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RESEARCH ARTICLE

The effects of cognitive load and encoding modality on prospective memory

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Abstract
Successful execution of an intention as planned is necessary for people's normal life. However, people sometimes even forget intentions that they consider as very important. Hence, the issues that whether prospective memory performance can be improved under high cognitive load tasks are worth discussing. In this study, we used a 2 (cognitive load: high or standard) × 2 (encoding modality: verbal or enactment encoding) mixed design to explore the effects of encoding modality and cognitive load of ongoing tasks on prospective memory. The results showed that the prospective memory performance under high cognitive load condition was significantly worse than that under standard cognitive load condition for verbal encoding condition. However, for enactment encoding condition, enactment encoding enhanced the performance and abolished the difference between high and low cognitive load effects on prospective memory. Strategic issues of prospective memory will be discussed.

Keywords Prospective memory · Cognitive load · Enactment encoding · Verbal encoding · Multi-process theory

Introduction

Prospective memory

Carrying out a planned event or activity at a certain situation or time in future is typically referred to as prospective memory (Brandimonte et al. 2014; Guynn, 2008; Kliegel et al., 2000). Successful implementation of prospective memory tasks, such as remembering to buy a notebook while passing the supermarket on the way to work or remembering to attend a conference at two o'clock, depends on the effective cooperation of prospective components and retrospective components (Einstein et al., 1992). The prospective components are mainly responsible for the detection of the prospective memory cues, while the retrospective components are responsible for recalling correct response when the cue is detected (Woods et al., 2015). Most of us need to transform one task to another task according to their needs of normal life. However, if there are more tasks needed to perform, people often forget certain tasks. Such failures in remembering to perform an intended intention at an appropriate moment described as errors of prospective memory (Ellis & Freeman, 2008; Haas et al., 2020). Therefore, it is particularly important to find an encoding strategy that can improve prospective memory performance (Jones et al. 2021).

To explain the mechanism of event-based prospective memory, a large number of researchers have paid attention to cognitive resource consumption when performing prospective memory tasks. For example, some studies showed that the reaction time of ongoing task is prolonged by embedding prospective memory tasks (Smith, 2003; Smith & Bayen, 2004; Smith et al., 2007) or by increasing the number of prospective memory cues (Boag et al., 2019; Cohen et al., 2008; Strickland et al., 2020) compared with the baseline group. Even if no prospective memory cues appeared (Smith, 2003), or prospective memory cues are particularly prominent (Smith et al., 2007), the reaction time of ongoing tasks

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is also prolonged (Smith, 2003). Based on the research, they proposed preparatory attention and memory (PAM) processing theory. According to this theory, people need to keep the intention in memory at all times when they were informed to perform a prospective memory task, and maintain a state of readiness for preparatory attention to monitor the possible target cues in the environment (Anderson & Einstein, 2016; Smith, 2003). The latest research shows that there are age differences in the demand for this cognitive resource, namely that children are less efficient than adults in prospective memory monitoring (Ball, & Bugg, 2018; Cottini, & Meier, 2020).

Einstein et al. (2005) presented an alternative frame-work (Multi-process theory) to explain the mechanism of event-based prospective memory, considering that prospective memory task requires cognitive resources in some cases, but in other specific cases (e.g., the cues are salient), the tasks can be performed in an automatic fashion. They provided evidence in five experiments showing that under some conditions, the retrieval of prospective memory task is supported by capacity-demanding monitoring of the environment for targets that trigger an associated intention, but that under other conditions, the task is supported by more spontaneous processing, in which the associated intention seems to "pop" into mind. Whether the prospective memory task can be retrieved successfully depends on the extent to which the cue is fully processed at the time of retrieval and the degree to which the cue and the intended action is sufficient encoded (Einstein et al., 2005). Later research also showed that successful retrieval of the prospective memory task does not necessarily harm the ongoing tasks when the cues are salient, or the association between the cue and target action to be performed is sufficient encoded (McDaniel et al., 2008). Mullet et al. (2013) conducted a series of experiments, and revealed no age differences when spontaneous retrieval was encouraged, which supported the Multi-process theory from a developmental perspective.

