Research

Rapid acquisition through fast mapping: stable memory over time and role of prior knowledge

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In recent years, there have been intensive debates on whether healthy adults acquire new word knowledge through fast mapping (FM) by a different mechanism from explicit encoding (EE). In this study, we focused on this issue and investigated to what extent retention interval, prior knowledge (PK), and lure type modulated memory after FM and EE. Healthy young participants were asked to learn novel word-picture associations through both FM and EE. Half of the pictures were from familiar categories (i.e., high PK) and the other half were from unfamiliar categories (i.e., low PK). After 10 min and 1 wk, the participants were tested by forced-choice (FC) tasks, with lures from different categories (Experiment 1) or from the same categories of the target pictures (Experiment 2). Pseudowords were used to denote names of the novel pictures and baseline performance was controlled for each task. The results showed that in both Experiments 1 and 2, memory performance remained stable after FM, while it declined after EE from 10 min to 1 wk. Moreover, the effect of PK appeared at 10 min after FM while at 1 wk after EE in Experiment 2. PK enhanced memory of word-picture associations when the lures were from the same categories (Experiment 2), rather than from different categories (Experiment 1). These results were largely confirmed in Experiment 3 when encoding condition was manipulated as a between-subjects factor, while lure type as a within-subjects factor. The findings suggest that different from EE, FM facilitates rapid acquisition and consolidation of word-picture knowledge, and highlight that PK plays an important role in this process by enhancing access to detailed information.

[Supplemental material is available for this article.]

Fast mapping (FM) is a word-learning process through which participants acquire association between an item and its name (Brown 1957; Carey and Bartlett 1978; Coutanche and Thompson-Schill 2015). Different from explicit encoding (EE) tasks in which participants are asked to remember a novel word-picture association directly, in a typical FM, participants are exposed to a novel picture of a concept (e.g., numbat) alongside a familiar item (e.g., zebra) and asked a perceptual detection question related to the novel picture. Subsequently, the participants are tested using either a word-picture forced-choice (FC) task (e.g., Sharon et al. 2011; Coutanche and Thompson-Schill 2014; Greve et al. 2014; Smith et al. 2014; Warren and Duff 2014; Himmer et al. 2017), or an implicit test (e.g., Coutanche and Thompson-Schill 2014; Coutanche and Koch 2017). A remarkable finding is that amnesic patients following hippocampal damage have relatively normal memory performance on word-picture associations after FM, although their performance is impaired after EE (Sharon et al. 2011). The results suggest a possible mechanism of rapid acquisition that is independent of the hippocampus, and provide a potential way for amnesic patients to quickly acquire episodic memory.

However, the studies on FM have obtained inconsistent results in recent years, and there have been intense debates on whether healthy adults and amnesic patients acquire new word knowledge through FM by a different mechanism from EE. An influential review on FM (Cooper et al. 2019a) concludes that the evidence for FM is weak and the underlying processes might not be distinct from episodic encoding mechanisms in adults. On the other hand, a consensus in this field is that the FM learning process is complex, and is influenced by various factors. With the mixed results on FM, continued and systematic investigation of boundary conditions is urgent to clarify the FM mechanisms (e.g., Cooper et al. 2019a, 2019c; Coutanche 2019; Gilboa 2019; Mak 2019; Warren and Duff 2019; Zaiser et al. 2019).

On a cognitive perspective, the critical question is whether FM has distinctive features from EE to help participants reach rapid acquisition (Coutanche 2019). The findings on lexical integration (Coutanche and Thompson-Schill 2014), interference susceptibility (Merhav et al. 2014), and the impact of sleep (Himmer et al. 2017) support the view. For example, through the implicit test, investigators found a significant effect of lexical competition, as FM slowed the reaction times (RTs) to words that were orthographically similar to the newly learned concept (Coutanche and Thompson-Schill 2014). With the explicit FC task, Himmer et al. (2017) found that memory after EE decayed slowly following sleep (vs. wakefulness), whereas memory after FM did not benefit from sleep and remained stable regardless of sleep or wakefulness conditions. These results suggest that FM facilitates fast acquisition of new information. However, other studies have failed to find significant dissociations in explicit memory after FM and EE in healthy adults, except that memory accuracy after FM tends to be lower than that after EE (e.g., Sharon et al. 2011; Greve et al. 2014; Smith et al. 2014).

To clarify the mechanism of fast acquisition after FM, one useful manipulated factor is retention interval. Rapid acquisition refers to the processes that new information could be quickly encoded, consolidated, and integrated into memory networks (Coutanche and Thompson-Schill 2015). If FM learning is

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dependent on rapid acquisition of information into neocortical networks, memory representations through FM should be established quickly right after the encoding, and therefore show little change over time (Gilboa 2019). In contrast, memory performance under more traditional intentional encoding declines significantly (Ebbinghaus 1885/1964) due to system consolidation (Frankland and Bontempi 2005; Dudai et al. 2015). However, previous studies have consistently shown that memory after FM and EE declines over time with similar rates under various conditions (e.g., Sharon et al. 2011; Coutanche and Thompson-Schill 2014; Greve et al. 2014; Smith et al. 2014; Merhav et al. 2015). In these studies, younger and older adults were enrolled, different retention intervals were used, and pictures were learned multiple times. It seems that similar forgetting pattern after FM and EE is not influenced by the factors such as aging, delay interval, and repetition time.

Nevertheless, other factors should be taken into considerations before a conclusion is made. First, the familiarity of novel words is not well controlled in most previous studies (Cooper et al. 2019c). True names are usually used to describe novel objects (but see Coutanche and Thompson-Schill 2014; Coutanche and Koch 2017). As novel objects are from the same category as the paired ones, the true names may share similar phonological or orthographical features with others, which interferes with novel word-object associations when the FC task is used (Cooper et al. 2019c). Previous studies have suggested that stronger interference leads to weaker memory after FM especially 24 h later, but does not significantly influence memory after EE (Merhav et al. 2014; Gilboa 2019). Second, the familiarity of objects could also be controlled (Coutanche and Thompson-Schill 2014; Merhav et al. 2015; Himmer et al. 2017). If participants are already somewhat familiar with a supposedly novel object, they are likely to focus their attention on that object to answer the FM question without comparing it with the familiar FM referent object. These two possibilities could both lead to comparable levels of forgetting after FM and EE. Note that the familiarity of objects and their names could both increase the baseline performance for word-picture associations (Smith et al. 2014). Therefore, it may be necessary to include pseudowords instead of true names (Cooper et al. 2019c; Warren and Duff 2019) and to match object familiarity and baseline performance in order to find dissociations between FM and EE.

One mechanism believed to be responsible for rapid acquisition is the concurrent presentation of a familiar object during FM (Sharon et al. 2011; Coutanche and Thompson-Schill 2014, 2015; Mak 2019; Zaiser et al. 2019; but see Cooper et al. 2019b). Through the FM perceptual task, the familiar knowledge of sports facilitated subsequent associations between sport words and unfamiliar faces (Bruett et al. 2018). In contrast, when the familiar items were removed during encoding, immediate lexical competition was absent (Coutanche and Thompson-Schill 2014). The results support the updated complementary learning systems (CLS) theory, which holds that neocortical learning can be rapid for information that is consistent with existing structure (McClelland 2013; Kumaran et al. 2016). On the other hand, previous studies have shown that prior knowledge (PK) enhances subsequent memory after EE as well, in which conceptual/category familiarity is used to manipulate participants' level of PK (e.g., DeWitt et al. 2012; van Kesteren et al. 2014; Chen et al. 2018). Thus, PK facilitates explicit memory after both FM and EE, and it is unclear whether PK influences them differently. This issue is important because it helps elucidate whether memory after FM has different characteristics from that after EE.

Studies have suggested that one distinct feature of memory after EE is that the effect of PK is more obvious at longer intervals rather than immediately after learning (van Kesteren et al. 2010, 2013; Durrant et al. 2015; Hennies et al. 2016; Bonasia et al. 2018). For example, Bonasia et al. (2018) found that congruence with PK enhanced memory for events after 1 wk, but not immediately after encoding. On the contrary, if FM learning facilitates rapid acquisition and cortical integration, the memory should be consolidated quickly. Thus, enhancement due to PK should appear right after FM learning. In this study, we manipulated both the participants' PK and retention interval to clarify the dissociation of memory after FM and EE.

A related issue is whether task manipulation or lure type modulates the effect of PK after FM and EE. FC tasks are usually used to examine memory performance after FM and EE, with pictures from different categories serving as lures (e.g., Sharon et al. 2011; Greve et al. 2014; Smith et al. 2014; Merhav et al. 2015). In this between-category FC task, participants could choose a picture to match the target word based on the related categorical information, whereas in a within-category FC task (Coutanche and Thompson-Schill 2014; Himmer et al. 2017), they have to decide based on their perception of differences among pictures from the same category. Thus, a more detailed processing of the pictures is required for the latter task. Studies have suggested that PK enhances memory performance in terms of details (Long and Prat 2002; Brandt et al. 2005; DeWitt et al. 2012; Chen et al. 2018). For example, DeWitt et al. (2012) found that levels of PK positively predicted memory of contextual details after participants studied a number of images from seven categories. This is because PK provides a semantic context which increases the availability of details that can support later retrieval. Thus, it is possible that the effect of PK does not work after FM unless details are necessary during testing (e.g., a within-category FC task). However, there is little empirical evidence to support this hypothesis.

