After the last phrase, the whole learning discourse was presented on the screen. Participants were asked to press the space button if they had understood the discourse and learned the meaning of the novel word. A 2000-ms blank screen was presented before the next trial began.

After learning 10 or 12 novel words, participants were allowed to have a break and then the lexical decision task began. A fixation cross was presented for a random duration of 800–1200 ms in the centre of the screen. Then a prime word was presented for 300 ms followed by an inter-stimulus interval of 200 ms. After that, a target word appeared for 300 ms. Once the target word appeared, participants were asked to judge whether the target was a real word or not as quickly as possible by pressing the "F" or "J" buttons on the keyboard. Then a 2000-ms blank screen was presented before the next trial started. The two key-pressing responses were counterbalanced across participants.

The learning discourses were presented randomly while the word pairs were presented in a pseudo-random order. In order to ensure that the meaning of the novel words was not learned by the pairing of the corresponding concepts with the novel words in the lexical decision task, the novel word-CC target pairs were always presented after the THS-1, THS-2, THD, and NR targets. Word pairs containing the same novel word were separated by at least three other word pairs. The same response would not repeat for more than three times in succession. Each version (62 discourses, 31 discourses per learning condition) was divided into six blocks, each of which contained a learning phase (10 or 12 discourses) and a testing phase (i.e. the lexical decision task, containing 100 or 120 trials). There were 31 trials in each condition. Following task instructions and a practice phase, participants completed the six blocks with a short break between blocks.

EEG acquisition and preprocessing

EEGs were recorded in the lexical decision task from the scalp with a 64-channel Ag-AgCl electrode cap (10–20 system) at a sampling rate of 1000 Hz, with a band-pass filter 0.05–100 Hz. Bipolar horizontal and vertical electro-oculograms (EOGs) were recorded simultaneously to monitor eye movements. EEG and EOG data were amplified with two 32-channel BrainAmp MR Plus amplifiers. An electrode placed between FPz and Fz served as the ground. The impedance of the electrodes was kept below 5 KΩ throughout the recording session. EEG data were referenced online to the left mastoid and then re-referenced offline to the algebraic average of the left and right mastoids.

The NeuroScan software 4.3 was used to analyse data offline. After apparent artifacts being rejected, eye blinks were automatically corrected according to Semlitsch, Anderer, Schuster, and Presslich (1986). Then the EEG data were filtered offline with a 0.05–30 Hz band-pass zero-phase shift digital filter (slope 24 db/Oct). The data were then segmented into epochs of 1200 ms, starting 200 ms prior to the onset of the primes (i.e. the learned novel words) and target words respectively in the lexical decision task. After artifact rejection with criterion of ±75 μV, average 12.69% trials were rejected from the total prime and target words. ERP amplitude was measured with respect to the average baseline voltage over the interval from −200 to 0 ms before prime and target words. Mean ERP amplitudes were computed for each participant at each electrode in each condition within each selected time window.

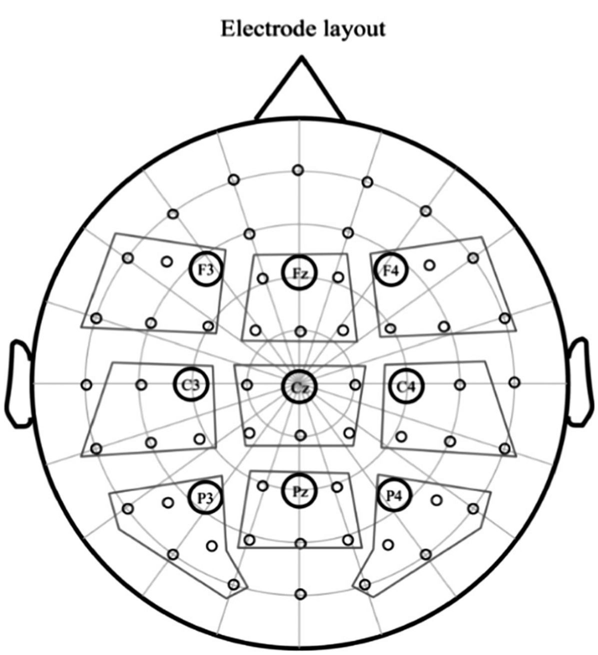

Figure 1. Electrode layout on the scalp. The electrodes selected for statistical analysis are grouped into nine regions: left-frontal, left-central, left- posterior, middle-frontal, middle-central, middle- posterior, right-frontal, right-central, and right-posterior. The indicated electrodes (F3, Fz, F4, C3, Cz, C4, P3, Pz and P4) were used to present the ERP waveforms.

ERP data analysis

The electrodes selected for analysis were demonstrated in Figure 1 (enclosed in solid lines). Repeated measures ANOVAs were conducted separately on primes and targets. For the primes (i.e. the learned novel words), Episodic variety (single and multiple episodes), Laterality (left, middle, and right), and Anteriority (Frontal, Central, and Posterior) were submitted to the repeated measures ANOVAs. For the targets, Target condition (CC, THS-1, THS-2, THD, and NR) serving as another within-subject factor was submitted to the repeated measures ANOVAs. We applied the Greenhouse-Geisser correction if the degree of freedom was larger than one and the Mauchly's sphericity test was significant. In these cases, the original degrees of freedom and the corrected p values were reported. In addition, when there were any interactions with Episodic variety or Target condition in the ANOVAs, simple effects tests and planned comparisons were conducted. The pair-wise comparisons were all adjusted by Bonferroni correction.

Results

Behavioural data

Prior to the statistical analysis, the trials with errors were excluded from the latency analysis (4.70%). Then the trials with latencies exceeding ±2.5 standard deviations were also excluded in each target condition for each participant (4.62%). In order to test whether the latencies were normally distributed, the normal probability (Q-Q) plot was applied as the indicator which shows the distribution of the data against the expected normal distribution. For normally distributed data, observations should lie approximately on a straight line. The results showed that the distributions of the original data in each condition were skew. Then the original latencies were log-transformed to follow a normal or near normal distribution. The accuracy results (left panel) and the RT results (right panel) are shown in Figure 2.

We performed 2 (Episodic variety: single and multiple episodes) × 5 (Target condition: CC, THS-1, THS-2, THD and NR targets) repeated measures ANOVAs by participants (F_1, t_1) and by items (F_2, t_2) to the log-transformed latency results. There was a significant main effect of Target condition, $F_1(4,80) = 12.28$, $p < .001$, $\eta_p^2 = .38$, $F_2(4,610) = 5.81$, $p < .001$, $\eta_p^2 = .04$. The reaction time was faster for the CC targets than that for the THS-1 ($t_1 = -3.88$, $p = .008$, $t_2 = -3.40$, $p = .004$), THS-2 ($t_1 = -3.75$, $p = .014$, $t_2 = -3.80$, $p = .001$), THD ($t_1 = -4.50$, $p = .002$, $t_2 = -3.80$, $p = .001$), and NR targets ($t_1 = -4.57$, $p = .001$, $t_2 = -3.60$, $p = .002$). The main effect of Episodic variety was not significant, $F_1F_2 < 1$. The interaction

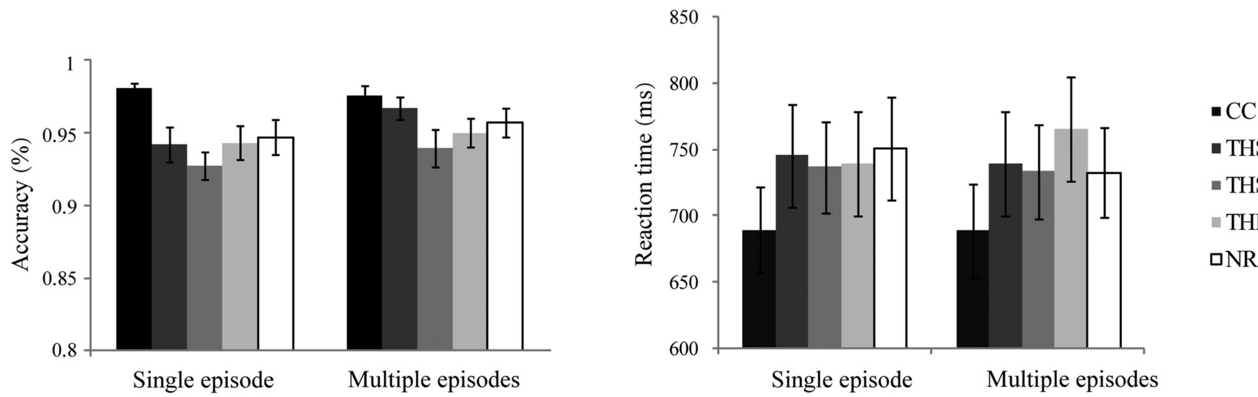

Figure 2. Accuracies (in percentage, left panel) and reaction times (in ms, right panel) for the target words (CC, THS-1, THS-2, THD, and NR) in each learning condition. Error bars represent the standard error.

between Episodic variety and Target condition was not significant either, $F_1(4,80) = 1.21$, $p = .31$, $\eta_p^2 = .06$, $F_2 < 1$.

For the accuracy analysis, it has been found that ANOVA for the categorical outcome variables, such as question-answer accuracy, can yield spurious results (Jaeger, 2008). Therefore, we adopted logistic regression in which Episodic variety and Target condition were explanatory variables and accuracy was dependent variable. The results showed that the main effects of Episodic variety ($Z = .87$, $p = .39$) and Target condition ($Z = -1.07$, $p = .29$) were not significant. The interaction between Episodic variety and Target condition was not significant either, $Z = -.06$, $p = .96$. Overall, the CC targets showed a faster response compared to the THS-1, THS-2, THD and NR targets.

ERP data

Prime words. The grand average waveforms elicited by the novel words (i.e. the prime words) in different conditions at nine representative electrodes (F3, Fz, F4, C3, Cz, C4, P3, Pz and P4) are presented in Figure 3. The prime word was presented for 300 ms followed by an inter-stimulus interval of 200 ms. Then a target word or pseudoword appeared for 300 ms. Therefore, epochs for the novel words covered the primes and targets. After 500 ms relative to the onset of the primes, participants should process targets. The difference between the multiple and single conditions in this period might be the continuation of the preceding effect. Therefore, the mean N400 amplitudes were measured in time window of 300–500 ms post the novel words onset where N400 effects are typically largest (Kutas & Hillyard, 1980). Based on previous studies (Chen et al., 2014; Mestres-Missé et al., 2007; Zhang et al., 2017) and visual inspections, two time windows were selected for statistical analyses: (1) The P200 time window: 180–220 ms; (2) The standard N400 time window: 300–500 ms.