Previous studies have shown that the cognitive demand for ongoing tasks can also affect prospective memory performance (Einstein et al., 1997; Marsh et al., 2003; March et al., 2002; Smith, 2003). For example, Einstein et al. (1997) controlled the cognitive load of ongoing tasks by adding a digit-monitoring task to the ongoing tasks and revealed that the accuracy of prospective memory decreased compared with the baseline group. It is suggested that the increase in cognitive load of ongoing tasks occupies more attentional resources, which leads to a reduction in attentional resources allocated to prospective memory tasks and affects the retrieval of intended actions (McDaniel et al., 2004).

Kidder et al. (1997) examined the effect of cognitive load on prospective memory performance by manipulating the difficulty of ongoing tasks and used verbal working memory tasks as the ongoing task. Subjects were required to recall the second or third word before the current word at unpredictable intervals. The results showed that prospective memory performance was significantly worse under a high cognitive load condition than that under standard cognitive load condition. Other studies explored the effects of cognitive load on prospective memory by adding additional tasks to the ongoing tasks, such as by increasing the number of arithmetic tasks, the visuospatial monitoring tasks, and the counting and random number generation tasks, and obtained similar conclusion (Logie et al., 2004; Marsh & Hicks, 1998; McDaniel, et al., 2008; McDaniel & Scullin, 2010). Recent studies reported that although the prospective memory performance did not decrease under high cognitive load condition compared with the standard cognitive load condition, it was at the expense of the response speed of the prospective memory task as well as the performance and speed of the ongoing tasks (Guo et al. 2016). Meier and Zimmermann (2015) reported that when prospective memory load is low, the ongoing task load does not affect prospective memory performance. However, when prospective memory load is high, the increases of ongoing task load can affect prospective memory performance. As Loft et al. (2008) suggested subjects can flexibly allocate limited cognitive resources according to task consumption when multiple tasks need to consume cognitive resources. With the increase of cognitive load on ongoing tasks, people allocated less cognitive recourses on prospective memory tasks, causing a declining trend of prospective memory performance. Therefore, whether prospective memory performance could be improved under high cognitive load condition was a question that worth discussing.

Prospective memory after enactment encoding

Studies on retrospective memory commonly established that free recall or recognition performance would be better if people were instructed to learn action phrases (e.g., " look into the mirror") while performing the actions (enactment encoding) rather than learning the phrases by only reading silently (verbal encoding). That is, memory performance is significantly improved by enactment encoding compared with verbal encoding. This superior effect is called enactment effect (Cohen, 1989; Nilsson, 2000). One explanation for this phenomenon is that enactment accompanied with a higher degree of self-involvement, which helps individuals focus the encoding on action-relevant information instead of contextual information (Engelkamp, 1995; Kormi-nouri, 1995) and thus promoted the integration of action and object.