In sum, we focused on the central issue of rapid acquisition through FM learning and investigated how retention interval, PK, and lure type modulated memory after FM and EE. In experiments 1 and 2, participants were asked to learn associations between novel pictures and names through FM and EE. Half of the pictures were from familiar categories (i.e., high PK) and the other half were from unfamiliar categories (i.e., low PK). Then they performed a word-picture FC task. We defined PK as knowledge of familiar categories (e.g., DeWitt et al. 2012; Hennies et al. 2016; Chen et al. 2018) and the effect of PK referred to the memory difference between familiar and unfamiliar categories. Differing from typical FM procedure, a category name of the target picture was presented at the beginning of the encoding session to activate PK (Alba and Hasher 1983; Packard et al. 2017). To assess long-term retention, memory was tested after both 10-min and 1-wk intervals in younger adults. To test whether lure type influenced the effect of PK on FM, participants performed a between-category FC task (Experiment 1) as most studies have used, or a within-category FC task (Experiment 2) in which lures were from the same category as the targets. A word-category FC task (e.g., Sharon et al. 2011; Smith et al. 2014) was also used as an index of explicit memory in Experiments 1 and 2.

In Experiment 3, the influence of encoding order was considered. In many FM studies, the FM condition is performed before the EE condition to ensure that participants incidentally encode the word-picture associations (e.g., Sharon et al. 2011; Smith et al. 2014; Warren and Duff 2014; Warren et al. 2016). But at the same time, the fixed order would introduce different levels of general pro/retroactive interference, practice/fatigue or inference to FM and EE (Cooper et al. 2019a, 2019b). To diminish these confounds (Greve et al. 2014; Cooper et al. 2019b, 2019c), separate groups of participants performed the FM and EE tasks in Experiment 3. In addition, to confirm that the lure choice was important for the effect of PK, we included lure type as a within-subjects factor.

The familiarity of the novel word-picture associations was well controlled in this study. To minimize the possibility of semantic transparency of Chinese words (Chen et al. 2014) and interference (Cooper et al. 2019c), pseudowords were created and used as the names for the unfamiliar pictures. To obtain participants' baseline performance, additional groups of participants were enrolled to perform the FC tasks without the encoding phase. As memory performance was higher for the EE than FM condition, to control for the initial memory performance (Cooper et al. 2019a), the forgetting rate was calculated as the following: (accuracy at 10 min—accuracy at 1 wk)/(accuracy at 10 min). The rest of the methods we used in this study—including the selection of target and lure pictures, encoding and test procedures, and trial exclusions—followed the rules established by FM literatures (e.g., Sharon et al. 2011).

If memory after FM is rapidly acquired and integrated with preexisting knowledge, memory for the word-picture associations after FM should remain relatively stable from 10 min to 1 wk, and the effect of PK should appear right after learning. In contrast, memory after EE should decline quickly and the effect of PK should appear at 1 wk. On the other hand, as PK facilitates memory of new details of word knowledge after both FM and EE, the effect of PK should manifest in the within-category word-picture FC task, rather than in the between-category FC task.

Results

Experiment 1

For the FM encoding phase (Fig. 1), the participants in the task group performed better and faster in the high PK than the low PK condition (Accuracy: $t_{(25)} = 4.15$, $P < 0.001$; RTs: $t_{(25)} = -2.61$, $P = 0.02$), which suggests that PK helps answer the presented perceptual questions.

For the control group, the accuracies were at chance level (0.33) in the word-picture FC task (P's > 0.10, Fig. 2A), but higher than chance level (0.25) in the word-category FC task (P's < 0.05, Fig. 2B). More importantly, the participants had comparable accuracy for the high and low PK conditions in the word-picture FC task ($t_{(19)} = -1.80$, $P = 0.09$) and word-category FC task ($t_{(19)} = 0.10$, $P = 0.92$), suggesting that the baseline FC performance is optimally matched regarding the level of PK.

Repeated measures ANOVAs were performed for each FC task, with encoding condition (FM, EE), PK (high, low) and retention interval (10 min, 1 wk) as within-subjects factors. For the word-picture FC task, the participants in the task group performed better than those in the control group in all conditions (P's < 0.001, Fig. 2A). It suggests that after FM and EE, participants could acquire word-picture associations and retain them for 1 wk. As expected, the memory performance was worse in the FM than the EE condition ($F_{(1,25)} = 73.48$, $P < 0.001$, $\eta_p^2 = 0.75$). Importantly, there was a significant interaction between encoding condition and retention interval ($F_{(1,25)} = 29.30$, $P < 0.001$, $\eta_p^2 = 0.54$). This was because the accuracy decreased from 10 min to 1 wk after EE ($P < 0.001$), but remained stable over time after FM ($P = 0.09$) (Fig. 2A). There was no significant effect of PK ($F_{(1,25)} = 0.08$, $P = 0.78$, $\eta_p^2 = 0.003$) or PK-related interactions (F's < 2, P's > 0.10).

As the memory performance was higher for the EE than FM condition, to control for the initial memory performance, the forgetting rate was calculated as the following: (accuracy at 10 min—accuracy at 1 wk)/(accuracy at 10 min), and a repeated-measures ANOVA was performed, with encoding condition (FM, EE) and PK (high, low) as within-subject factors. The forgetting rate was greater than zero for the EE condition ($P < 0.001$) but lower than zero for the FM condition ($P = 0.04$). In addition, there was a significant effect of encoding condition ($F_{(1,25)} = 20.43$, $P < 0.001$, $\eta_p^2 = 0.45$), as the memory after EE was forgotten more quickly than that after FM (Fig. 2C). No significant effect of PK or the interaction between encoding condition and PK (F's < 2, P's > 0.10) was found.

For the word-category FC task, the participants in the task group performed better than those in the control group in all conditions (P's < 0.001, Fig. 2B). The memory performance was worse in the FM than the EE condition ($F_{(1,25)} = 31.94$, $P < 0.001$, $\eta_p^2 = 0.56$). Similar to the results of the word-picture FC task, a significant interaction was found between the encoding condition and retention interval ($F_{(1,25)} = 28.07$, $P < 0.001$, $\eta_p^2 = 0.53$), indicating that word-category associations remained stable after FM ($P = 0.82$) but declined over time after EE ($P < 0.001$). There was also a significant PK effect (high PK: 0.61 ± 0.13, low PK: 0.58 ± 0.14; $F_{(1,25)} = 4.86$, $P = 0.04$, $\eta_p^2 = 0.16$), as high PK enhanced memory performance in both the FM and EE conditions. By controlling the initial memory performance, the forgetting rate was significantly quicker for EE than for FM ($F_{(1,25)} = 14.58$, $P = 0.001$, $\eta_p^2 = 0.37$), with no significant effect of PK and their interaction (F's < 1, P's > 0.10) (Fig. 2D). In addition, the forgetting rates were comparable to zero after FM ($P > 0.10$) but significantly higher than zero after EE ($P < 0.001$).

In sum, the main results of Experiment 1 were that the memory performance was forgotten more slowly and remained stable after FM but was forgotten quickly after EE. The dissociation of the forgetting pattern after FM and EE was also observed after the initial memory performance was controlled. In Experiment 2, we applied the within-category word-picture FC task to explore the effects of retention interval and PK on memory after FM and EE.

Experiment 2

For the FM encoding phase (Fig. 1), the participants performed better and faster for the high PK than the low PK condition (Accuracy: $t_{(22)} = 3.30$, $P = 0.003$; RTs: $t_{(22)} = -4.77$, $P < 0.001$), which was consistent with the results of Experiment 1.

For the control group, in the word-picture FC task, the accuracy was comparable to chance level (0.33) for the high PK condition ($t_{(19)} = 0.65$, $P = 0.53$), but significantly higher for the low PK condition ($t_{(19)} = 3.40$, $P = 0.003$). The accuracies in the two conditions were significantly different ($t_{(19)} = 3.39$, $P = 0.003$, Fig. 3A). However, the baseline difference between the two PK conditions did not influence the results of memory performance, because similar results were obtained when the two conditions were matched in the baseline by excluding trials beyond two standard deviations in the low PK condition (Supplemental

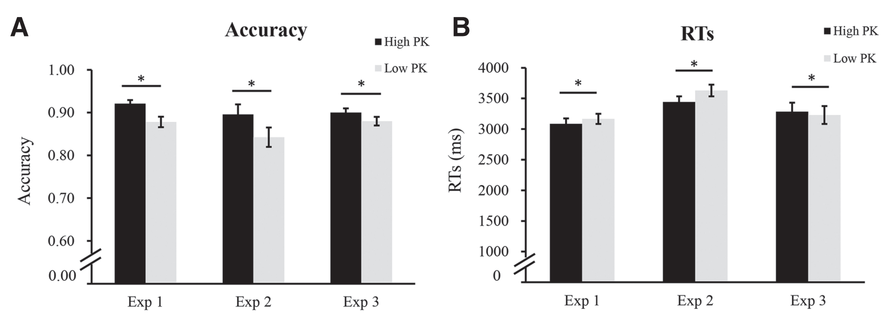

Figure 1. Results of the encoding phase for the FM condition. The participants performed the perceptual task with higher accuracy for the high PK than the low PK condition in Experiments 1–3 (*A*). They responded more quickly for the high PK than the low PK condition in Experiments 1–2 (*B*). The error bars represent the standard errors of the means. (*) $P < 0.05$.