The P200 time window. Repeated measures ANOVA revealed that the main effect of Episodic variety was significant, $F(1,20) = 7.35$, $p = .013$, $\eta_p^2 = .27$. Pair-wise comparisons indicated that the novel words learned from the single episodic condition elicited a larger P200 than that learned from the multiple episodic condition. The interaction between Episodic variety and Anteriority was also significant, $F(2,40) = 4.46$, $p = .018$, $\eta_p^2 = .18$. Simple effects test revealed that the main effect of Episodic variety was significant in the Frontal ($F(1,20) = 7.84$, $p = .011$, $\eta_p^2 = .23$), and Central regions ($F(1,20) = 9.48$, $p = .006$, $\eta_p^2 = .26$).

The n400 time window. The interaction between Episodic variety and Laterality was marginally significant, $F(2,40) = 3.03$, $p = .059$, $\eta_p^2 = .13$. Separate ANOVAs conducted for the left hemisphere, middle region, and right hemisphere revealed that the main effect of Episodic variety was approaching significant in the middle region, $F(1,20) = 4.24$, $p = .053$, $\eta_p^2 = .18$. In view of the distribution of the N400 effect in Figure 3, we directly compared the average amplitudes of the electrodes fell within the parietal-central region (FC1, FCz, FC2, C1, Cz, C2, CP1, CPz, CP2) between the two learning conditions. Repeated measures ANOVA revealed that the main effect of Episodic variety was significant, $F(1,20) = 4.89$, $p = .039$, $\eta_p^2 = .20$, indicating that the novel words learned from the multiple episodic condition elicited a larger N400 than those learned from the single episodic condition.

Overall, the novel words elicited a smaller P200 over Frontal and Central regions and larger N400 over parietal-central region in the multiple episodic condition compared to those in the single episodic condition.

Target words

The grand average waveforms elicited by the target words in single (Figure 4) and multiple (Figure 5)

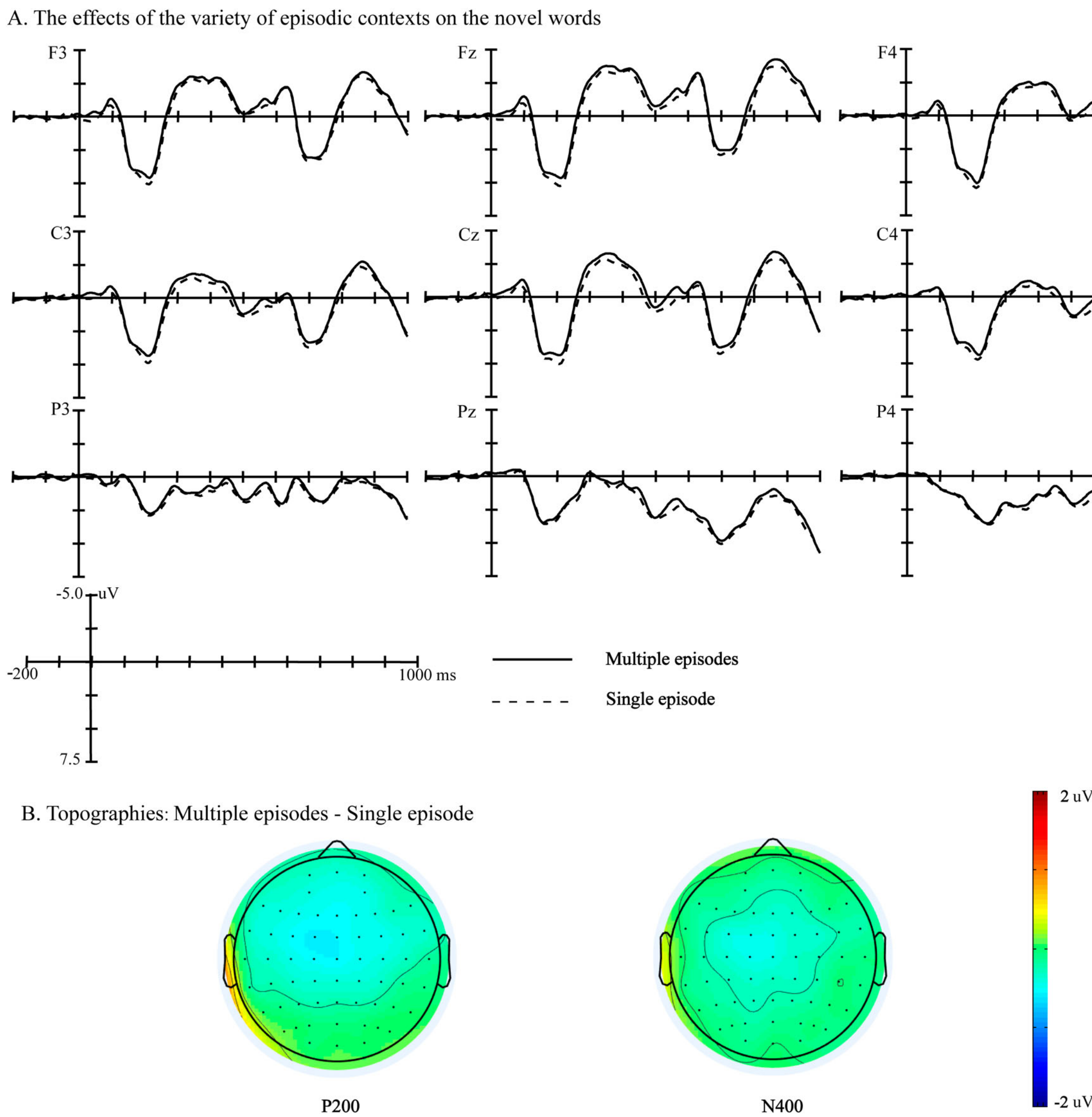

Figure 3. The effects of the variety of episodic contexts on the novel words in Experiment 1. (A) Waveforms for the novel words in the single and multiple episodic learning conditions were presented at nine representative electrodes. (B) Topographies showing the average amplitude voltage differences between the novel words in the single and multiple episodic learning conditions in 180–220 ms and 300–500 ms time windows.

conditions at nine representative electrodes (F3, Fz, F4, C3, Cz, C4, P3, Pz and P4) are presented. Based on previous studies (e.g. Chen et al., 2014; Mestres-Missé et al., 2007; Zhang et al., 2017) and visual inspections, two time windows were selected for statistical analysis: (1) The N400 time window: 300–500 ms; (2) A late positivity time window: 600–800 ms. Only significant effects containing the critical manipulation (Episodic variety and Target condition) were reported.

The N400 time window. Repeated measures ANOVA revealed a significant main effect of Target condition ($F(4,80) = 23.82$, $p < .001$, $\eta_p^2 = .54$). Pair-wise comparisons indicated that the CC, THS-1, THS-2, THD elicited smaller N400s relative to the NR targets (*ps* < .001). And the CC targets also elicited smaller N400 than the THS-2 and THD targets (*ps* < .05). In addition, the interaction among Episodic variety, Target condition, and Anteriority was significant, $F(8,160) = 3.83$, $p < .001$, $\eta_p^2 = .16$. Separate ANOVAs were conducted for the Frontal, Central, and Posterior regions. In the Frontal and Central regions, the interactions between Episodic variety and Target condition were significant (Frontal: $F(4,80) = 4.75$, $p = .002$, $\eta_p^2 = .19$; Central: $F(4,80) = 2.68$, $p = .037$, $\eta_p^2 = .12$). Simple effects tests revealed that the main effect of Target condition was significant in both the single (Frontal: $F(4,17) = 6.17$, $p = .003$, $\eta_p^2 = .59$; Central: $F(4,17) = 6.61$, $p = .002$, $\eta_p^2 = .61$) and multiple episodic conditions (Frontal: $F(4,17) = 15.25$, $p < .001$, $\eta_p^2 = .78$; Central: $F(4,17) = 10.84$, $p < .001$, $\eta_p^2 = .72$). In the single episodic condition, the CC and