However, researches did not draw a consistent conclusion whether the prospective memory performance can be improved by enactment encoding. Passolunghi et al. (1995) were the first research to focus on the effect of enactment encoding on prospective memory. They compared the prospective memory performance in 7–8-year-old children and 10–11-year-old children under three encoding conditions (enactment encoding/verbal encoding/visual encoding). The results showed that only 10–11-year-old children benefited from enactment encoding. Similar results was obtained by Li and Wang (2015) which found that enactment encoding can only improve the prospective memory performance in the group of eight- and nine-year-old children, but not the group of 7-year-old children. Both studies revealed that enactment can improve the prospective memory performance for older children, but not for young children (7 years old). It may be that enactment encoding as a strategy can be gradually gained with the increase in children's age, and 6–7 years may be the critical period of children's motor development. In addition, study from retrospective memory also showed that the memory performance can be enhanced for 8-year-old children by enactment encoding but not for 6-year-old children (Mecklenbräuker et al., 2011). Freeman and Ellis (2003) instructed subjects either to enact or to read verb lists during the study phase and to form the intended intention to enact or to verbally recall the lists after a recognition test. They demonstrated faster response latencies for enacted as well as to-be-enacted verbs compared to a verbal-only control condition. Pereira et al. (2012a, 2012b) explored the effects of enactment encoding on prospective memory in adult and older subjects and discovered that enactment encoding can improve prospective memory performance in both groups. Recent researches explored the effect of enactment encoding on prospective memory in patients with mild cognitive impairment and found that prospective memory performance under enactment encoding were significantly better than those in verbal encoding (Pereira et al. 2015, 2018). The above studies found that enactment encoding can improve prospective memory performance. It is mainly because that in these studies, the enactment tasks drew attention to the processing of the association between the intended action and the cue component (Li & Wang, 2015; McDaniel & Scullin, 2010; Pereira et al. 2012a, 2012b, 2015). Thus, enactment can effectively promote the association between the intended action and the cue component, which enhanced the retrieval of prospective component. However, several studies drawn different conclusions, which showed that enactment encoding not only failed to improve the prospective memory performance, but also reduced the performance (Schaefer et al., 1998; Schult & Steffens, 2017). Schaefer et al (1998) suggested that the failure of enactment encoding to improve prospective memory performance might be due to individuals underestimating the difficulty of prospective memory task under enactment conditions. For example, doing some simple preparations might lead subjects to deem that the required tasks were relatively simple. Recent study suggested that enactment may appear deceptively easy (von Stülpnagel, 2016), so that subjects spend less attention on maintaining prospective memory tasks. However, Schult and Steffens (2017) focused on enactment encoding as a strategy to improve the retention of several intended activities, not as a strategy to strengthen association between intended action and cue component. It is suggested that higher intention retention is only a necessary condition, not a sufficient condition, to ensure a successful prospective memory, and the high association between intended action and cue component is a sufficient condition to improve prospective memory (Smith & Bayen, 2004, 2006).

The current study focused on enactment encoding as a strategy to strengthen the cue-action association, not as a strategy to enhance the retention of several intended activities. Therefore, this study hypothesized that the prospective memory performance can be improved by enactment encoding. According to the theory of multiple processing, the retrieval of prospective memory task is affected by the difficulty of ongoing task and the strength of the association between the cue and the intended action. Thus, increasing the difficulty of ongoing tasks or reducing the strength of the association between the cue and the intended action will hinder the completion of prospective memory.

Specifically, under the standard cognitive load condition, the ongoing task is simple, people can allocate more cognitive resources on the retrieval of prospective memory task, thus facilitating the successful retrieval of prospective memory. Therefore, this study hypothesized that the prospective memory performance is better under standard condition than under high cognitive load condition for verbal encoding. However, for enactment encoding, since the association between the cue and the intended action is sufficient encoded, it can make up for the decline of the prospective memory caused by high cognitive resource occupation. Thus, this study hypothesized that the prospective memory performance is not affected by the difficulty of ongoing task for the enactment encoding.

Method

Participants

A power analysis (using the statistical program G*Power 3.1.9.2; Faul et al., 2009) indicated that—to obtain significant medium-sized Encoding Modality by Cognitive load interaction effects ($f = 0.25$) with a statistical power of 0.80 per effect (Cohen, 1988)—we needed at least 38 participants. Thus, we recruited 40 participants (19–23 years old, $M = 20.83$ years old, $SD = 1.01$; 22 males and 18 females) from Jiangsu Normal University in China. All participants were of at least normal intelligence as well as eyesight (Based on school admittance tests). No participants were previously involved in any similar experiment, and none was psychology students. This study was approved by the Ethics Committee of Jiangsu Normal University, and the written informed consent was obtained from all participants.