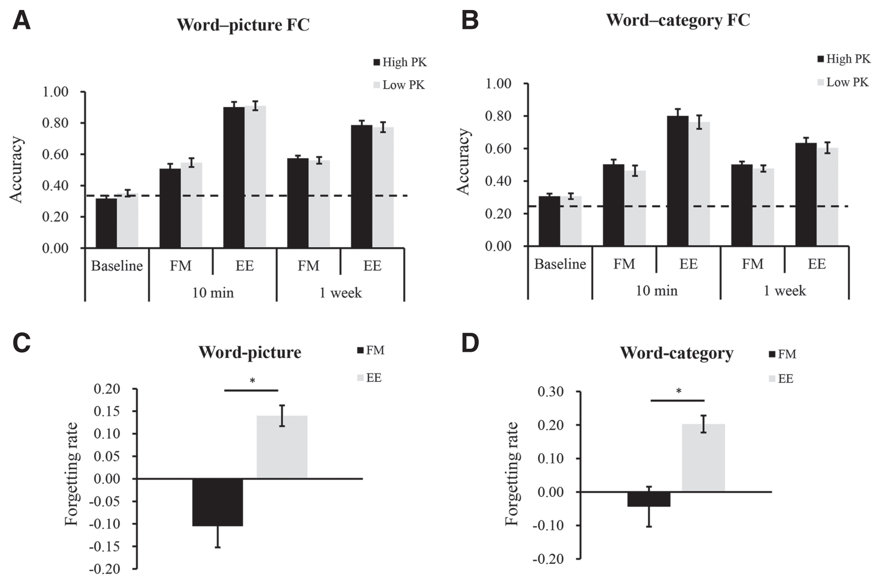

Figure 2. Results of Experiment 1. For both the word-picture FC (*A*) and word-category FC (*B*) tasks, memory performance remained stable after the FM, while it declined after the EE. This pattern was also significant when the initial memory performance was controlled (*C,D*). The dashed lines represent chance level for each task. The error bars represent standard errors of the means. (*) $P < 0.05$.

Material, Fig. S1). In the word-category FC task, the accuracies were at chance level (0.25; P's > 0.30), and the participants had comparable accuracy for different levels of PK ($t_{(19)} = 0.09$, $P = 0.93$, Fig. 3B).

For the word-picture FC task, the participants performed better in the task group than in the control group for all the conditions (P's < 0.05, Fig. 3A), except for the low PK condition after FM at 10 min ($t_{(41)} = -0.03$, $P = 0.98$). This was because the memory was at chance level (0.33) in the low PK condition after FM at 10 min (mean: 0.38 ± 0.17; $t_{(22)} = 1.51$, $P = 0.15$), which suggested that PK is important for memory through FM. The memory performance was worse in the FM than in the EE condition ($F_{(1,22)} = 48.56$, $P < 0.001$, $\eta_p^2 = 0.69$). As in Experiment 1, there was a significant interaction between encoding condition and retention interval ($F_{(1,22)} = 16.13$, $P = 0.001$, $\eta_p^2 = 0.42$), as the accuracy decreased from 10 min to 1 wk after EE ($P < 0.001$), but remained stable after FM ($P = 0.12$). Different from Experiment 1, the effect of PK was significant, as memory performance was higher for the high PK than low PK condition (0.67 ± 0.12 vs. 0.63 ± 0.11; $F_{(1,22)} = 6.65$, $P = 0.02$, $\eta_p^2 = 0.23$; Fig. 3A). Specifically, there was a significant three-way interaction of PK × encoding condition × retention interval ($F_{(1,22)} = 4.44$, $P = 0.05$, $\eta_p^2 = 0.17$). Further analysis indicated that the effect of PK was significant at 10 min after FM ($P = 0.05$), while significant at 1 wk after EE ($P = 0.04$). These results suggest that when the lures are from the same categories, the PK enhances memory performance, but the effect is modulated by the encoding condition and retention interval.

When the initial memory performance was controlled, memory forgetting was also significantly quicker after EE than that after FM ($F_{(1,21)} = 13.44$, $P = 0.001$, $\eta_p^2 = 0.39$) (Fig. 3C), with no significant effect of PK ($F_{(1,21)} = 0.76$, $P = 0.39$, $\eta_p^2 = 0.04$) or interaction between PK and encoding condition ($F_{(1,21)} = 2.06$, $P = 0.17$, $\eta_p^2 = 0.09$). In addition, the forgetting rate was significantly lower than zero ($P = 0.03$) after FM but higher than zero after EE ($P < 0.001$).

For the word-category FC task, the participants in the task group performed better than those in the control group in all conditions (P's < 0.05, Fig. 3B). Similar to the results in Experiment 1, the memory performance was worse for the FM than the EE condition ($F_{(1,22)} = 19.85$, $P < 0.001$, $\eta_p^2 = 0.48$), and the interaction of encoding condition and retention interval was significant ($F_{(1,22)} = 10.88$, $P = 0.003$, $\eta_p^2 = 0.33$). The accuracy declined from 10 min to 1 wk after EE ($P = 0.003$), but remained stable after FM ($P = 0.20$). In addition, PK enhanced the memory for word-category associations ($F_{(1,22)} = 12.42$, $P = 0.002$, $\eta_p^2 = 0.36$). There was a marginally significant three-way interaction of PK × encoding condition × retention interval ($F_{(1,22)} = 3.95$, $P = 0.06$, $\eta_p^2 = 0.15$), and further analysis showed that the effect of PK occurred at 10 min and 1 wk after FM (P's < 0.05), while at 1 wk after EE ($P = 0.06$).

For the forgetting rate, the memory after EE was forgotten more quickly than that after FM ($F_{(1,20)} = 3.64$, $P = 0.07$, $\eta_p^2 = 0.16$) (Fig. 3D). There was no significant effect of PK ($F_{(1,20)}$

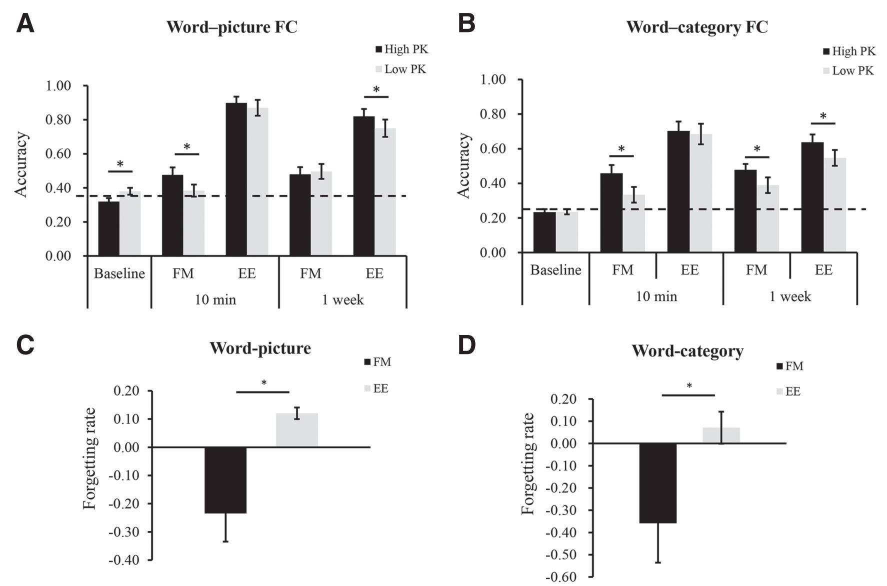

Figure 3. Results of Experiment 2. For both the word-picture FC (*A*) and word-category FC (*B*) tasks, memory performance remained stable after the FM, while it declined after the EE. This pattern was also significant when the initial memory performance was controlled (*C,D*). For the word-picture FC task, the PK enhanced the memory performance after FM at 10 min, but at 1 wk after EE (*A*). For the word-category FC task, the PK enhanced the word-category associations after FM from 10 min to 1 wk and after EE at 1 wk (*B*). The dashed lines represent chance level. The error bars represent standard errors of the means. (*) $P < 0.05$.

$=0.06$, $P=0.80$, $\eta_p^2 = 0.003$) or interaction between PK and encoding condition ($F_{(1,20)}=3.23$, $P=0.09$, $\eta_p^2 = 0.14$). In addition, the forgetting rate was lower than zero after FM ($P=0.04$) but comparable to zero after EE ($P=0.34$).

In sum, the main results of Experiment 2 were that the memory performance was forgotten more slowly and remained stable after FM but was forgotten quickly after EE. When the lures were from the same categories, there was a PK-enhanced memory performance in the word-picture tasks, and the effect was modulated by encoding condition and retention interval. The results suggest that PK increases the availability of details that can support subsequent within-category discrimination. In Experiment 3, to diminish the influence of task order and individual variability, the encoding task (FM, EE) was manipulated as a between-subjects factor, and the lure type (between-category, within-category FC task) was included as a within-subjects factor. Only the word-picture FC task was performed during test.

Experiment 3

For the FM encoding phase (Fig. 1), the participants performed better but slower for the high PK than the low PK condition (Accuracy: $t_{(22)}=2.26$, $P=0.03$; RTs: $t_{(22)}=2.33$, $P=0.03$). The encoding accuracies and RTs were comparable to those in Experiments 1 and 2 (P's>0.10).

For the control group, the baseline accuracies were comparable to chance level (0.33) (P's>0.10), and they were comparable for the high and low PK conditions in the between- and within-category FC tasks (P's>0.10, Fig. 4A,B).