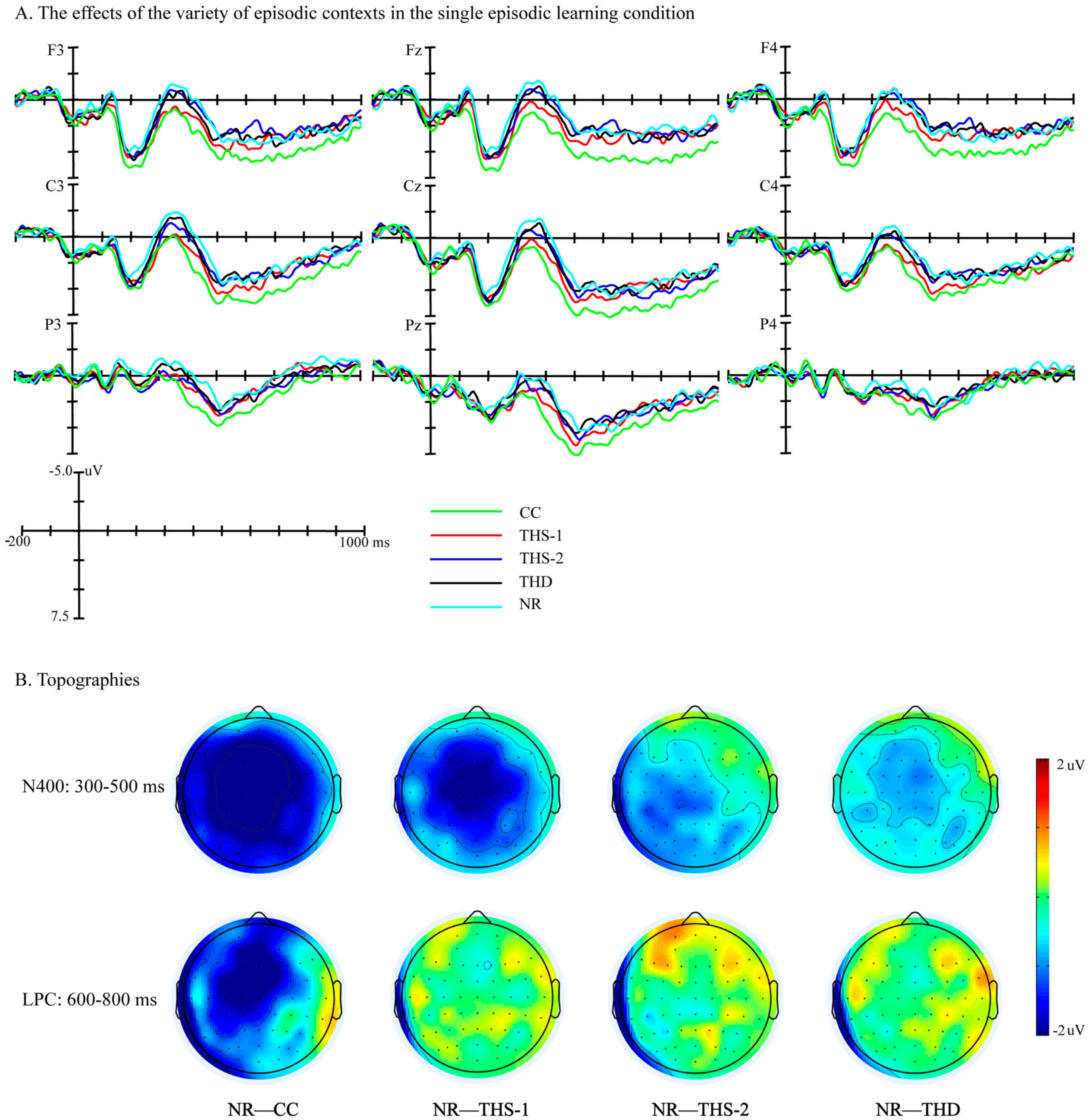

Figure 4. The effects of the variety of episodic contexts on the integration of novel words into the thematic system in the single episodic learning condition. (A) Waveforms for CC, THS-1, THS-2, THD and NR targets were presented at nine representative electrodes. (B) Topographies showing the average amplitude voltage differences between the CC, THS-1, THS-2, THD targets, and the NR targets, respectively. CC: corresponding concepts; THS-1: words thematically related to the shared episode in both learning conditions; THS-2: words thematically related to the episode only in multiple episodic condition; THD: words thematically related to unlearned episodes; NR: unrelated words.

THS-1 targets elicited smaller N400s than the NR targets (Frontal: CC vs. NR: $t(20) = 5.24$, $p < .001$; THS-1 vs. NR: $t(20) = 4.51$, $p = .002$; Central: CC vs. NR: $t(20) = 5.54$, $p < .001$; THS-1 vs. NR: $t(20) = 4.28$, $p = .004$). And the CC targets also elicited a smaller N400 compared to the THS-2 and THD targets (Frontal: CC vs. THS-2: $t(20) = 4.64$, $p = .002$; CC vs. THD: $t(20) = 3.53$, $p = .021$; Central: CC vs. THS-2: $t(20) = 3.81$, $p = .011$; CC vs. THD: $t(20) = 4.02$, $p = .007$). In the multiple episodic condition, the CC, THS-1, THS-2, and THD targets elicited smaller N400s than the NR targets (Frontal: CC vs. NR: $t(20) = 6.06$, $p < .001$; THS-1 vs. NR: $t(20) = 5.52$, $p < .001$; THS-2 vs. NR: $t(20) = 6.97$, $p < .001$; THD vs. NR: $t(20) = 6.56$, $p = .001$; Central: CC vs. NR: $t(20) = 5.32$, $p < .001$; THS-1 vs. NR: $t(20) = 5.01$, $p = .001$; THS-2 vs. NR: $t(20) = 6.08$, $p < .001$; THD vs. NR: $t(20) = 5.85$, $p < .001$).

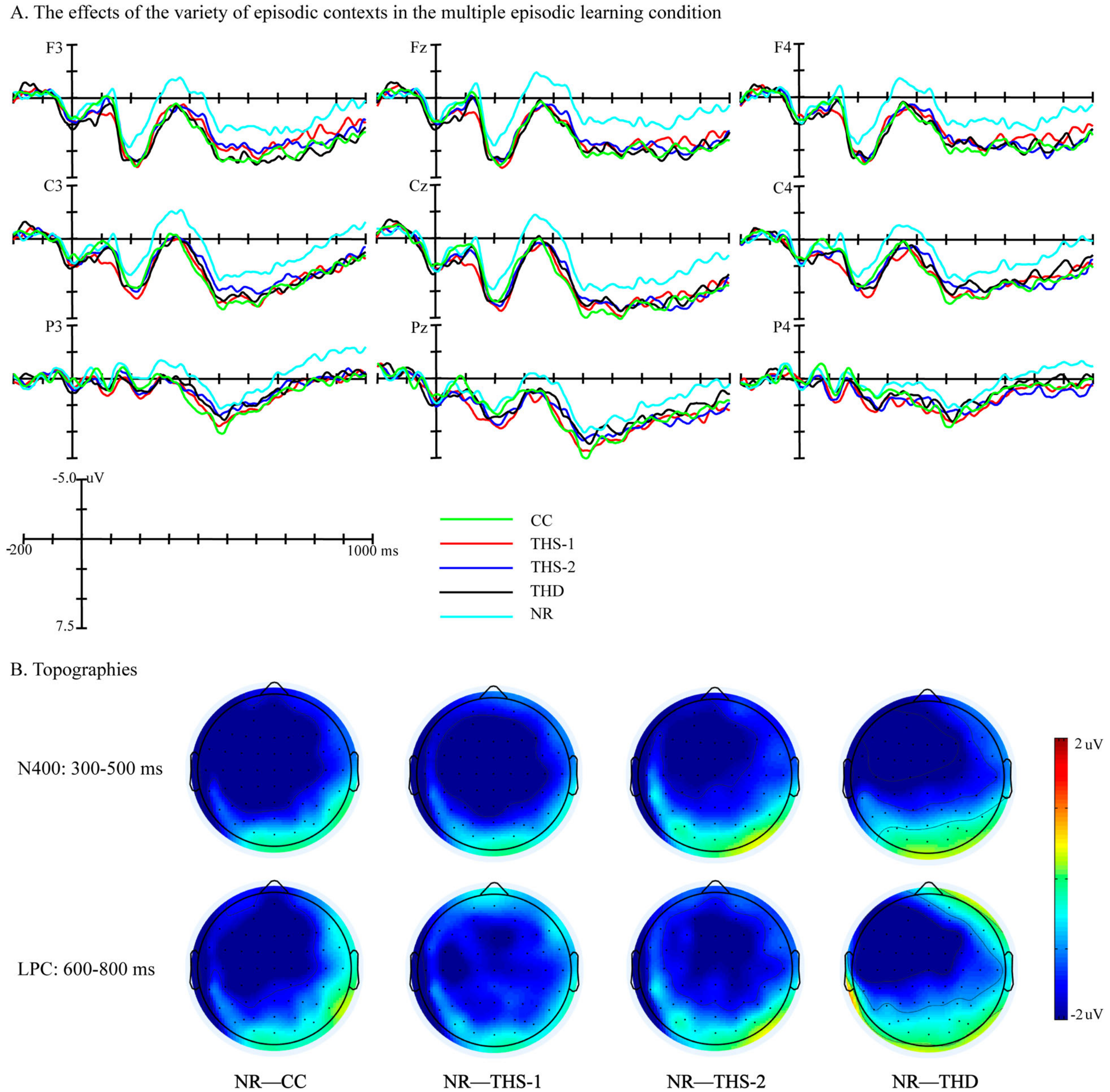

Figure 5. The effects of the variety of episodic contexts on the integration of novel words into the thematic system in the multiple episodic learning condition. (A) Waveforms for CC, THS-1, THS-2, THD and NR targets were presented at nine representative electrodes. (B) Topographies showing the average amplitude voltage differences between the CC, THS-1, THS-2, THD targets, and the NR targets, respectively. CC: corresponding concepts; THS-1: words thematically related to the shared episode in both learning conditions; THS-2: words thematically related to the episode only in multiple episodic condition; THD: words thematically related to unlearned episodes; NR: unrelated words.

Overall, the CC and THS-1 targets elicited smaller N400s than the NR targets in the single episodic condition. However, the CC, THS-1, THS-2, and THD targets elicited smaller N400s than the NR targets in the multiple episodic condition. These effects distributed over Frontal and Central regions.

The LPC time window. A repeated measures ANOVA revealed significant main effects of Episodic variety ($F(1,20) = 7.95$, $p = .011$, $\eta_p^2 = .29$) and Target condition ($F(4,80) = 5.22$, $p = .001$, $\eta_p^2 = .21$). Pair-wise comparisons indicated that the novel words learned from multiple episodes elicited a larger LPC than those learned from single episode. And the CC targets elicited an enhanced LPC relative to the NR targets ($t(17) = 3.55$, $p = .020$). Most importantly, the interaction of Episodic variety, Target condition, and Anteriority was significant ($F(8,160) = 2.30$, $p = .024$, $\eta_p^2 = .10$). Separate ANOVAs were also conducted across Frontal, Central, and Posterior regions. In the Frontal and Central regions, the interaction between Episodic variety and Target condition was significant (Frontal: $F(4,80) = 4.24$, $p = .004$, $\eta_p^2 = .18$; Central: $F(4,80) = 3.21$, $p = .017$, $\eta_p^2 = .14$). Simple effects tests revealed that the main effect of Target condition was significant in both the single (Frontal: $F(4,17) = 3.03$, $p = .047$, $\eta_p^2 = .42$; Central: $F(4,17) = 4.51$, $p = .012$, $\eta_p^2 = .51$) and multiple episodic conditions (Frontal: $F(4,17) = 4.65$, $p = .010$, $\eta_p^2 = .52$; Central: $F(4,17) = 3.59$, $p = .027$, $\eta_p^2 = .46$). In the single episodic condition, the CC targets elicited a larger LPC than the THS-1 and THD targets (Frontal: CC vs. THS-1: $t(20) = 3.54$, $p = .021$; CC vs. THD: $t(20) = 3.30$, $p = .036$; Central: CC vs. THS-1: $t(20) = 3.34$, $p = .033$; CC vs. THD: $t(20) = 3.34$, $p = .033$). In the multiple episodic condition, the CC, THS-1, THS-2, and THD targets all elicited larger LPCs than the NR targets (Frontal: CC vs. NR: $t(20) = 3.59$, $p = .018$; THS-1 vs. NR: $t(20) = 4.05$, $p = .006$; THS-2 vs. NR: $t(20) = 4.14$, $p = .005$; THD vs. NR: $t(20) = 4.39$, $p = .003$; Central: CC vs. NR: $t(20) = 3.09$, $p = .057$; THS-1 vs. NR: $t(20) = 3.40$, $p = .029$; THS-2 vs. NR: $t(20) = 4.00$, $p = .007$; THD vs. NR: $t(20) = 3.31$, $p = .035$).