Design

We applied a 2 (cognitive load: high or standard, within subjects) × 2 (encoding modalities: verbal or enactment, between subjects) mixed design. Dependent variables were measured according to the accuracy and reaction time of prospective memory tasks and ongoing tasks. Ongoing tasks are word-sorting tasks and additional tasks named as n-back tasks (classifying into two types, 1-back and 2-back tasks, in order to create standard and high cognitive load condition).

Materials

The experimental materials included 140 words, 20 of which were used as exercises and 120 words as ongoing tasks (114 new words and 6 cue words). All the words were selected from the *Modern Chinese common vocabulary (draft)*. These cues come from the nouns in the following action phrases: throwing the ball; driving the car; smelling the flowers; knocking on the eggs; opening the magazine; drinking beer.

Procedure

The procedures for practicing tasks and ongoing tasks were divided into two parts, 1-back (standard cognitive load condition) and 2-back (high cognitive load condition), each part has 3 PM cues. In order to balance the sequence effect, half of individuals would first perform a 1-back part of the task, then a 2-back part of the task, and the other half is in reverse order. There was a short break (20 s) between blocks for instructions.

The instructions for the ongoing tasks were displayed on the computer screen. Participants were told that they would do a word-sorting and judging task, in which they need to compare the stimulus appeared on the screen with the previous first (standard cognitive load condition) or second stimulus (high cognitive load condition) to determine whether the two words were in the same category by pressing the "Z" key ('Z') or the different types by pressing the "M" key ('M'). As soon as the participants pressed any of the reaction keys, the computer showed the next word. If the participants did not make response within six seconds, the next word was presented automatically. Participants were arranged for the practice stage if they understood the instructions for the ongoing tasks.

After practicing, participants learned the prospective memory cues. The cues appeared at the center of the computer screen in the form of noun–verbs, and each phrase was displayed for eight seconds under the two encoding conditions. Half of the participants were randomly assigned to the condition of verbal encoding, in which the participants were required to read the phrases silently. The other half of the participants were assigned to the condition of enactment encoding, in which individuals were instructed to read the noun–verbs silently while performing the actions (e.g., individuals would pretend to open the magazine with the additional image of a magazine while learning the phrase "opening the magazine"). To ensure that all individuals learn the phases adequately, the learning stage was repeated right after each other.

Next, the instructions for prospective memory tasks were shown on the computer screen. Subjects were informed to stop the word-sorting and judge tasks (ongoing tasks) and press the space key as soon as they met any of the six prospective memory target cues (ball, car, flowers, egg, magazine, and beer) and reported the verb corresponding to the phrase. All of individuals were required to respond to the tasks as quickly as possible without sacrificing accuracy.

After all individuals comprehended the prospective memory task instruction, they were informed to complete interesting math problems displayed on the computer screen in five minutes, in case individuals kept the prospective memory tasks in their working memory. Following the distractor tasks, the formal experiment instruction reappears on the computer, and no reminders were given during the whole experiment. Then the 120-word (114 new, 6 PM cues) word-sorting and judge task (ongoing task) began to appear, and the six prospective memory cue words were located at 19, 39, and 59 of Block1 and 2, respectively, to avoid alert task.

Results

Ongoing tasks accuracy

A 2 (encoding modality) × 2 (cognitive load) repeated measure ANOVA on the ongoing tasks performance shown in Fig. 1. The results revealed a significant cognitive load effect, $F(1, 38) = 12.02$, $MSE = 0.02$, $p < 0.001$, $\eta_p^2 = 0.24$, demonstrating that the performance of ongoing tasks under standard cognitive load condition was significantly higher than that under high cognitive load condition. The main effect of encoding modality was not significant, $F(1, 38) = 1.58$, $MSE = 0.04$, $p > 0.05$, $\eta_p^2 = 0.04$. The interaction between cognitive load and encoding modality was not significant, $F(1, 38) = 0.19$, $MSE = 0.02$, $p > 0.05$, $\eta_p^2 = 0.005$.