For the word-picture FC task, a repeated-measures ANOVA was performed with PK (high, low), lure type (between-category, within-category), retention interval (10 min, 1 wk) as within-subjects factors and encoding condition (FM, EE) as a between-subjects factor. The memory performance was worse in the FM than in the EE condition ($F_{(1,47)}=45.31$, $P<0.001$, $\eta_p^2 = 0.49$), and the participants performed better in the between-category than in the within-category FC task ($F_{(1,47)}=5.29$, $P=0.03$, $\eta_p^2 = 0.10$). As in Experiment 1 and 2, there was a significant interaction between encoding condition and retention interval ($F_{(1,47)}=5.25$, $P=0.03$, $\eta_p^2 = 0.10$), showing that the accuracy decreased from 10 min to 1 wk after the EE ($P<0.001$), but remained relative stable after FM ($P=0.07$). Note that the interaction was modulated by lure type, which was reflected as a significant three-way interaction of encoding condition × retention interval × lure type ($F_{(1,47)}=4.47$, $P=0.04$, $\eta_p^2 = 0.09$). Further analysis indicated that the accuracy decreased from 10 min to 1 wk after EE ($P<0.001$) but remained stable after FM ($P=0.70$) in the between-category FC task, while the accuracy decreased from 10 min to 1 wk after both FM and EE (P's<0.01) in the within-category FC task.

The effect of PK was significant, as there was better memory performance for the high PK than low PK condition (0.66 ± 0.21 vs. 0.63 ± 0.22; $F_{(1,47)}=5.33$, $P=0.03$, $\eta_p^2 = 0.10$). Specifically, there was a significant four-way interaction of PK × encoding condition × retention interval × lure type ($F_{(1,47)}=4.25$, $P=0.05$, $\eta_p^2 = 0.08$). Further analysis indicated that similar as that in Experiment 2, the effect of PK was marginally significant at 10 min after FM ($P=0.08$), while significant at 1 wk after EE ($P=0.05$) in the within-category FC task. Same as that in Experiment 1, no PK effect was found in the between-category FC task.

For the forgetting rate, it was higher than zero for each of the EE conditions (P's<0.05) and the FM condition in the within-category FC task ($P=0.06$), but it was comparable with zero for the FM condition in the between-category FC task ($P=0.26$). Similar to the results in Experiments 1 and 2, the memory after EE was forgotten more quickly than that after FM ($F_{(1,47)}=3.69$, $P=0.06$, $\eta_p^2 = 0.07$). In addition, there was a significant interaction of encoding condition and lure type ($F_{(1,47)}=4.72$, $P=0.04$, $\eta_p^2 = 0.09$, Fig. 4C,D), indicating that memory after EE was forgotten more quickly than that after FM in the between-category FC task ($P<0.005$), but declined at a similar rate in the within-category FC task ($P=0.86$).

In sum, the results of Experiment 3 confirmed that memory performance was forgotten more slowly after FM than EE, and further found that lure type modulated the forgetting rate after FM and EE. The encoding order did not influence the result patterns. Same as that in Experiments 1 and 2, the PK effect occurred only in the within-category FC task, and was modulated by encoding condition and retention interval.

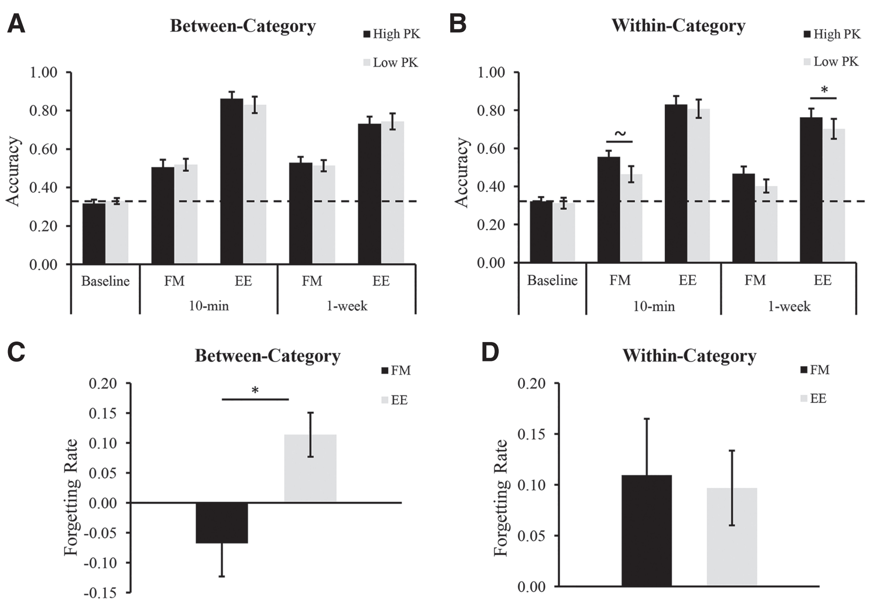

Figure 4. Results of Experiment 3. When the between-category FC task was used (*A*), memory performance remained stable after the FM, while it declined after the EE. When the within-category FC task was used (*B*), memory performance declined after both FM and EE. The patterns were also shown when the initial memory performance was controlled (*C*,*D*). The PK enhanced the memory performance after FM at 10 min, but at 1 wk after EE when the within-category FC task was used (*B*). The dashed lines represent chance level. The error bars represent standard errors of the means. (*) $P<0.05$, and (~) $P<0.10$.

Discussion

The present study explored to what extent retention interval, PK, and lure type modulated memory after FM and EE. There were three main findings. First, FM and EE were dissociated in memory forgetting. Memory performance decayed significantly after EE, whereas relatively stable after FM from 10 min to 1 wk. Second, encoding condition and retention interval interacted to influence the effect of PK. The effect of PK appeared 10 min after FM but appeared 1 wk after EE. Third, PK enhanced memory of word-picture associations when the lures were from the same categories (in Experiment

2) rather than from different categories (in Experiment 1). These results were largely replicated in Experiment 3 when the encoding condition was manipulated as a between-subjects factor, while the lure type as a within-subjects factor. In addition, lure type modulated the forgetting rate after FM and EE in Experiment 3. That is, memory performance remained stable from 10 min to 1 wk after FM (as in Experiment 1), though when within-category lures were used, it declined at similar rates to the memory after EE (different from Experiment 2). These findings support the updated CLS theory (McClelland 2013; Kumaran et al. 2016) in that memory after FM could be quickly acquired and retained over time through integration with PK, which may differ from that after EE. In addition, PK facilitates rapid acquisition and consolidation of related knowledge after FM by increasing the discrimination of the target picture from lure pictures.

Slower forgetting of word-picture associations after FM

Whether FM learning enables rapid integration of novel associations into existing networks is a critical issue in the field of FM. Himmer et al. (2017) found that the memory performance through FM does not benefit from sleep and remain stable follows learning (Himmer et al. 2017), which indicates that FM allows rapid neocortical integration during encoding. In this study, by enrolling healthy young adults and including a longer interval (i.e., 1 wk), we further found a clear dissociation between FM and EE in regard to memory forgetting. In both Experiments 1 and 2, memory performance after FM did not change significantly and remained stable through the 1-wk test, while it declined over time after EE. When the initial memory level was controlled, the results of forgetting rate revealed the same pattern. Taken together, these results provided convincing evidence that FM facilitates integrating information rapidly into memory networks (Sharon et al. 2011; Coutanche and Thompson-Schill 2014, 2015; Himmer et al. 2017; Coutanche 2019).

To our knowledge, this is the first study to find significant slower forgetting after FM than after EE in younger adults. Compared to other studies, the familiarity of novel word-picture associations was well controlled. Instead of using true names of the novel pictures, pseudowords were created and selected. In addition, baseline FC performance was at chance level and familiar pictures were excluded for further analysis. As true names contain clues about object category, and share orthographical and phonological features with other names, using them may induce higher baseline rates and greater interferences during encoding and retrieval (Cooper et al. 2019c; Gilboa 2019; Warren and Duff 2019). In addition, the participants may adopt a strategy similar to EE to perform the perceptual task if they are familiar with a specific novel object. The procedures we adopted ensured that the participants learned word-picture associations by FM with minimal interference and different from EE.

Previous studies have suggested that the FM learning is more influenced by interference than EE especially at longer intervals (Merhav et al. 2014; Gilboa 2019). In a study of Merhav et al. (2014), memory performance after FM was impaired for the interfered pictures at 24 h, but remained relatively stable after EE. Thus, it is possible when the true names were used in previous studies, memory performance after FM decayed from 10 min to 1 wk with similar rates as that after EE because of more influence of interference on FM. Note that in the study of Coutanche and Thompson-Schill (2014), pseudowords were also used, but they found a nonsignificant interaction between retention interval and encoding condition when participants were tested immediately and 1 d later. The longer delay seems a factor in reconciling the inconsistent findings. At shorter retention intervals (e.g., 1 d), the forgetting after EE may not be obvious after participants learned the word-picture associations twice, because repetitive learning has been demonstrated to slow memory forgetting at shorter intervals (e.g., 1 d) for the EE condition (Sadeh et al. 2014; Yang et al. 2016).