Overall, the CC targets elicited a larger LPC than the THS-1 and THD targets in the single episodic condition, while the CC, THS-1, THS-2, and THD targets elicited a larger LPC than the NR targets in the multiple episodic condition. These effects distributed over the Frontal and Central regions.

Discussion

Experiment 1 explored whether the variety of episodic contexts would influence the establishment of thematic relations of the novel words learned from thematic knowledge. Specifically, whether the novel words learned from multiple episodic contexts could automatically connect to other concepts irrelevant to the learned episodes. The behavioural results of the response latency showed priming effects for the CC targets, as reflected by the shorter reaction time for the CC targets than those for the THS-1, THS-2, THD, and NR targets. The priming effects suggest that the corresponding concepts were recognised more easily than the thematically related and unrelated targets when they were preceded by the novel words.

As for the ERP results, it was found that, in the single episodic condition, the CC and THS-1 targets elicited reduced N400s relative to the unrelated targets and the CC targets elicited an enhanced LPC compared to THS-1 and THD targets; In the multiple episodic condition, semantic-priming N400/LPC effects were found for the CC, THS-1, THS-2, and THD targets compared to the unrelated words. The N400 effect is proposed to reflect the spreading activation of semantic information (Kiefer & Pulvermüller, 2012; Lau, Phillips, & Poeppel, 2008) and the LPC effect is associated with conscious awareness of semantic relationship between primes and targets at a late processing stage (Bouaffre & Faita-Ainseba, 2007). The corresponding concepts (CC targets) and the words thematically related to the learning episodes (THS-1 targets in the single episodic condition; THS-1 and THS-2 targets in the multiple episodic condition) elicited semantic-priming N400/LPC effects relative to the unrelated words (NR targets). These results are consistent with our previous study (Zhang et al., 2017). In the learning phase, participants read the discourses and retrieved relevant episodic information from long-term memory to infer the meaning of the novel words. Although the thematically related words in the learning episodes were not directly presented, they might be activated due to their frequent co-occurrence with the other information presented in the same episodes. Then during the testing phase, the recognition of the novel words facilitated the access to the learning-episode related targets which induced a decreased N400 (Lau et al., 2008), lasting to the late semantic processing stage. These results suggested that the novel words could be successfully mapped onto the corresponding concepts and established thematic relations with the words thematically related to the learning episodes.

Most importantly, different from the study of Zhang et al. (2017), we found a semantic-priming N400/LPC effect for the thematically related words in unlearned episode (THD targets) compared to the NR targets in the multiple episodic condition. Since the thematic knowledge might be organised in separate episodes (Zhang et al., 2017), and limited episodic information may be not sufficient enough for the novel words to establish thematic associations with the concepts from unlearned episodes, the thematic relations of the novel words therefore were constrained in the learning episodes in the single episodic condition. However, in the multiple episodic condition, encountering a novel word across different episodes activated more thematically related information from the two learning episodes. The convergence of activated information enabled the novel word to establish more extensive thematic relations, as indicated by the connection between the novel word and another concept from an episode different from learning episodes. This result suggested that learning a novel word across variable episodes facilitates the generalisation of the novel word to other episodes in the thematic system. Moreover, the novel words learned from the multiple episodic condition elicited a smaller P200 and a larger N400 compared to those learned from the single episodic condition. The analysis of the target words has showed that the new words across variable episodic contexts could build extensive thematic associations. It has been proposed that the P200 (Amsel, 2011; Kounios et al., 2009; Müller et al., 2010) and the N400 (Amsel, 2011; Rabovsky, Sommer, & Abdel Rahman, 2012b) components are sensitive to semantic richness. These results further suggested that the novel words appeared in different episodic contexts establish rich thematic associations with the preexisting words.

The findings of the Experiment 1 suggested that multiple episodic contexts facilitate the generalisation of novel words in the thematic system. Due to the neural dissociation between the thematic and taxonomic systems, it is still unclear whether the novel words learned from descriptive episodic discourses focusing on the external relations of concepts could be also integrated into the taxonomic system in which concepts are connected by semantic similarities (Hashimoto et al., 2007; Murphy, 2010; Springer & Keil, 1991). Therefore, Experiment 2 was conducted to address this issue that whether the novel words learned from episodic contexts could be integrated into semantic network via taxonomic relations. If the answer is yes, we are also concerned whether the novel words learned from the single and multiple episodic conditions would show different patterns in the learning effects.

Experiment 2

In Experiment 1 we found that the multiple episodic contexts enable the novel words to establish a rich set of thematic associations. In Experiment 2, we further explored the impact of variable episodic contexts on the semantic integration of the novel word into the taxonomic-semantic network. Concepts are typically represented by distributed features in conceptual system (e.g. furry, four legs, for the concept of dog; Tyler & Moss, 2001; Tyler et al., 2004). Especially in the taxonomic system, concepts relate to each other based on similar semantic features (Mirman et al., 2017). Accordingly, Experiment 2 aimed to explore whether the novel words learned from descriptive episodes could be associated with their taxonomically related words. And if yes, whether the variety of episodic contexts would affect the integration of novel words into taxonomic systems. As conceptual feature is an essential factor for the taxonomic connection between concepts, we would like to further clarify the differential integration patterns in different learning conditions at concept-feature level. Thus, in the current experiment, we tested the priming effects of the novel words on the corresponding concepts (CC), taxonomically related words (TR), feature-related words (FR), and unrelated words (NR).

It has been suggested that encountering a word across a variety of contexts could promote the understanding of its denotative and connotative meaning (Beck et al., 2013), we hypothesised that the novel words learned from the variable episodic contexts could be extended to the taxonomic system. Thus, there would be semantic priming effects (i.e. a reduction of N400 or a lager LPC) for the TR and FR target words in the multiple episodic condition. In the single episodic condition, there were two possibilities. First, if the novel words learned from the single episodic context, focusing on the external relations of concepts, are constrained in the thematic system, there would be no semantic priming effects for either the TR or FR target words. Second, since taxonomic relations are primary in conceptual system (for a review see Mirman et al., 2017), the novel words learned from any types of contexts could establish taxonomic relations with known words. Thus, there would be semantic priming effects for the TR target words. However, the connotative meaning of the novel words might not be understood well in the single condition, there would be no priming effect for the FR target words. We would also analyse the ERPs elicited by the novel words (i.e. the prime words) in the lexical decision task to replicate the results of Experiment 1.

Method

Ethical approval

The study was approved by the Institutional Review Board of the Institute of Psychology, Chinese Academy of Sciences.

Participants

Twenty undergraduate students were recruited in the EEG experiment (Mean age = 21.75 ± 1.71 years; 10 males). All were strongly right-handed, bilingual, native Mandarin Chinese speakers, and had normal or corrected-to-normal vision. None had any history of neurological impairment or psychoactive medication use. All provided informed consent and were paid for their participation.

Materials, procedure, EEG acquisition and preprocessing

The learning materials, procedure, acquisition and preprocessing of EEG data were identical to Experiment 1. In the lexical decision task, the learned novel words were used as prime words, followed by real-word or unlearned-pseudoword targets (see Table 3). The four conditions of the target words were: 1) the corresponding concepts of the novel words (CC, e.g. *candle*), 2) the

Table 3. Examples of the testing primes and targets.

Primes and Targets in the testing phase			
Target conditions	Primes		Targets
Corresponding concepts (CC):	狙辉 (*Juhui*)	–	蜡烛 (*candle*)
Taxonomic-related words (TR):	狙辉 (*Juhui*)	–	火炬 (*torch*)
Feature-related words (FR):	狙辉 (*Juhui*)	–	火焰 (*flame*)
Unrelated words (NR):	狙辉 (*Juhui*)	–	相机 (*camera*)
Pseudoword:	狙辉 (*Juhui*)	–	浑坎 (*hunkan*)
Pseudoword:	狙辉 (*Juhui*)	–	秒底 (*miaodi*)
Pseudoword:	狙辉 (*Juhui*)	–	笔项 (*bixiang*)
Pseudoword:	狙辉 (*Juhui*)	–	睹迅 (*duxun*)

Note: The learning discourses were identical to Experiment 1. The English translations of the target words are given after the original Chinese words in parenthesis.

Table 4. The linguistic properties of the stimuli.

	CC	TR	FR	NR
Semantic relatedness	–	5.68 ± .46	5.82 ± .33	1.89 ± .54
Word frequency	2.41 ± .76	2.23 ± .80	2.07 ± .73	2.10 ± .67
Number of strokes	16.37 ± 4.84	15.89 ± 5.51	16.47 ± 4.73	15.97 ± 4.14

Note: The data are expressed in Mean ± SD. CC = Corresponding concepts, TR = Taxonomic-related words, FR = Feature-related words, and NR = Unrelated words.

taxonomic-related words (TR, e.g. *torch*), 3) the feature-related words (FR, e.g. *flame*), and 4) the unrelated words (NR, e.g. *camera*). The 62 discourses (31 discourses per learning condition) was divided into six blocks, each of which contained a learning phase (10 or 12 discourses) and a testing phase (i.e. the lexical decision task, containing 80 or 96 trials). Altogether, there were 248 novel word-target pairs and 248 novel word-pseudoword pairs, and each condition contained 31 trials. After preprocessing, 13.04% trials were rejected from the total prime and target words.