A two-way repeated measure ANOVA was performed on the reaction time of ongoing tasks shown in Fig. 2. A significant main effect of cognitive load was observed, $F(1, 38) = 32.184$, $MSE = 176{,}410.92$, $p < 0.001$, $\eta_p^2 = 0.46$, suggesting that the response speed under standard cognitive load

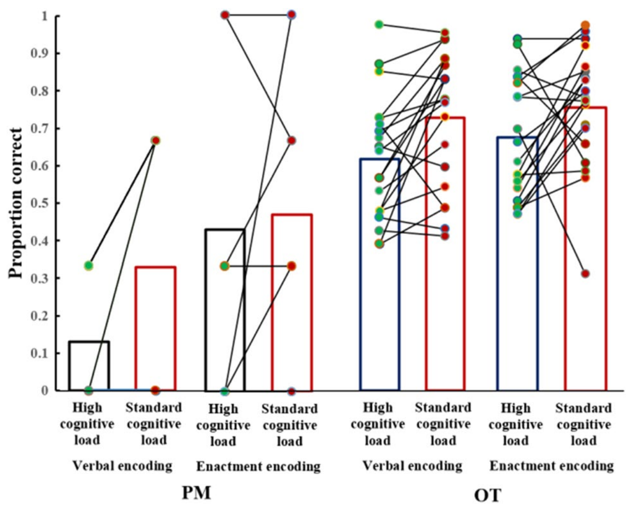

Fig. 1 Mean proportion of prospective memory tasks and ongoing tasks accuracy under different cognitive load conditions and encoding modalities; PM = prospective memory; OT = ongoing tasks

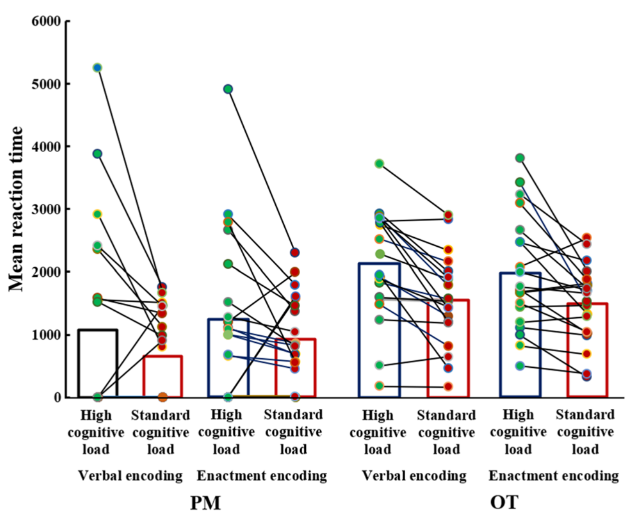

Fig. 2 Mean reaction time of prospective memory tasks and ongoing tasks under different cognitive load conditions and encoding modalities; PM = prospective memory; OT = ongoing tasks

condition was significantly faster than that under high cognitive load condition. The main effect of encoding modality was not significant, $F(1, 38) = 0.211$, $MSE = 1{,}084{,}367.69$, $p > 0.05$, $\eta_p^2 = 0.006$. The interaction between cognitive load and encoding modality was not significant, $F(1, 38) = 0.171$, $MSE = 176{,}410.92$, $p > 0.05$, $\eta_p^2 = 0.004$.