In Experiment 3, the dissociation of FM and EE in memory forgetting was confirmed as a significant interaction of encoding condition and retention interval. However, the slower decay after FM (vs. EE) was modulated by lure type. When the between-category lures were used in the word-picture FC task, memory performance remained stable from 10 min to 1 wk after FM (as in Experiment 1), whereas when the within-category lures were used, it declined at similar rates to the memory after EE (different from Experiment 2). We consider that an interference mechanism may explain the different results of Experiment 2 and 3. In Experiment 3, both within-category and between-category conditions were included. Thus, for the FM condition, each participant learned two lots of 48 trials in Experiment 3, whereas in Experiment 2, each participant learned two lots of 24 trials. As FM memory relies on cortical mechanisms for rapid acquisition and consolidation, it is subject to interference without the protection of hippocampal function (McClelland et al. 1995). The higher memory load from greater number of stimuli introduces higher level of interference (Gilboa 2019) and influences memory that relies more on cortical consolidation (Feld et al. 2016; Feld and Born 2017). This phenomenon should be obvious for the within-category condition, because the participants have to distinguish between the target and lures, during which the similarity of detailed perceptual information interacts with higher memory load for a higher level of interference. On the contrary, the hippocampus is involved in EE memory acquisition and consolidation, which effectively prevents catastrophic forgetting (McClelland et al. 1995; McClelland 2013) even when the number of trials increased.

One unexpected finding was that when the forgetting rate was analyzed, the memory after FM was even stronger for 1 wk than 10 min especially in Experiments 1 and 2. This is likely attributed to testing effect (Roediger and Karpicke 2006; Roediger and Butler 2011). In most FM studies, the same material is tested twice, once immediately after learning and the second time 1 d or 1 wk after learning. When the material is retrieved, the testing effect is more obvious at longer retention intervals, presenting as slow forgetting or even no forgetting over time (Roediger and Karpicke 2006; Roediger and Butler 2011). FM seems to benefit more from the testing effect than EE, which is consistent with the assumption that neocortical activation responsible for semantic elaboration is associated with the testing effect (van den Broek et al. 2016).

Rapid representation of PK effect after FM

In addition to the slower forgetting of word-picture associations after FM, the results of Experiment 2 showed that the encoding condition interacted with retention interaction for the effect of PK. For the EE condition, the effect of PK appeared at 1 wk, whereas for the FM condition it appeared at 10 min. This finding was confirmed in Experiment 3, when the task order was treated as a between-subjects factor. The delayed enhancement for the EE condition was consistent with the findings that the effect of PK becomes more obvious at longer intervals (van Kesteren et al. 2010; Durrant et al. 2015; Hennies et al. 2016; Bonasia et al. 2018). For the FM condition, the effect of PK appeared at 10 min for the word-picture and word-category associations. The dissociation of FM and EE in regard to the PK effect suggests that PK facilitates acquisition and consolidation through FM learning, whereas the PK effect requires more time to be consolidated through EE learning, which leads to delayed memory enhancement.

The effect of PK diminished at 1 wk after the participants learned the word-picture associations through FM. We consider a similar testing effect works as the mechanism. The same word-picture associations were tested at two retention intervals in the FC tasks. Prior studies have shown that retrieving previously presented stimuli results in greater retention on a memory test (Roediger and Karpicke 2006; Rowland 2014; Kornell and Vaughn 2016). Thus, it is possible that the testing effect influences memory for the low PK condition to a greater extent via a tagging mechanism (Redondo and Morris 2011; Dunsmoor et al. 2015), making the difference in memory between the two PK conditions smaller at longer intervals.

Effect of prior knowledge in the within-category FC tasks

Another novel finding of the present study was that PK enhanced memory when the lures in the word-picture FC task were from the same categories (Experiment 2), rather than from different categories (Experiment 1). This finding was also confirmed in Experiment 3. Most FM studies typically use between-category FC tasks (e.g., Sharon et al. 2011; Greve et al. 2014; Merhav et al. 2014, 2015; Smith et al. 2014) and have shown that FM encoding facilitates subsequent memory for word knowledge. One mechanism for this is that during FM, the pairing with a familiar picture provides a context for enhancing encoding processing (Sharon et al. 2011; Coutanche and Thompson-Schill 2015; Mak 2019). Our study further demonstrated that only familiar pictures from familiar categories enhanced within-category discrimination after FM. The results suggest that the presentation of familiar pictures with stronger conceptual knowledge in the FM encoding results in rapid acquisition and higher memory performance for the word-picture associations.

The encoding-dependent mechanisms account for a rapid integration of current and existing congruent semantic information (van Kesteren et al. 2010, 2014; Packard et al. 2017). During the within-category FC task, distinguishing between the target and within-category lures requires more detailed perceptual information of the target word-picture associations. It has been demonstrated that PK enhances memory by facilitating the processing of detailed and perceptual information using EE (Long and Prat 2002; DeWitt et al. 2012; Chen et al. 2018). Our study also showed that PK facilitates encoding performance especially in accuracy for both EE and FM conditions. During encoding, PK can free attentional resources and allocate them to elaborately encode feature details associated with PK (Rawson and Overschelde 2008; DeWitt et al. 2012). Then, during retrieval, the information in the PK system can be used to aid memory by retrieving the information and associations made during encoding. All these processes facilitate assimilation of new knowledge into a preexisting knowledge system (van Kesteren et al. 2012; Ghosh and Gilboa 2014). Notably, the memory performance in the word-picture FC task was not influenced by the task order in Experiment 2. During the word-picture FC task, all the lures were from the same category as the targets, which could not provide information about the targets from the word-category FC task used before.

In Experiments 1 and 2, when the word-category FC tasks were used, the effects of PK were significant after both FM and EE at 10 min and maintained until 1 wk. The word-category FC task was used in studies by Sharon et al. (2011) and Smith et al. (2014), who found that memory performance for this task is usually consistent with that of the word-picture FC task. Participants may have acquired the word-category associations during FM and EE when the words and pictures were presented together. Additionally, these associations were learned when the participants were presented with them explicitly in sentences at the beginning of each trial (e.g., "Dengle is an animal"), which may have activated an existing knowledge system and initiated enhanced processing of the related information (Alba and Hasher 1983; Packard et al. 2017). Thus, the specific encoding manipulation used in the present study could account for significant effect of PK in both Experiments 1 and 2 in the word-category FC task. We consider that the results of the word-category task confirmed the success of PK manipulation, but that the task may not be optimal for testing the effects of PK on the word-pictures associations in the present study.

Fast mapping and prior knowledge

Whether FM learning enables the rapid integration of novel associations into cortical networks is a critical issue in the field of FM. Therefore, it is important to evaluate memory after both FM and EE in the same study to clarify whether they are differentially modulated by any specific factors. In this study, by using pseudowords and controlling for the baseline performance, we found two pieces of evidence of rapid acquisition after FM that were distinct from memory after EE. Memory after FM was forgotten more slowly than that after EE, and the effect of PK was manifested immediately after FM, but at 1 wk after EE. Combined with previous findings (e.g., Coutanche and Thompson-Schill 2014; Merhav et al. 2014; Himmer et al. 2017), the results suggest that in younger adults, FM learning is distinct from EE (Coutanche and Thompson-Schill 2015), although both lead to explicit memory as confirmed by the confidence rating results.

A theoretical significance of this study is that it clarifies the role of the familiar object as a key feature in the FM paradigm and a possible mechanism for rapid acquisition through FM. The effect of PK suggests that semantic integration mediated by familiar items is important for FM learning. It broadens the CLS theory (McClelland 2013; Kumaran et al. 2016) in that in addition to the rapid hippocampal learning system and slow neocortical learning system, FM is one of the encoding conditions that could promote learning and decrease forgetting, which is mediated by PK. The FM learning paradigm thus provides a useful method of acquiring new word knowledge quickly via the cortical memory system, and retaining it for a long time (Carey 1978; Wagner et al. 2015).

Limitations and future directions

FM learning includes complex processes, such as incidental learning, familiar pairs and disjunctive inference (Coutanche and Thompson-Schill 2015; Cooper et al. 2019a). It has been suggested that both long-term maintenance and interference susceptibility are important characteristics of memory traces acquired through FM (Gilboa, 2019). Although our study found a significant dissociation in memory forgetting between FM and EE, the dissociation was modulated by some factors, for example, lure type and number of trials. Other factors, such as co-occurring familiar object (Mak 2019), inference from familiar objects (Warren and Duff 2019) and discrimination between two objects (Zaiser et al. 2019), also modulate the outcome of FM learning. These factors seem to interact with each other (e.g., Coutanche 2019; Gilboa 2019; Mak 2019; Warren and Duff 2019; Zaiser et al. 2019), which makes boundary conditions for FM learning more subtle to be determined. The current finding provides a promising launch point for future investigations. Further studies may use pseudowords and control baseline performance to clarify how these factors interact to modulate memory after and EE.

Our results focused on cognitive mechanisms of FM learning. We found a rapid acquisition of word knowledge after FM, which supported the CLS theory that the neocortex plays an important role in the rapid learning mechanism (McClelland 2013; Kumaran et al. 2016). However, much remains to clarify the neural mechanisms of FM learning. For example, to what extent the hippocampus and its interaction with the neocortical learning system are involved in FM learning (Merhav et al. 2015; Coutanche 2019;

Cooper et al. 2019a; Waren and Duff 2019; Zaiser et al. 2019). Further neuroimaging and patient studies are needed to consider possible factors and their interactions.

Conclusion

In summary, our study demonstrated that the memory of word-picture associations acquired by FM remained stable for 1 wk, while it decreased over time after EE. In addition, the effects of PK appeared right after FM learning, but at 1 wk after EE. The PK enhanced word-picture associations when the lures were from the same categories (rather than from different categories), for both the FM and EE conditions. The results clarified that FM facilitates the rapid acquisition and consolidation of word-picture knowledge, and highlight that PK plays an important role in this process by enhancing access to detailed information.