Ten participants (mean age: 23.2, five males) were asked to judge to what extent the TR, FR, and NR targets were semantically related to the CC targets in a 7-point Likert scale (7 indicates the most closely related and 1 indicates unrelated). One-factor repeated measures ANOVA revealed that the main effect of Target condition was significant, $F(2,122) = 1642.59$, $MSE = .19$, $p < .001$, $\eta_p^2 = .90$. Participants rated the TR and FR targets to be more semantically related to the CC targets than the NR targets (TR vs. NR: $t(61) = 42.11$, $p < .001$; FR vs. NR: $t(61) = 50.95$, $p < .001$). In addition, there was no difference between the semantic relatedness of the TR and FR targets with the CC targets (TR vs. FR: $t(61) = -2.08$, $p = .12$). The target words in the four conditions were also matched for word frequency based on the corpus developed by Cai and Brysbaert (2010) ($F(3,153) = 1.90$, $MSE = .56$, $p = .13$, $\eta_p^2 = .04$) as well as number of strokes ($F < 1$; see Table 4).

EEG data analysis

The selected electrodes were identical to Experiment 1 (as shown in Figure 1). Repeated measures ANOVAs were conducted separately on primes (i.e. the learned novel words) and targets. For the primes, Episodic variety (single and multiple episodes), Laterality (left, middle, and right), and Anteriority (Frontal, Central, and Posterior) were submitted to the repeated measures ANOVAs. For the targets, Target condition (CC, TR, FR, and NR) serving as another within-subject factor was submitted to the repeated measures ANOVAs. Other analytical approaches were identical to Experiment 1.

Results

Behavioural data

Similar to Experiment 1, the error trials and trials with latencies being more than 2.5 standard deviations away from the mean in each condition were excluded from the latency analysis (5.30%). The original latencies were log-transformed to follow a normal or near normal distribution, as indicated by the majority of points in the QQ-normal plots distributing on a straight diagonal line. The accuracy results (left panel) and the RT results (right panel) are shown in Figure 6.

We conducted 2 (Episodic variety: single and multiple episodes) × 4 (Target condition: CC, TR, FR, and NR targets) repeated measures ANOVAs by participants (F_1, t_1) and by items (F_2, t_2) for the log-transformed latency results. In the latency analysis, there was a significant main effect of Target condition, $F_1(3,57) = 33.97$, $p < .001$, $\eta_p^2 = .64$, $F_2(3,488) = 29.33$, $p < .001$, $\eta_p^2 = .15$. Compared with the CC targets, the reaction time was longer in the TR ($t_1(19) = 5.80$, $p < .001$, $t_2(244) = 6.67$, $p < .001$), FR ($t_1(19) = 9.20$, $p < .001$, $t_2(244) = 9.67$, $p < .001$), and NR conditions ($t_1(19) = 4.20$, $p = .003$, $t_2(244) = 5.00$, $p < .001$). In addition, the responses to FR targets were also longer than those to TR ($t_1(19) = 5.33$, $p < .001$, $t_2(244) = 3.17$, $p = .020$) and NR targets ($t_1(19) = 4.00$, $p = .002$, $t_2(244) = 4.83$, $p < .001$). In the accuracy analysis, the logistic regression revealed that there was no significant effect for either main effects (Episodic variety: $Z = -.02$, $p = .98$; Target condition: $Z = -1.44$, $p = .15$) or interaction effect ($Z = .47$, $p = .64$). Overall, the CC targets showed faster responses compared to the TR, FR and NR targets. And the FR targets also showed the longest responses compared with the other targets.

ERP data

Prime words. The grand average waveforms elicited by the novel words in different conditions at nine representative electrodes (F3, Fz, F4, C3, Cz, C4, P3, Pz and P4) are

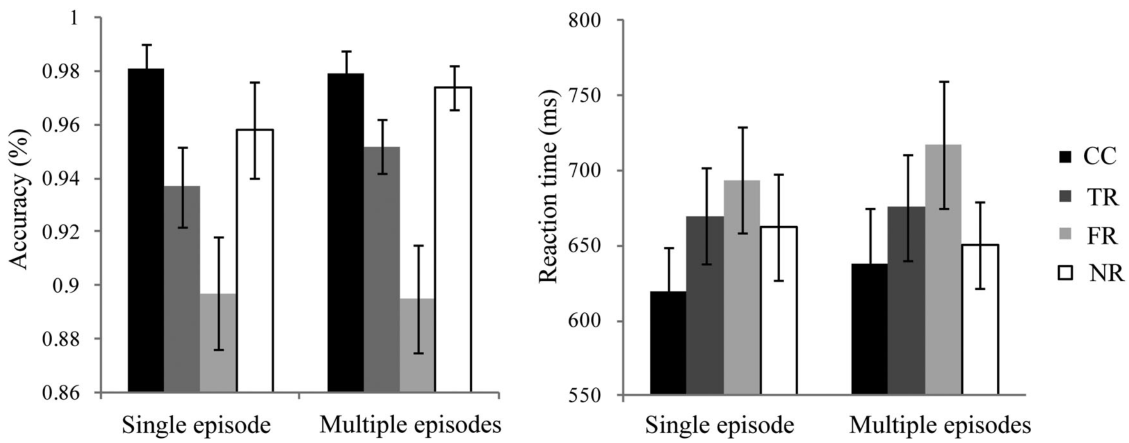

Figure 6. Accuracies (in percentage, left panel) and reaction times (in ms, right panel) for the target words (CC, TR, FR, and NR) in each learning condition. Error bars represent the standard error.

presented in Figure 7. Consistent with Experiment 1, two time windows were selected for statistical analyses: (1) The P200 time window: 180–220 ms; (2) The standard N400 time window: 300–500 ms.

The P200 time window. A repeated measures ANOVA revealed that the main effect of Episodic variety was significant, $F(1,19) = 8.38$, $p = .009$, $\eta_p^2 = .31$, with the novel words learned from the single episodic condition eliciting a larger P200 than those learned from the multiple episodic condition. The interaction between Episodic variety and Laterality was significant, $F(2,38) = 3.89$, $p = .029$, $\eta_p^2 = .17$. Separate ANOVAs conducted for the left hemisphere, middle region, and right hemisphere revealed that the main effect of Episodic variety was significant in the left hemisphere ($F(1,19) = 5.74$, $p = .027$, $\eta_p^2 = .23$), middle region ($F(1,19) = 8.40$, $p = .009$, $\eta_p^2 = .31$) and right hemisphere ($F(1,19) = 9.59$, $p = .006$, $\eta_p^2 = .34$).

The N400 time window. There was a significant main effect of Episodic variety, $F(1,19) = 13.94$, $p = .001$, $\eta_p^2 = .42$, showing that the novel words learned from multiple episodic condition elicited a larger N400 than those learned from single episodic condition. The interaction between Episodic variety and Anteriority was also significant, $F(2,38) = 10.57$, $p < .001$, $\eta_p^2 = .36$. Simple effects tests revealed that the main effect of Episodic variety was significant over the Frontal ($F(1,19) = 18.95$, $p < .001$, $\eta_p^2 = .50$) and Central regions ($F(1,19) = 14.89$, $p = .001$, $\eta_p^2 = .44$).

Overall, the novel words learned from the multiple episodic condition elicited a smaller P200 over the whole brain and a larger N400 over the Frontal and Central regions compared to those learned from the single episodic condition.

Target words

The grand average waveforms elicited by the target words in the single (Figure 8) and multiple (Figure 9) conditions are presented at nine representative electrodes (F3, Fz, F4, C3, Cz, C4, P3, Pz and P4). Consistent with Experiment 1, two time windows were selected for statistical analyses: (1) The standard N400 time window: 300–500 ms; (2) The LPC time window: 600–800 ms.

The N400 time window. We found a significant main effect of Target condition, $F(3,57) = 19.36$, $p < .001$, $\eta_p^2 = .51$. Pair-wise comparisons indicated that the CC and TR targets elicited smaller N400s than the FR and NR targets ($ps < .01$). The interaction among Episodic variety, Target condition, and Laterality was significant, $F(6,114) = 3.01$, $p = .009$, $\eta_p^2 = .14$. Separate ANOVAs were conducted for the left hemisphere, middle region, and right hemisphere. In the middle region and right hemisphere, the interactions between Episodic variety and Target condition were significant (Middle region: $F(3,57) = 4.91$, $p = .004$, $\eta_p^2 = .21$; Right hemisphere: $F(3,57) = 6.67$, $p = .001$, $\eta_p^2 = .26$). Simple effects tests revealed that the main effect of Target condition was significant in both the single (Middle region: $F(3,17) = 24.42$, $p < .001$, $\eta_p^2 = .81$; Right hemisphere: $F(3,17) = 25.31$, $p < .001$, $\eta_p^2 = .82$) and multiple episodic conditions (Middle region: $F(3,17) = 10.26$, $p < .001$, $\eta_p^2 = .64$; Right hemisphere: $F(3,17) = 12.07$, $p < .001$, $\eta_p^2 = .68$). In the single episodic condition, pair-wise comparisons indicated that the CC and TR targets elicited smaller N400s than the FR and NR targets (Middle region: CC vs. FR: $t(19) = 5.00$, $p < .001$; TR vs. FR: $t(19) = 4.00$, $p = .005$; CC vs. NR: $t(19) = 7.44$, $p < .001$; TR vs. NR: $t(19) = 4.66$, $p = .001$; Right hemisphere: CC vs. FR:

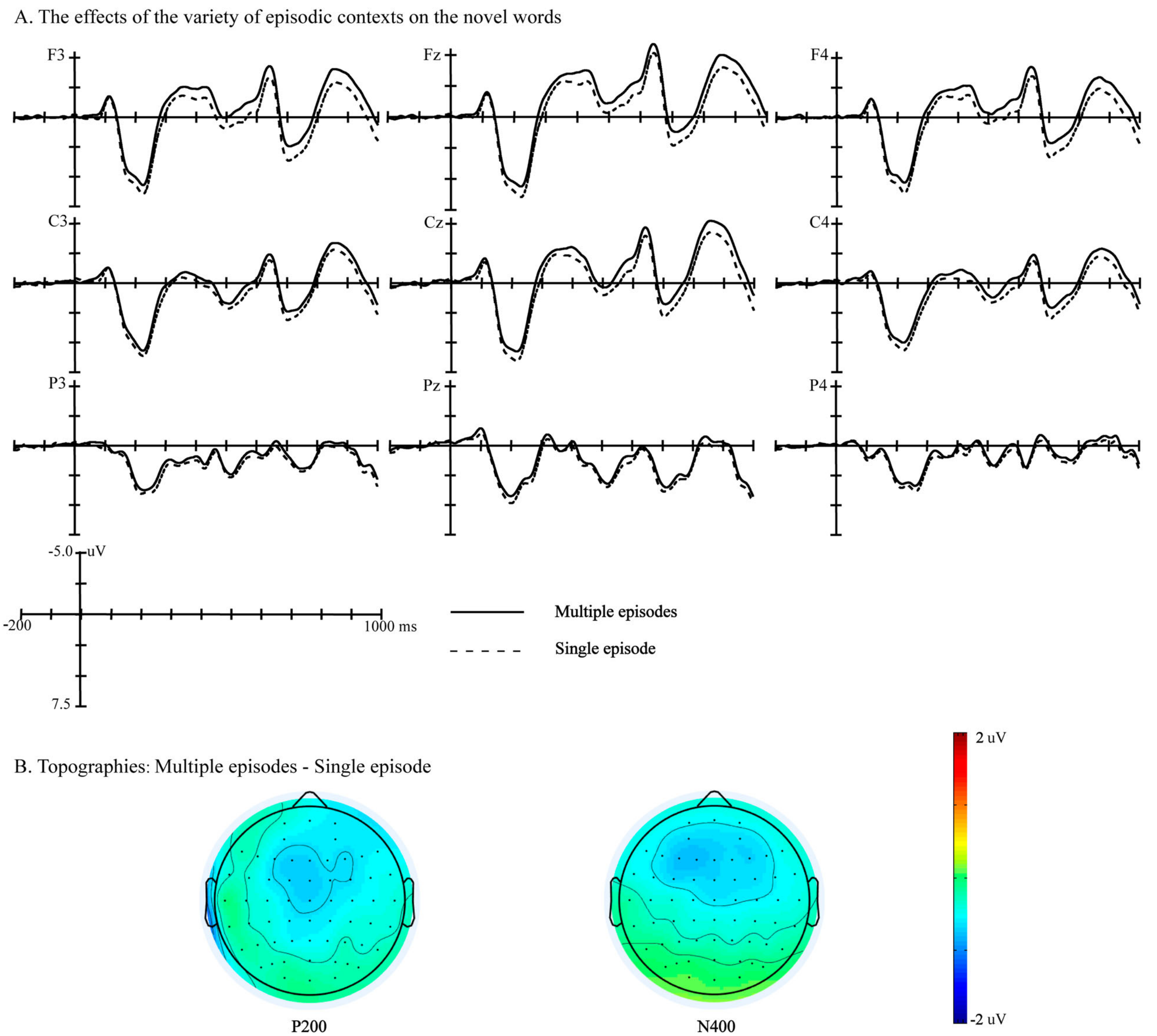

Figure 7. The effects of the variety of episodic contexts on the novel words in Experiment 2. (A) Waveforms for the novel words in the single and multiple episodic learning conditions were presented at nine representative electrodes. (B) Topographies showing the average amplitude voltage differences between the novel words in the single and multiple episodic learning conditions in 180–220 ms and 300–500 ms time windows.

$t(19) = 4.94$, $p = .001$; TR vs. FR: $t(19) = 3.48$, $p = .015$; CC vs. NR: $t(19) = 8.18$, $p < .001$; TR vs. NR: $t(19) = 4.90$, $p = .001$). In the multiple episodic condition, the CC, TR, and FR targets all elicited smaller N400s than the NR targets (Middle region: CC vs. NR: $t(19) = 3.98$, $p = .005$; TR vs. NR: $t(19) = 4.43$, $p = .002$; FR vs. NR: $t(19) = 4.74$, $p = .001$; Right hemisphere: CC vs. NR: $t(19) = 4.61$, $p = .001$; TR vs. NR: $t(19) = 4.55$, $p = .001$; FR vs. NR: $t(19) = 4.03$, $p = .004$).

Overall, the CC and TR targets elicited smaller N400s than the FR and NR targets in the single episodic condition. In addition, the CC, TR, and FR targets elicited smaller N400s than the NR targets in the multiple episodic condition. These effects were distributed over the Middle region and Right hemisphere.

The LPC time window. We found a significant main effect of Target condition, $F(3,57) = 10.54$, $p < .001$, $\eta_p^2 = .36$. Pair-wise comparisons indicated that the CC, TR, and FR targets elicited larger LPCs than the NR targets ($ps < .05$). A marginally significant interaction among Episodic variety, Target condition, and Laterality was found, $F(6,114) = 2.12$, $p = .056$, $\eta_p^2 = .10$. Separate ANOVAs were conducted for the left hemisphere, middle region, and right hemisphere. In the middle region and right hemisphere, the interactions between Episodic variety and Target condition were significant (Middle region: $F(3,57) = 4.60$, $p = .006$, $\eta_p^2 = .20$; Right hemisphere: $F(3,57) = 3.51$, $p = .021$, $\eta_p^2 = .16$). Simple effects tests revealed that the main effect of Target condition was significant in both the single (Middle region:

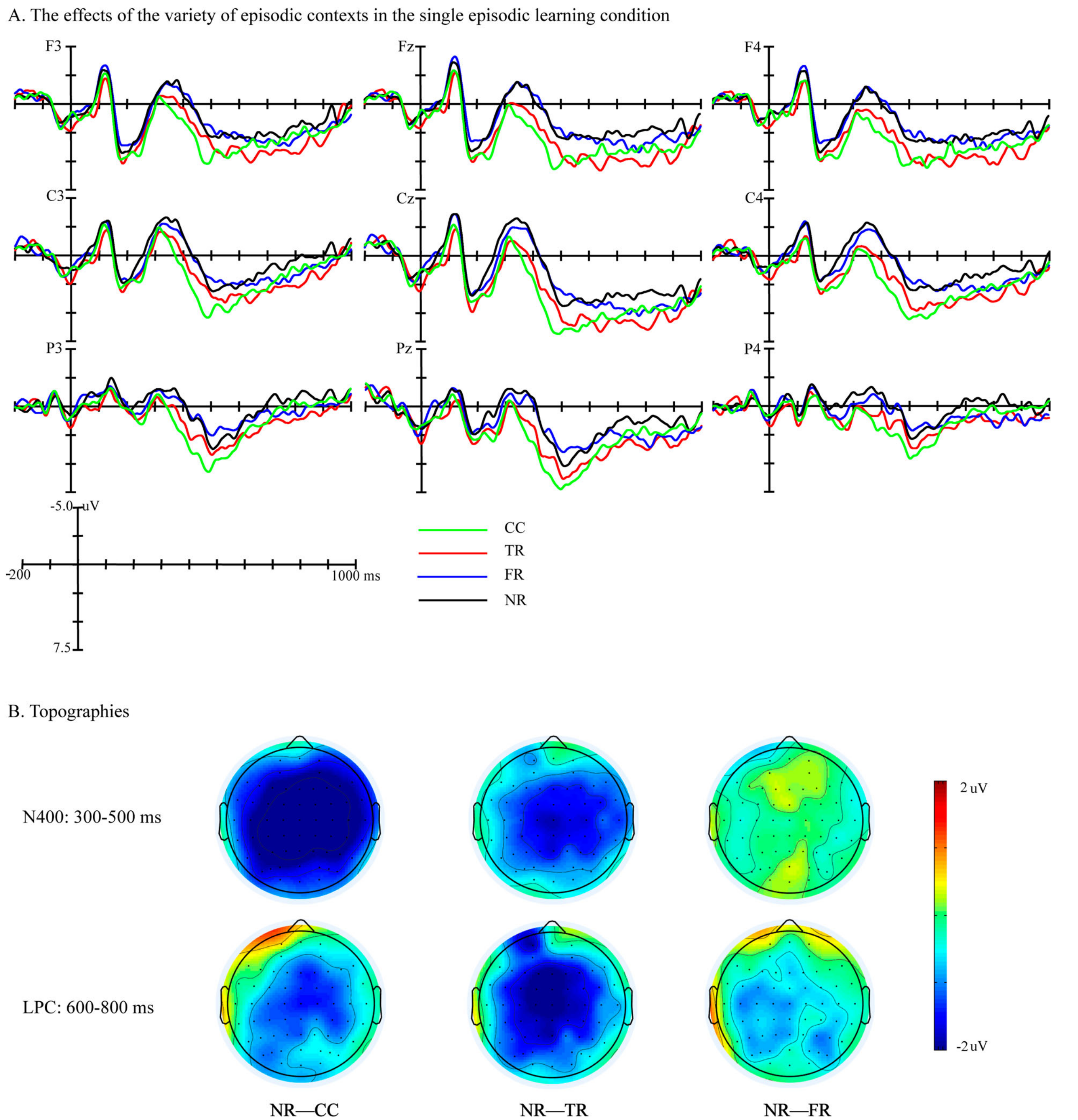

Figure 8. The effects of the variety of episodic contexts on the integration of novel words into the taxonomic system in the single episodic learning condition. (A) Waveforms for CC, TR, FR, and NR targets were presented at nine representative electrodes. (B) Topographies showing the average amplitude voltage differences between the CC, TR, FR targets, and the NR targets, respectively. CC: corresponding concepts; TR: taxonomically related words; FR: feature-related words; NR: unrelated words.

$F(3,17) = 16.99$, $p < .001$, $\eta_p^2 = .75$; Right hemisphere: $F(3,17) = 9.23$, $p = .001$, $\eta_p^2 = .62$) and multiple episodic condition (Middle region: $F(3,17) = 10.27$, $p < .001$, $\eta_p^2 = .65$; Right hemisphere: $F(3,17) = 10.18$, $p < .001$, $\eta_p^2 = .64$). Pair-wise comparisons revealed that the CC and TR targets elicited larger LPCs than the NR targets in the single episodic condition (Middle region: CC vs. NR: $t(19) = 4.00$, $p = .005$; TR vs. NR: $t(19) = 6.32$, $p < .001$; Right hemisphere: CC vs. NR: $t(19) = 4.00$, $p = .005$; TR vs. NR: $t(19) = 3.11$, $p = .035$). In addition, the TR targets elicited a larger LPC than the FR targets in the middle region (TR vs. FR: $t(19) = 3.20$, $p = .028$). In the multiple episodic condition, the TR and FR targets elicited larger LPCs than the NR targets (Middle region: TR vs. NR: $t(19) = 3.36$, $p = .020$; FR vs. NR: $t(19) = 5.36$, $p < .001$; Right hemisphere: TR vs. NR: $t(19) = 3.99$, $p = .005$; FR vs.