Prospective memory accuracy

We performed a 2 (encoding modality) × 2 (cognitive load) mixed design ANOVA on the prospective memory performance shown in Fig. 1. A significant cognitive load effect was obtained, $F(1, 38) = 8.26$, $MSE = 0.03$, $p < 0.05$, $\eta_p^2 = 0.18$, with superior prospective memory performance under standard cognitive load condition than under high cognitive load condition. The main effect of encoding modality was significant as well, $F(1, 38) = 5.13$, $MSE = 0.18$, $p < 0.05$, $\eta_p^2 = 0.12$, indicating that the prospective memory performance in enactment encoding was better than that in verbal encoding. The interaction between the encoding modality and cognitive load was significant, $F(1, 38) = 4.21$, $MSE = 0.03$, $p < 0.05$, $\eta_p^2 = 0.10$, simple main effects showing that prospective memory performance was better under standard condition than under high cognitive load condition for verbal encoding, $F(1, 38) = 12.14$, $MSE = 0.07$, $p < 0.05$, $\eta_p^2 = 0.24$, but not for enactment encoding, $F(1, 38) = 0.34$, $MSE = 0.08$, $p > 0.05$, $\eta_p^2 = 0.009$.

A two-way repeated measure ANOVA was performed on the reaction time of prospective memory tasks shown in Fig. 2. The result showed that the main effect of cognitive load was significant, $F(1, 38) = 4.74$, $MSE = 582{,}613.04$, $p < 0.05$, $\eta_p^2 = 0.111$, indicating that the response under standard cognitive load condition was significantly faster than that under high cognitive load condition. The main effect of encoding modality was not significant, $F(1, 38) = 0.550$, $MSE = 1{,}986{,}848.44$, $p > 0.05$, $\eta_p^2 = 0.014$, and interaction between cognitive load and encoding modality was not significant yet, $F(1, 38) = 0.09$, $MSE = 582{,}613.04$, $p > 0.05$, $\eta_p^2 = 0.002$.

Discussion

The present study aimed to explore the effects of encoding modality and cognitive load on prospective memory. The results showed that the prospective memory performance under high cognitive load condition was significantly worse than that under standard cognitive load condition for verbal encoding condition. However, for enactment encoding condition, enactment encoding enhanced the performance and abolished the difference between high and low cognitive load effects on prospective memory.

In this study, we manipulated the cognitive load by controlling the difficulty of ongoing tasks to explore the effect of cognitive loads on prospective memory. The results showed that the accuracy and reaction time of prospective memory tasks and ongoing tasks under standard cognitive load condition are significantly better than that under high cognitive load condition. That is to say, different cognitive loads have different effects on prospective memory. It means that the method of controlling the cognitive load is successful in the study, that is, the n-back tasks can actually create both high and low cognitive load conditions and has a significant impact on prospective memory.

In addition, the accuracy and reaction time of ongoing tasks are not significantly different under different encoding modalities. This means that the cognitive resources allocated to ongoing tasks in different encoding modalities has not reduced. It is possible that the ongoing task is a top priorities and the prospective memory task is a secondary task (McDaniel et al., 2015). Subjects do not allocate extra resources to prospective memory tasks until sufficient cognitive resources are available to complete ongoing tasks. As previous research suggested that in case multiple tasks need to consume cognitive resources, cognitive resource allocation strategy can flexibly allocate limited cognitive resources to each task according to the consumption status of each task (Loft et al., 2008).

The difficulty of cognitive load can affect prospective memory performance, which is consistent with the existing research results (Kidder et al., 1997). Previous studies have suggested that when cognitive load increases, people assigned more cognitive resources on the ongoing tasks, resulting in less attentional resources allocated to prospective memory tasks, which in turn affects prospective memory performance (Einstein et al., 1997). Under standard cognitive load condition, the ongoing task is relatively easy, and occupies less cognitive resources. Thus, people can assign more cognitive resources on prospective memory tasks, ensuring higher prospective memory performance. However, under the high cognitive load condition, the ongoing task is more difficult and takes up more cognitive resources. Thus, people need to allocate less cognitive resources to prospective memory tasks, thus reducing prospective memory performance (Einstein et al., 1997; Marsh et al., 2002, 2003; Smith, 2003). However, people often have to face a variety of stress events in everyday life, which will inevitably produce different cognitive load, thus causing the failure of prospective memory.