Materials and Methods

Experiment 1

Participants

Forty-eight right-handed undergraduate students (22 males; mean age = 21.91 ± 2.94 yr) were recruited for Experiment 1. Among them, 20 participants (10 males; mean age = 21.26 ± 2.18 yr) were in the control group. As factors of PK, retention interval were manipulated in the task group, to obtain higher statistical power, 28 participants (12 males; mean age = 21.38 ± 2.12 yr) were recruited. All the participants were native Chinese speakers, and gave written informed consent in accordance with the procedures and protocols approved by the Review Board of Department of Psychology, Peking University.

Material

Three within-subjects factors were included in the study: level of prior knowledge (PK, familiar category as high PK, unfamiliar category as low PK), encoding condition (FM, EE), and retention interval (10 min, 1 wk) (Fig. 5).

The main results of the material preparations are presented in the main body of the paper, and the detailed information is found in the Supplemental Material.

We first selected four familiar and four unfamiliar categories to manipulate the level of PK. Among these categories, four familiar (fruit, vegetable, animal, and tool) (Fig. 5A) and three unfamiliar categories (flower, fish, and musical instrument) were from Van Overschelde et al. (2004). The familiarity of a category is dependent on the quantity of exemplars that participants could produce for that category (Supplemental Material). For the unfamiliar categories, participants can produce fewer exemplars than for the familiar categories. Considering cultural differences, we added one unfamiliar category (i.e., Chinese medicine, as shown in Fig. 5B). The mean category familiarity was significantly different between the high and low PK conditions (5.47 ± 0.62 and 3.74 ± 0.39, respectively, $t_{(18)} = 10.19$, $P < 0.001$) (Table 1; Supplemental Material).

Thirty-six unfamiliar pictures for each of the two PK conditions (18 each for the FM and EE conditions) were selected and used as target pictures (72 in total). As each of the target pictures was paired with a familiar picture from the same category in the FM condition, 18 familiar pictures for each PK condition were selected (36 in total). These pictures formed 36 target trials for each PK condition (18 each for the FM and EE conditions). In addition, to minimize attentional bias to the unfamiliar pictures (Sharon et al. 2011; Smith et al. 2014; Warren and Duff 2014, 2019), six unfamiliar and six familiar pictures were combined to form lure trials during the FM condition for each PK condition (Fig. 5A,B), and six familiar pictures were used as lure trials during the EE condition for each PK condition (Fig. 5C,D) (12 unfamiliar and 24 familiar pictures in total were used as the lure trials). The lure trials were not tested. Altogether, there were 84 unfamiliar pictures and 60 familiar pictures from the eight categories (ranging from 5–10 familiar and 7–14 unfamiliar exemplars per category). The accuracy of naming and picture familiarity for familiar items, unfamiliar items and targets were matched with regard to the level of PK (F's < 1, P's > 0.07; Table 1).

Eighty-four pseudowords were used as the names for the unfamiliar pictures. They were constructed by randomly recombining the first character of one real word with the second character of the other. The meaningfulness and number of strokes were matched between the level of PK (P's > 0.10; Table 1). The pseudowords were randomly allocated to the unfamiliar pictures.

The 36 unfamiliar pictures used in the target trials for each PK condition were randomly assigned to two sets of 18 pictures to be

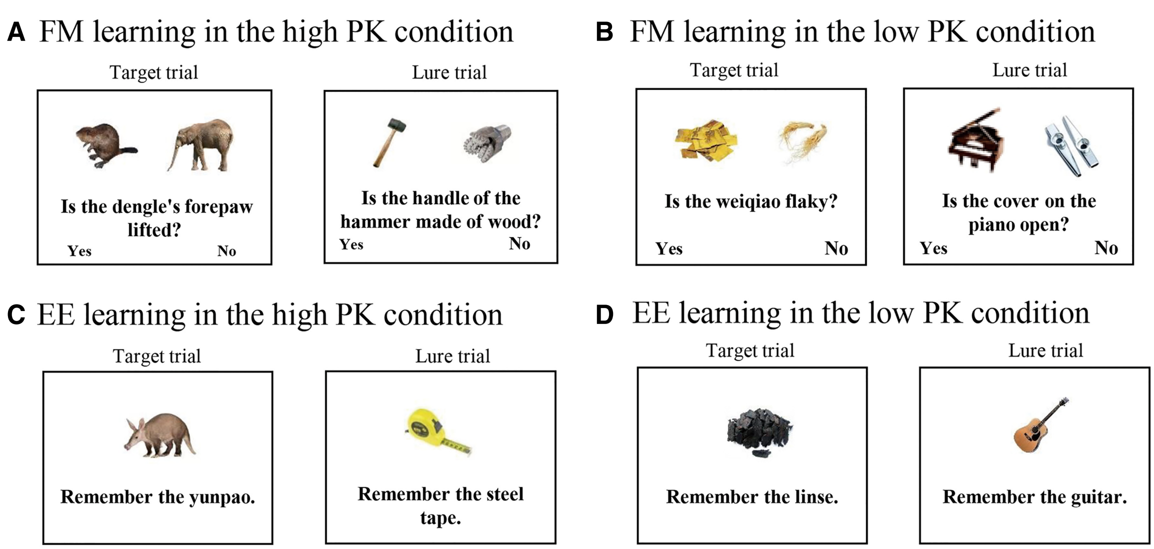

Figure 5. Stimulus and trial exemplars. The categories in the high PK condition were selected from familiar categories (*A*,*C*), and the categories in the low PK condition were selected from unfamiliar categories (*B*,*D*). For the target trials, in the FM condition the questions pertained to unfamiliar pictures, while for the lure trials, the questions pertained to familiar pictures. The Chinese is translated into English for illustration purpose only.

Table 1. Results of stimulus features

		Experiment 1			Experiment 2			Experiment 3		
		High PK	Low PK	P	High PK	Low PK	P	High PK	Low PK	P
Category	Category familiarity (1–7)	5.47 ± 0.79	3.74 ± 0.99	<0.001	5.08 ± 0.96	3.97 ± 1.10	<0.001	5.51 ± 0.74	3.71 ± 1.03	<0.001
Picture	Naming accuracy of familiar items	0.98 ± 0.03	0.97 ± 0.04	0.45	0.97 ± 0.04	0.98 ± 0.03	0.57	0.83 ± 0.13	0.83 ± 0.16	0.79
	Naming accuracy of unfamiliar items	0.01 ± 0.02	0.01 ± 0.01	0.11	0.01 ± 0.02	0.01 ± 0.01	0.15	0.01 ± 0.02	0.01 ± 0.02	0.84
	Naming accuracy of targets	0.00 ± 0.01	0.00 ± 0.01	0.17	0.01 ± 0.02	0.00 ± 0.01	0.17	0.01 ± 0.02	0.01 ± 0.02	0.96
	Picture familiarity of familiar items (1–7)	6.39 ± 0.34	6.25 ± 0.21	0.07	6.24 ± 0.34	6.18 ± 0.18	0.54	5.79 ± 0.44	5.87 ± 0.85	0.93
	Picture familiarity of unfamiliar items (1–7)	2.11 ± 0.31	2.17 ± 0.40	0.45	2.07 ± 0.29	2.14 ± 0.42	0.40	2.01 ± 0.21	2.00 ± 0.26	0.55
	Picture familiarity of targets (1–7)	2.09 ± 0.32	2.15 ± 0.38	0.91	2.06 ± 0.29	2.15 ± 0.41	0.21	1.95 ± 0.21	1.93 ± 0.22	0.91
Pseudowords	Meaningfulness (1–7)	2.05 ± 0.39	2.11 ± 0.44	0.51	2.04 ± 0.43	2.12 ± 0.41	0.50	2.09 ± 0.45	2.01 ± 0.36	0.46
	Number of strokes	19.00 ± 5.03	18.26 ± 4.23	0.47	19.68 ± 5.48	19.32 ± 4.40	0.79	17.25 ± 3.59	18.13 ± 4.12	0.44

used for FM and EE conditions. The six unfamiliar pictures in the lure trials for the FM condition were the same for each participant but counterbalanced across the conditions. The 30 familiar pictures for each PK condition were randomly assigned to one set of 18 familiar pictures in the target trials for the FM condition, and two sets of six familiar pictures in the lure trials for the FM and EE conditions. The unfamiliar pictures and the paired familiar pictures were pseudorandomly paired, ensuring that the two pictures (one unfamiliar and one familiar) were from the same categories. Because the unfamiliar pictures were learned twice, each unfamiliar picture was randomly paired with two different familiar pictures during the FM encoding. The two sets of the 18 unfamiliar pictures for each PK condition were matched in terms of picture familiarity and naming accuracy (F's < 2, P's > 0.10). They were also matched in terms of the meaningfulness and number of strokes of the pseudowords (F's < 1, P's > 0.50). The materials were counterbalanced across the conditions so that each unfamiliar picture had an equal chance to appear in each encoding condition. Consistent with previous studies (Sharon et al. 2011; Coutanche and Thompson-Schill 2014; Greve et al. 2014; Smith et al. 2014), we used the same materials at both retention intervals.

Procedure

The participants enrolled in the control group were tested with the two FC tasks, without any learning sessions. The participants enrolled in the task group learned the word-picture associations under the FM and EE conditions, and performed the word-picture FC task and word-category FC task at 10-min and 1-wk intervals.