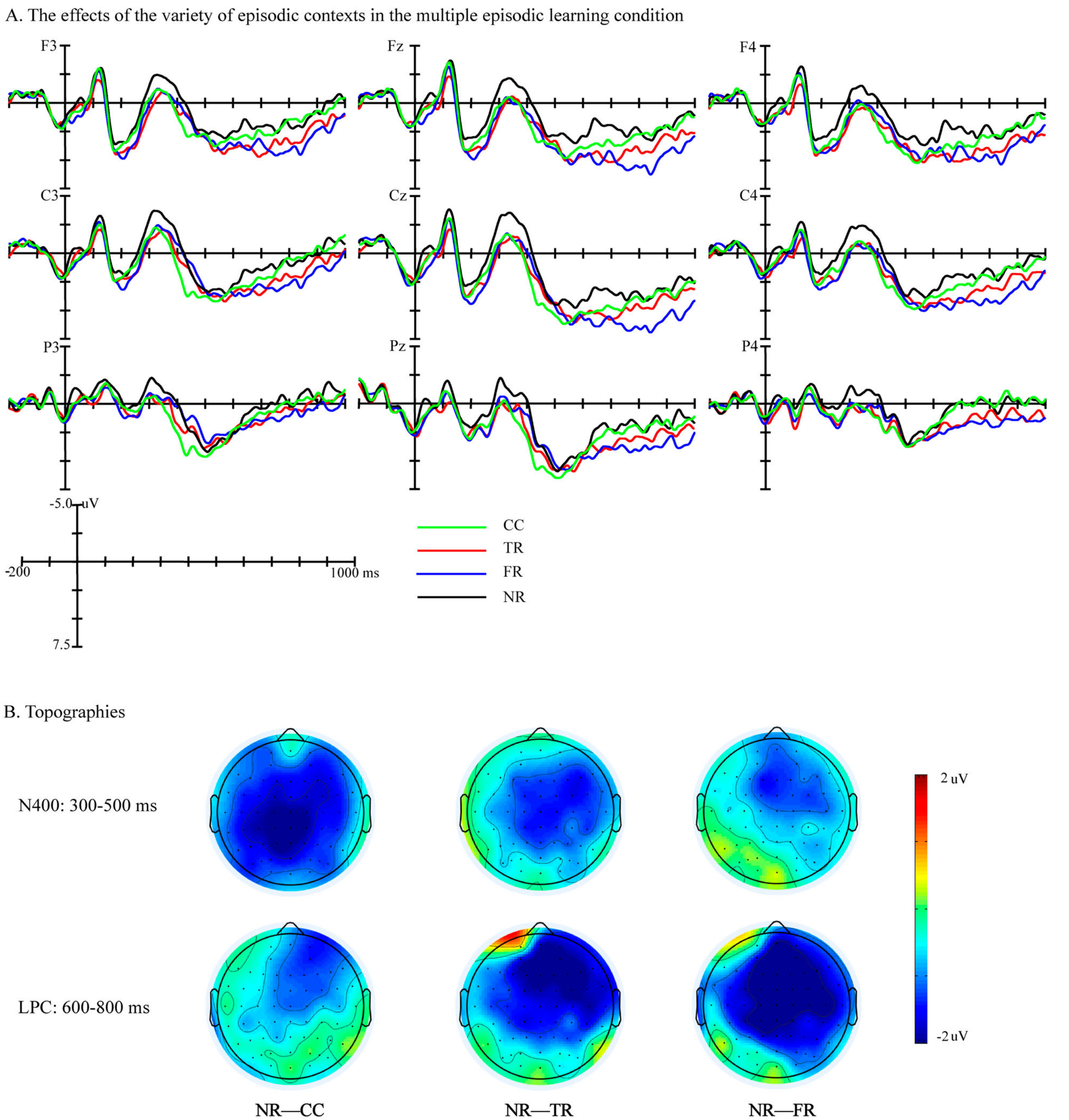

Figure 9. The effects of the variety of episodic contexts on the integration of novel words into the taxonomic system in the multiple episodic learning condition. (A) Waveforms for CC, TR, FR, and NR targets were presented at nine representative electrodes. (B) Topographies showing the average amplitude voltage differences between the CC, TR, FR targets, and the NR targets, respectively. CC: corresponding concepts; TR: taxonomically related words; FR: feature-related words; NR: unrelated words.

NR: $t(19) = 4.79$, $p = .001$). In addition, the FR targets elicited a larger LPC than the CC targets (Middle region: CC vs. FR: $t(19) = -3.17$, $p = .031$; Right hemisphere: CC vs. FR: $t(19) = -3.53$, $p = .014$).

Overall, in the single episodic condition the CC and TR targets elicited smaller N400s and larger LPCs than the NR targets. In the multiple episodic condition, the CC, TR and FR targets elicited smaller N400s, and TR as well as FR targets elicited larger LPCs than the NR targets. These effects were distributed over the Middle region and Right hemisphere.

Discussion

Experiment 2 further examined whether the novel words learned from descriptive episodes could be extended to the taxonomic system in semantic memory, and if yes, whether the extension of novel word meaning was modulated by the episodic variety. In the behavioural data, participants responded to the TR, FR and NR targets slower than that to the CC targets. The priming effects suggest that the corresponding concepts were recognised more easily than the taxonomically related and unrelated targets. In addition, the FR targets showed the longest responses compared to CC, TR and NR targets. This result pattern is consistent with our previous study (Chen et al., 2014), in which participants were asked to infer the meaning of novel words (e.g. *fangfen* corresponding to the concept *turtle*) from discourse passages providing semantic features. We found that the unlearned FR targets (e.g. *long-lived*) produced the longest response compared to the CC and NR targets in the inferring learning condition. The distributed features may be activated once seeing the novel words, leading to a competition to process a specific feature-concept association. However, that competition did not exist during the processing of the CC, TR, and NR target words. Thus, the more processing demands led to longer response time compared to CC, TR, and NR targets.

The learned novel words showed priming effects for the corresponding concepts and the taxonomically related words in both the single and multiple episodic conditions, as indicated by the semantic-priming N400/LPC effects compared to the unrelated targets (NR targets). This result suggested that the novel words learned from both episodic conditions could establish taxonomic relations with the pre-existing words. However, only the novel words learned from the multiple episodic condition, but not from the single episodic condition, showed the N400/LPC priming effects for the feature-related targets (FR targets). This might be attributed to the more activated information from different episodes, which facilitated deeper representations of the novel words. In addition, similar to the results of Exp.1, the novel words learned from multiple episodic condition also elicited a smaller P200 and a larger N400 than those learned from the single episodic condition. It seems that the P200 and N400 effects in response to the semantic richness of novel words in Experiment 2 is larger than those in Experiment 1. This discrepancy might be accounted for by the individual difference between the two experiments. Nevertheless, these converging ERP results indicated that learning across multiple episodes enables the novel words to establish taxonomic relations and form a deeper semantic representation at a conceptual feature level.

One might argue that the behavioural data and the ERP data are contradictory because the responses to the FR target words was slower than the other target words with no significantly difference in accuracy. However, the FR target words elicited smaller N400 than the NR target words in the multiple episodic contexts. We speculated that the behavioural and ERP data reflected different processes. For instance, the RT and accuracy data, as offline measurements, reflect the combination of multiple cognitive processes (e.g. perception, decision making and motor operations). However, the N400 effect was purely related to the semantic representation of the learned words in the two learning conditions (Chen et al., 2014), which was immune to the decision making process. The smaller N400s for the FR target words, relative to the NR target words, reflected the facilitation of the novel words for the FR target words. However, this facilitation during the semantic activation disappeared after the other cognitive processes reflected on the behavioural data.

Overall, the converging evidence from the testing phase indicated that the novel words learned from both the single and multiple episodic conditions could be extended to the taxonomic system, while encountering novel words across multiple episodes could enable the novel words to establish deeper semantic representation at conceptual feature level.

General discussion

In the current study, we examined the impact of the variety of episodic contexts on the integration of novel words into the semantic memory. In the behavioural results, no priming effect was found for either taxonomic or thematic relations between the learned novel words and the targets. As for the ERP results, in Experiment 1, the ERP data showed that the learned novel words could prime the corresponding concepts (CC targets) and the thematically related words from the learned episodes (THS-1 targets in the single episodic condition, and THS-1 as well as THS-2 targets in the multiple episodic condition), as reflected by reduced N400s and enhanced LPCs relative to the unrelated words (NR targets). However, the semantic-priming N400/LPC effects for the thematically related words in unlearned episodes (THD targets) were only found in the multiple episodic condition, but not in the single episodic condition. In Experiment 2, the ERP data showed that the learned novel words primed both the CC and taxonomically related targets (TR targets) in both learning conditions; the feature-related words (FR targets) showed a semantic-priming N400/LPC effect only in the multiple episodic condition, but not in the single episodic condition. In addition, the novel words appeared in multiple episodes elicited a smaller P200 and a larger N400 than those only appeared in single episode. The dissociation between the ERP and behavioural measures is not uncommon in the novel word learning studies. For instance, McLaughlin, Osterhout, and Kim (2004) also only found N400 priming effects in the absence of RT priming effects in the second language learning study. In fact, a number of behavioural studies have suggested that priming effects only emerge after the novel words have been consolidated (Clay, Bowers, Davis, & Hanley, 2007; Tamminen & Gaskell, 2013; van der Ven, Takashima, Segers, & Verhoeven, 2015). Hence, the ERP effects in the absence of behavioural effects in the current study may suggest that the semantic integration of the novel words into semantic memory begins rapidly, but may need to undergo a long consolidation process. The main findings and implications are further discussed in the following.