We also observed that different encoding modalities have different effects on prospective memory. The prospective memory performance under enactment encoding condition is significantly better than that under verbal encoding condition, which supports the previous results (McDaniel & Scullin, 2010; Pereira et al., 2018, 2015, 2012a, 2012b). McDaniel and Scullin (2010) compared the prospective memory performance between enactment group and execution intention group and showed that the prospective memory performance under the enactment condition is better than that under the execution intention condition. It may be that the two encoding methods have different effects on the monitoring and retrieval of intentions. Specifically, enactment encoding is better at responding to the prospective memory cues and retrieving the intended intention than execution intention encoding. It is likely that enactment encoding may facilitate both the automatically recognizing of the prospective memory cues and the spontaneously retrieving of the intended intention. On the one hand, participants focus on the verb, the noun, and the whole action phrase during encoding, so that the information of the action phrase is fully processed by enactment (Kormi-Nouri, 1995). In addition, performing an action makes people focus on the action-relevant information, thus providing optimal item-specific information, which makes the items more distinctive, thus allowing the items to emerge in memory easily (Schatz et al., 2011; Zimmer et al., 2000). As previous research pointed out that the more distinctive the target cue relative to the array of other stimuli is, the more likely the successful detection of that cue (Cohen et al., 2003). Thus, the distinctive cues result in the involuntary capture of attention (McDaniel & Einstein, 2000) and switch attention from an ongoing task to the prospective task and causes the individual to retrieve the cues spontaneously (Einstein et al., 2000). On the other hand, previous researches demonstrated that enactment allows a particularly strong unitization of the cue–action components (Kormi-nouri, 1995), which creates a strong association between the expected cue and intended action. When the target cue occurs, it will lead subjects to retrieve the intended intention, prompting subjects to respond to prospective memory tasks quickly, thereby improve the prospective memory performance. Due to the existence of these two processes, the retrieval of prospective memory can be stably affected by the enactment encoding and less affected by the cognitive load. However, this study does not support the findings of several researches, which took enactment encoding as a strategy to promote the execution of intentional retention, not a strategy to enhance cue-action associations (Schaefer et al., 1998; Schult & Steffens, 2017).

In this study, our findings in the enactment encoding condition are in line with Einstein et al.'s (2005) multi-process framework, suggesting that intended intentions can be retrieved automatically without affected by the difficulty of the ongoing task. This mainly reflected in the following two aspects. For one thing, enactment encoding may facilitate both the automatic monitoring of prospective memory cues and the spontaneously retrieving of the intended intention, making the prospective memory performance no significant difference under the two cognitive load condition, suggesting that intended intentions can be retrieved without the need for strategic monitoring. For another, prospective memory performance under high cognitive load condition was significantly worse than that under standard cognitive load condition, suggesting that the retrieval of prospective memory is a non-automatic process in certain condition. Therefore, we considered that different encoding modality can lead to the retrieval of prospective memory either be controlled or relatively automatic processing. Whether the retrieval relies on control process or the relatively automatic process, is related to the strength of the association between the cue and the intended action (Einstein et al., 2000).

Conclusions

To summarize, the results revealed that the higher the cognitive load of ongoing tasks, the worse the performance of prospective memory for verbal encoding. However, for enactment encoding, enactment encoding enhanced the performance and abolished the difference between high and low cognitive load effects on prospective memory. We believe that enactment encoding may facilitate both the automatically monitoring of prospective memory cues and the spontaneously retrieving of the intended intention. However, these explanations are speculative, and should be verified in future research.

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Conflict of Interest The authors declare that they have no conflict of interest.

Ethical approval The procedure performed in the study involving human participants was in accordance with the ethical standards of the Ethnic Committee of Jiangsu Normal University.

Informed consent The informed consent was obtained from all individual participants in the study.

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