During FM, for each trial a sentence that described the category of a picture was randomly presented (both visually and auditorily) for 3000 msec (e.g., "Dengle is an animal.") (Fig. 6A, left). Then, two pictures appeared simultaneously on the screen for 6000 msec, with one being the unfamiliar picture, and the other being the paired (familiar) picture. At the same time, a question (e.g., "Is the dengle's forepaw lifted?") appeared both visually and auditorily, and the participants were asked to make a FC judgment. Half of the answers were "yes" and the other half were "no." If the participants did not know the answer, they were asked to press a third button. There were 24 trials for each PK condition during the FM encoding: 18 target trials and six lure trials. The questions for the target trials were related to the 18 unfamiliar pictures, while those for the six lure trials were related to the paired familiar pictures. Only the 18 unfamiliar pictures in the target trials for each PK condition were subsequently tested. The unfamiliar pictures were presented in two rounds in random order, and were paired with different familiar pictures; hence, the questions were different. The position of the targets (left or right) and the answers to the questions (correct or incorrect) were counterbalanced across the rounds and participants.

During EE, a category sentence was presented for 3000 msec, then a picture was presented on the center of the screen. The participants were asked to remember the picture (e.g., "Remember the linse.") (Fig. 6A, right). There were 24 trials for each PK condition, 18 of which related to the unfamiliar pictures, and 6 related to familiar pictures. Only the 18 unfamiliar pictures for each condition were tested. The pictures were presented twice in two rounds in random order. The test phase proceeded exactly as that in the FM condition.

During the testing phase, the participants performed two tasks: word-picture FC (Fig. 6B, left) and word-category FC (Fig. 6B, right). For each trial of the word-picture FC task, the name of a target picture was randomly presented on the top of the screen, and three unfamiliar pictures (as alternatives) were presented on the bottom of the screen in a random order. The three pictures were all learned during the same encoding condition (FM or EE) but were from different categories. The participants were asked to choose the corresponding picture without a time limitation. Then the participants were asked to make a confidence rating (unsure to sure on a scale from 1 to 6). For each trial in the word-category FC task, the procedure was similar to that of the word-picture FC task, except that four alternatives for the learned categories were presented on the bottom of the screen. Two were the names of the unfamiliar categories, and two were those of the familiar categories. The participants were asked to perform a four-alternative FC judgment without a time limitation, followed by a confidence rating (1–6).

The tests were performed at two retention intervals with the same materials. However, for each target word, the lure stimuli in the two tasks were different at the two retention intervals and counterbalanced across participants. The word-picture FC task was performed first, followed by the word-category FC task to diminish the influence on the word-picture task (Sharon et al. 2011; Smith et al. 2014). The position of the target stimuli in the two tasks was random and counterbalanced across the conditions and the participants.

To minimize the influence of intentional encoding on FM (e.g., Sharon et al. 2011; Smith et al. 2014; Warren and Duff 2014; Warren et al. 2016), the task order at 10-min interval was fixed. That is, the participants performed the encoding and test phases of the FM condition, then they performed those of the EE

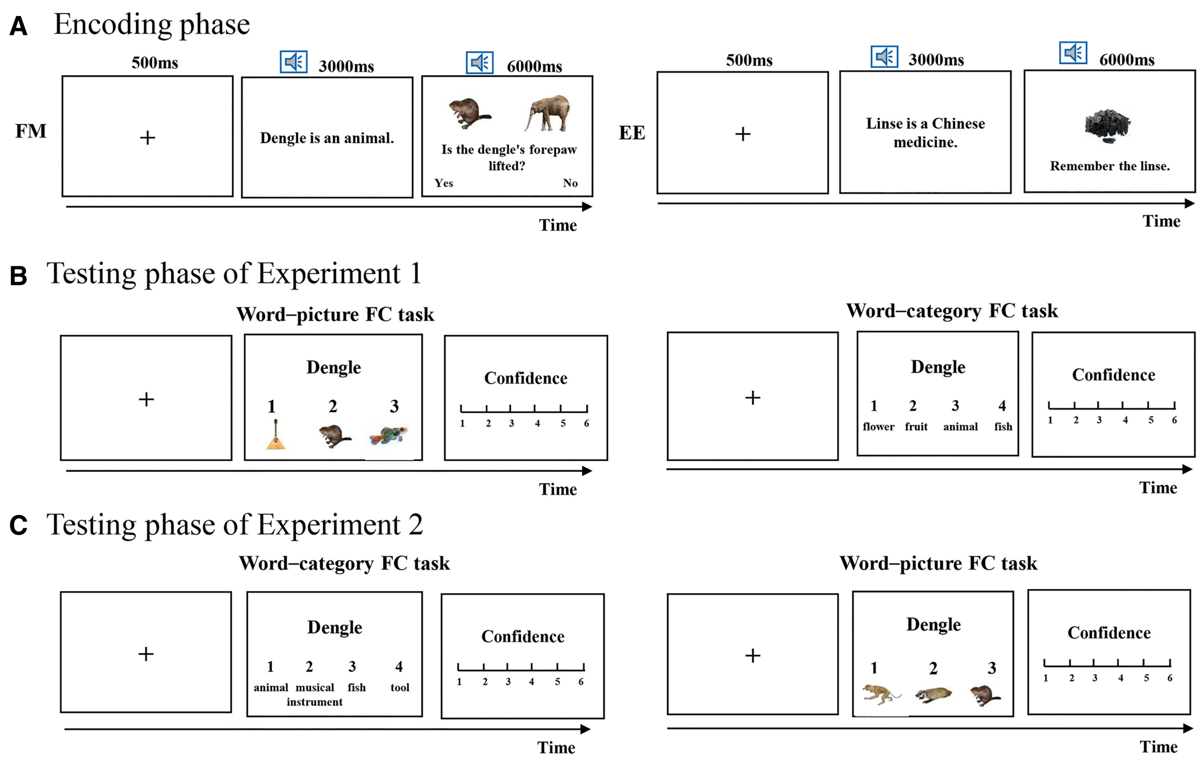

Figure 6. Procedures for the encoding and testing phases. In Experiments 1–2, participants learned the word-picture associations through both the FM (*left*) and EE (*right*) conditions (*A*). Then they performed the word-picture and word-category FC tasks. The procedures of Experiment 1 and 2 were the same in the encoding phase and the word-category FC task, but they differed in the word-picture FC task. For the word-picture FC task, the participants were asked to select the picture that had been associated with the name. The alternatives came from different categories in Experiment 1 (*B*), but from the same category in Experiment 2 (*C*). In Experiment 3, the encoding phase (FM, EE) was manipulated as a between-subjects factor, and the lure type (between-category, within-category FC task) was included as a within-subjects factor.

condition. The test order for the FM and EE conditions was counterbalanced across the participants at 1 wk.

After each encoding, the participants were asked to perform a subtraction task (starting with 1000, repeatedly take away 7) to prevent rehearsal. They had the chance to practice the encoding tasks and the two FC tasks. After all the tests at 1 wk, the participants were instructed to name the unfamiliar pictures to check if they were familiar with any of them (Sharon et al. 2011; Coutanche and Thompson-Schill 2014; Smith et al. 2014; Warren and Duff 2014; Atir-Sharon et al. 2015; Warren et al. 2016; Warren and Duff 2019).

Data analysis

For the control group, the accuracy for the two tasks were analyzed by the paired *t*-tests separately. The performance was also compared to the baseline level to indicate whether the chance level was obtained. For the task group, the accuracy and the RTs for the correct responses in the encoding phase were analyzed by paired t-tests to explore the effect of PK. The memory accuracy in the word-picture FC and the word-category FC tasks were analyzed by repeated-measures ANOVAs, with encoding condition (FM, EE), PK (high, low) and retention interval (10 min, 1 wk) as within-subject factors. In addition, to exclude the influence of initial memory performance (i.e., accuracy at 10 min), the forgetting rate was calculated as the following: (accuracy at 10 min—accuracy at 1 wk)/(accuracy at 10 min). The forgetting rates in the two FC tasks were analyzed by repeated-measures ANOVAs, with encoding condition (FM, EE) and PK (high, low) as within-subject factors. The confidence rating scores were also analyzed to be indicative of declarative memory (Supplemental Material; Sharon et al. 2011; Smith et al. 2014). Partial eta squared (η_p^2) was calculated to indicate the effect size of the difference, and post-hoc pairwise comparisons were Bonferroni-corrected (two-tailed, $P < 0.05$).

The exclusion of some trials is necessary for the FM analysis. The inclusion of familiar objects and objects that could not be learned well during encoding would introduce additional interference, inference or other confounding factors during FM (Gilboa 2019; Warren and Duff 2019). Therefore, to ensure that the pictures were unfamiliar to each individual participant, (1) two participants whose performance in the naming task was two standard deviations higher than mean (Coutanche and Thompson-Schill 2014), and (2) the pictures which were correctly identified in the naming task (mean 0.71 items per condition for each participant; e.g., Sharon et al. 2011; Smith et al. 2014) were excluded. To ensure that the pictures were optimally learned (Sharon et al. 2011; Smith et al. 2014), the pictures that were erroneously identified during FM (mean 3.77 items per condition for each participant) were excluded. We also performed the same analyses with the data of all trials, and the results showed similar patterns as those with trial exclusion. As the exclusion of some trials is necessary for the FM analysis, we kept those results in the main text.