The impact of episodic variety on the establishment of semantic relations of novel words

For the analysis of target words in the lexical decision task, it was found that the CC targets and THS targets elicited smaller N400s and enhanced LPCs relative to the NR targets in both learning conditions. These results replicated our previous study (Zhang et al., 2017), indicating that the meaning of the novel words was successfully inferred from descriptive episodes and linked with thematically related words from learned episodes. However, semantic-priming N400/LPC effects for the THD targets were only found in the multiple episodic condition, suggesting that only the novel words learned from variable episodic discourses could be generalised to other unlearned episodes. In our previous study (Zhang et al., 2017), we did not find N400 priming effect for the THD targets preceded by the novel words learned from one episode or event, but there was a late positivity effect, reflecting that the thematic associations between the novel words and thematically related concepts in unlearned episodes were consciously realised only in the late processing stage. These compatible findings further indicate that whether the establishment of thematic relations could be constrained by the learned episodes was affected by the variety of episodic contexts. In the current study, the novel words were embedded in different episodes or events, which are examples of schemas (Schank & Abelson, 1988). During the learning phase, inferring the meaning of the novel words would activate both explicit and implicit schema knowledge in the contexts (Bower, Black, & Turner, 1979). Compared to the limited episodic information provided by the single episodic condition, variable episodic contexts would activate more relevant schema knowledge during the inference which allows the novel words to link with richer information, such as extensive thematically related words. Moreover, previous studies have shown that the acquired new knowledge could be integrated into preexisting schemas when the new information is congruent or similar to existing schemas or mental representations (Skotko et al., 2004; van Kesteren, Rijpkema, Ruiter, Morris, & Fernández, 2014). As the increasing input of episodic information, the knowledge accumulation of the novel words may highlight the close link between the acquired knowledge of novel words and the prior knowledge, leading to strong links with the relevant semantic knowledge of the corresponding concepts. Therefore, the variable episodes facilitate the generalisation of novel words to new episodes, enabling the novel words to establish rich thematic associations distributed in both learned and unlearned scenarios.

In addition, the semantic-priming N400/LPC effects for the TR targets in both learning conditions did suggest that the novel words could be integrated into taxonomic system regardless of the episodic variety. Borovsky et al. (2012) also found that the N400 amplitudes to targets preceded by the novel words appeared in highly constraining sentences varied with prime-target relatedness, suggesting the fast-mapped word representation can develop strong associations with semantically related word meanings. These findings may reveal a rapid neural process that can integrate information about novel word meanings with the concepts overlapping in semantics. Word representations are complex and multi-faceted which refers to the word's phonological, form, and its semantic representation. During the contextual learning, its meaning must be appropriately situated within the local context and dynamic semantic landscape of the mental lexicon. For instance, when learning a novel bird's name, the learner might acquire information specific to the bird (e.g. its colour, size, and feeding habits) and also link this knowledge to their existing knowledge of birds and other creatures (Collins & Loftus, 1975; Rosch & Mervis, 1975), which may facilitate the semantic connections with the concepts with shared features. Our results may reveal that integrating into taxonomic system is a rapid and consequential process at the first stage of semantic integration of the novel words once the meanings are successfully inferred, independent of the variety of episodic contexts.

However, the deep of semantic representation varied in different episodic learning conditions as the reduced

N400 and enhanced LPC for the FR targets were only found in the multiple episodic condition, indicating that the novel words could associated with their conceptual features only when they occurred across variable episodes. It was proposed that encountering a word across variable contexts may promote a rich set of semantic associations, including both connotative and denotative meanings (Beck et al., 2013). The rich episodic contexts provide more contextual related features and some of them may repeatedly occur across different contexts, which may facilitate the comprehensive understanding of the novel words as well as the close associations between the novel words and the relevant features. Instead, the single episode could only provide few contextual related features which may only define and give partial semantic knowledge for the novel words (e.g. Beck et al., 1983). In addition, the relevant features inferred from the single episode might be represented unstably without repetition across variable episodes. Therefore, the variable episodic contexts facilitate the learned words with specific and deeper semantic representations at conceptual feature level.

Furthermore, the analysis of the prime words in the lexical decision task showed that the novel words learned from the multiple episodic discourses elicited a smaller P200 and a larger N400 compared to those learned from the single episodic discourses. Previous studies have shown that the N400s elicited by novel words are more negative-going with the increase of associated information (Rabovsky et al., 2012a, 2012b). Moreover, the words appearing in many different contexts also elicited a larger early N400 than words appearing in few contexts (Vergara-Martínez et al., 2017). Some other studies have suggested that the accessing of lexical semantics may start early as within the first 200 ms of word processing (e.g. Dambacher, Rolfs, Göllner, Kliegl, & Jacobs, 2009; Hauk, Davis, Ford, Pulvermüller, & Marslen-Wilson, 2006; Kiefer & Pulvermüller, 2012; Pulvermüller et al., 2009; Segalowitz & Zheng, 2009). And the effects during this period were susceptible to the semantic properties, such as the number of semantic features (Amsel, 2011) and semantic associations (Müller et al., 2010). The results from Experiment 1 and Experiment 2 indicated that, compared to the words learned from single episode, the words learned from multiple episodes could build rich associations with thematically related words from both learned and unlearned episodes, as well as with conceptual features. This contributes to the novel words learned from variable episodes with rich semantic information elicited a smaller P200 and a larger N400. Overall, the converging evidence suggests that the cumulative impact of exposures in multiple episodic contexts enables the novel words to integrate into both the thematic and taxonomic system in the semantic network and form a deeper semantic representation (Horst & Samuelson, 2008; McMurray et al., 2012; Yu & Smith, 2007).

Different learning mechanisms for different semantic relations

The difference in the impact of episodic variety on taxonomic and thematic relations may provide us some insight into the learning mechanisms of different semantic relations of novel words. For taxonomic relations, no matter what the learning contents provided, such as feature-related information (Chen et al., 2014; Ding et al., 2017) or episodic information (e.g. Experiment 2), the novel words could rapidly establish taxonomic relations with the preexisting words overlapping in semantic features (Borovsky et al., 2010, 2012; Mestres-Missé et al., 2007). This might be attributed to the concepts used in the current study which were known concrete concepts, typically represented by distributed features (Tyler & Moss, 2001) and organised into taxonomic categories. Meanwhile, during the acquisition of a concept, people learned not only its connotative meaning but also the category which it belongs to (Tyler & Moss, 2001). Thus, when the meaning of novel words was successfully inferred, the relevant category, such as superordinate and basic level concepts, may be immediately identified, leading to the rapid initial semantic integration into the hierarchical taxonomic system.

Borovsky et al. (2010) investigated the impact of contextual constraint on the integration of novel words into semantic memory. The procedure was the same as the current study. As the context "*Tina lined up where she thought the nail should go. When she was satisfied, she asked Bruce to hand her the* VORN" showed, the novel words (e.g. *VORN*, corresponding concept: *HAMMER*) ended the two-sentence contexts which described an event. They found that the semantically related words (e.g. *SCREWDRIVER*) elicited smaller N400s than the unrelated words when preceded by the novel words learned in the highly constraining sentences. The semantic relation investigated in this study was the taxonomic relation, as seen from the given examples. The results demonstrate that the establishment of taxonomic relation is immune to the information type provided by the learning discourse.

By contrast, the types of learning content showed a different pattern for the establishment of thematic relations. Our previous studies have shown that the novel words learned from contexts describing semantic features only showed an N400 priming effect for the taxonomically related words, but not for the thematically related words, indicating the establishment of taxonomic relations, instead of thematic relations (Ding et al., 2017); The novel words inferred from descriptive episodes could build thematic relations, as reflected by the reduced N400s for the thematically related words compared to that for the unrelated words (Zhang et al., 2017). These findings suggest that the semantic integration of the learned novel words into the thematic system is sensitive to the information types of learning contexts. Thematic relations are based on the concepts which externally relate to each other and play complementary relations within scenarios or events (Lin & Murphy, 2001), it is conceivable that they are closely linked to one's knowledge and personal experience with objects and events (Lin & Murphy, 2001; McRae, Spivey-Knowlton, & Tanenhaus, 1998). In this sense, the thematic relation is shaped by individual experience with concepts in specific events or scenarios but not perceptual features. Thus, the acquisition of thematic relation is highly dependent on information type which could induce the learners to pay more attention to the external relations of the concepts.

The contribution of episodic memory to the integration of novel words into semantic memory

The findings that the novel words learned from episodic contexts could be integrated into both taxonomic and thematic systems may highlight the contribution of episodic memory to the semantic integration of novel words into semantic memory. On the one hand, during the learning phase, when the learners inferred the meaning of novel words from the episodic contexts that were closely linked with the personal experiences, the corresponding episodes or relevant information might be retrieved from episodic memory to enable the successful inference of the novel words' meaning. On the other hand, the episodic memory is very essential at the initial stage of semantic learning since it enables the encoding of the discrete episodes of experiences, such as the first episode of seeing the novel object or the first experience of hearing its name. Then, with the increasing experiences of the novel words, a shift towards more abstract memory representation, semantic memory, occurs. After the learning phase, the describing episodes or events form the initial episodic memory of novel words, and the close link between the learning episodes and the previous experiences enables the learned novel words to be rapidly associated with the activated episodic knowledge stored in the thematic system. In addition, not only the meaning of the novel words, but also the features of the novel words could be inferred from episodic contexts. For example, in the episodic context "Tonight the electricity was cut off, Xiaoming lit up a *Juhui* to do his homework", the features of "*Juhui*", for example, it can be used for lighting or it produces flame, could be perceived from the describing episode. The feature-related information contributed to the integration of novel words into the taxonomic system. It has been proposed that episodic memory system is likely to be utilised when we retrieve the experiences of objects (Moscovitch, Nadel, Winocur, Gilboa, & Rosenbaum, 2006; Squire & Knowlton, 1995), which may facilitate the semantic integration into semantic memory system, leading to a stable semantic representation of the novel words. Even though we might not remember exactly where or when we encountered the novel words with time elapsing, the efficient shift from episodic memory to semantic memory still enables us to know the relevant knowledge of these concepts. Therefore, the episodic memory plays an essential role in both the learning phase and semantic integration into semantic memory of novel words.

In conclusion, this study investigated the impact of the variety of episodic contexts on the integration of novel words into thematic and taxonomic semantic systems. We found that the novel words could prime the corresponding concepts, the thematically related words from the learned episodes, and the taxonomically related words in both learning conditions. But only the novel words learned from the multiple episodic condition could prime the thematically related words in unlearned episodes and the feature-related words. These results suggested that variable episodes facilitate the newly learned words to build rich semantic associations with preexisting words and form a deeper semantic representation at conceptual feature level.

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Disclosure statement

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