Experiment 2

Participants

As in Experiment 1, 48 right-handed undergraduate students (18 males, mean age = 22.22 ± 3.01 yr) were recruited for Experiment 2. Among them, 20 participants (6 males, mean age = 23.55 ± 3.56 yr) were recruited for the control group, and 28 participants (11 males, mean age = 21.21 ± 2.08 yr) were recruited for the task group. All the participants were native Chinese speakers and gave written informed consent in accordance with the procedures and protocols approved by the Review Board of Department of Psychology, Peking University.

Materials

As in Experiment 1, three within-subjects factors were included in Experiment 2: level of PK (high, low), encoding condition (FM, EE), and retention interval (10 min, 1 wk).

The pictures, pseudowords and picture-pseudoword associations were the same as for Experiment 1. However, because within-category alternatives were used in the word-picture FC task, to control for the interference during the tests (Gilboa 2019), four categories with only three exemplars per condition were excluded (e.g., flowers), and only four categories that had six exemplars were included in Experiment 2. Two of the categories were familiar (i.e., animal, tool), and the other two were unfamiliar (i.e., fish, musical instrument) (Van Overschelde et al., 2004). Their category familiarity rated by the Chinese participants was significantly different ($t_{(18)} = 4.92$, $P < 0.001$).

Twenty-four unfamiliar pictures for each PK condition (12 each for the FM and EE conditions) were selected and used as target pictures in the target trials (48 in total). As the participants had to make within-category discrimination, to match the task difficulty of Experiment 1 and 2 and control for the interference from lures within the same category (Gilboa 2019), the number of target pictures within each category was six and the ratio of the target and lure trials in the two experiments was the same (3:1). The 12 familiar pictures from each PK condition were selected to be paired with the unfamiliar pictures from the same category in FM (24 in total). Four additional pairs during FM, and four additional familiar pictures during EE were used as lure trials for each PK condition. Altogether, there were 56 unfamiliar pictures and 40 familiar pictures from the four selected categories (10 familiar and 14 unfamiliar exemplars per category). The accuracy of naming and picture familiarity for familiar items, unfamiliar items and targets were matched with regard to the level of PK (F's < 1, P's > 0.05; Table 1).

The 24 unfamiliar pictures in each PK condition were randomly assigned to two sets of 12 unfamiliar pictures for the target trials to be used for FM and EE conditions. The four unfamiliar pictures in the lure trials in the FM condition were the same for each participant, but counterbalanced across the conditions. The 20 familiar pictures in each PK condition were randomly assigned to one set of 12 familiar pictures for the target trials in the FM condition, and two sets of four familiar pictures in the lure trials for the FM and EE conditions. The unfamiliar and familiar pictures were pseudorandomly paired, ensuring the paired pictures were from the same category. During the two rounds of FM learning, each unfamiliar picture was randomly paired with two different familiar pictures. The two sets of the unfamiliar pictures for the target trials in each PK condition were matched in picture familiarity and naming accuracy (F's < 1.0, P's > 0.10). They were also matched in meaningfulness, word frequency, and number of strokes in the pseudowords (F's < 1.0, P's > 0.10). The materials were counterbalanced across the conditions, ensuring each unfamiliar picture had an equal chance to appear in each encoding condition.

Procedure

The procedures were the same as those in Experiment 1, except that: (1) there were 16 trials for each PK condition in each encoding condition, of which 12 were target trials and four were lure trials; (2) in the word-picture FC task, the three alternatives were all from the same category, and the word-category FC task was performed before the word-picture FC task to minimize the influence between the tasks (Fig. 6C); and (3) as only four categories were used in the word-category FC task, the four category names were presented in all trials, and the participants were asked to make a four-alternative FC decisions. The position of the names was fixed for each participant, but counterbalanced across the participants.

Data analysis

Data analysis was performed in the same way as in Experiment 1. The data from five participants were excluded as they correctly identified the unfamiliar pictures beyond two standard deviations in the naming task. In addition, some trials were excluded from each participant's data analysis using the same criterion as that in Experiment 1 (mean 0.61 items per condition in the naming task due to familiarity, and mean 2.17 items per condition for each participant due to the participant answering erroneously twice during FM).

Experiment 3

Participants

Seventy-six right-handed undergraduate students (37 males; mean age = 21.62 ± 2.61 yr) were recruited for Experiment 3. Among them, 20 participants (12 males; mean age = 23.05 ± 3.17 yr) were in the control group. Half of the remaining participants (n = 28) were randomly assigned to the FM group, and the other half (n = 28) were to the EE group. All the participants were native Chinese speakers, and gave written informed consent in accordance with the procedures and protocols approved by the Review Board of Department of Psychology, Peking University.

Material

Three within-subjects factors: level of PK (high PK, low PK), lure type during test (between-category FC, within-category FC), and retention interval (10 min, 1 wk) were included in experiment 3. To reduce the impact of task order, encoding condition (FM, EE) was treated as a between-subjects factor.

Six categories in Experiment 1 were included in Experiment 3. Three of the categories were familiar (i.e., animal, tool, and fruit), and the other three were unfamiliar (i.e., fish, musical instrument and Chinese medicine). Categories of fruit and Chinese medicine were not used in Experiment 2. The category familiarity rated by the Chinese participants was significantly different (5.51 ± 0.74 and 3.72 ± 1.03, respectively, $t_{(18)} = 8.32$, $P < 0.001$).

Twenty-four unfamiliar pictures for each PK condition were selected and used as target pictures in the target trials (48 in total). The number of target pictures within each category was four. The 24 familiar pictures from each PK condition were selected to be paired with the unfamiliar pictures from the same category in the FM encoding (48 in total). Same as that in Experiments 1 and 2, the ratio of the target and lure trials in Experiment 3 was 3:1. Thus, eight additional pairs during FM, and eight additional familiar pictures during EE were used as lure trials for each PK condition. Altogether, there were 64 unfamiliar pictures and 64 familiar pictures from the six selected categories (ranging from 20 to 24 familiar and from 20 to 24 unfamiliar exemplars per category). The accuracy of naming and picture familiarity for familiar items, unfamiliar items and targets were matched with regard to the level of PK (F's < 2, P's > 0.10; Table 1). All the pseudowords were the same as those in Experiment 1, and they were randomly allocated to the unfamiliar pictures to form word-picture associations.

As the encoding condition was treated as a between-subjects factor, all the stimuli were learned for each participant. For the FM group, the 24 unfamiliar pictures in each PK condition were randomly assigned to two sets of 12 unfamiliar pictures to be used as target trials in the between-category and within-category conditions. Another eight unfamiliar pictures for each PK were randomly assigned to two sets of four unfamiliar pictures to be used in lure trials. The 32 familiar pictures in each PK condition were randomly assigned to two sets of 12 familiar pictures as the target trials, and two sets of four familiar pictures as the lure trials for the between-category and within-category conditions. The unfamiliar and familiar pictures in each category were pseudorandomly paired in each condition. Each unfamiliar picture was paired with a different familiar picture during the two rounds of FM learning. For the EE group, only 24 unfamiliar pictures in the target trials and the eight familiar pictures in the lure trials in each PK condition were presented. The picture familiarity and naming accuracy of the two sets of the unfamiliar pictures were matched in each PK condition (F's < 1.0, P's > 0.10), and they were also matched in meaningfulness, word frequency, and number of strokes in the pseudowords (F's < 1.0, P's > 0.10). The materials were counterbalanced across the conditions, ensuring that each unfamiliar picture had an equal chance to appear in each condition of lure type.

Procedure

The participants in the control group were tested by the between- and within-category word-picture FC tasks, without any encoding sessions. The participants in the FM or EE group learned the associations under the corresponding encoding task, and performed both the between- and within-category FC tasks at 10-min and 1-wk intervals.

The procedures were the same as those in Experiments 1 and 2, except that: (1) during the encoding phase, half of the participants were assigned in the FM condition, and the other half were in the EE condition. All the participants learned 48 word-pictures because the lure type was treated as a within-subjects factor. (2) during the testing phase, all the participants performed both the between- and within-category word-picture FC tasks. The task order of the two FC tasks was counterbalanced across the participants. (3) the word-category FC task was removed in Experiment 3 due to potential influence of task order on the word-picture FC tasks.

Data analysis

Data analysis for the control group was performed by the same way as that in Experiments 1 and 2. For the task group, repeated-measures ANOVAs were conducted for memory accuracy and forgetting rates. For memory accuracy, PK (high, low), lure type (between-category and within-category FC) and retention interval (10 min, 1 wk) were included as within-subjects factors, and encoding condition (FM, EE) was included as a between-subjects factor. The forgetting rates were analyzed with lure type (between- and within-category FC) as a within-subject factor and encoding condition (FM, EE) as a between-subjects factor.

The same criterion was used as that in Experiments 1 and 2 to exclude the participants and trials. Two participants in the FM group and two participants in the EE group were excluded as they correctly identified the unfamiliar pictures beyond two standard deviations in the naming task, two in the FM group were excluded as their performance below two standard deviations of the mean, and one in the FM group was excluded as the performance of the participant in the encoding phase below two standard deviations. In addition, some trials were excluded (mean 0.88 items per condition in the naming task due to familiarity, and mean 2.44 items per condition for each participant due to the participant answering erroneously twice during the FM encoding).

Data access

The materials, data sets, and analysis scripts for this study can be found on the Open Science Framework (OSF), DOI: 10.17605/OSF.IO/HZAU6.

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