PROSPECTIVE MEMORY: THE FUTURE FOR FUTURE INTENTIONS

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Prospective memory is the ability to remember to execute future intentions and thoughts. It is probably the newest established field of memory research. We provide a selective review of work conducted in the last two decades with respect to the following issues: (1) the different types and characteristics of prospective tasks, (2) the theoretical models of the cognitive processes supporting prospective memory, (3) prospective memory performance in younger and older adults and (4) the findings from neuropsychological and neuroimaging studies. The findings indicate an extraordinarily fast progress in our understanding of the behaviour and the brain regions that are involved in this important ability, and suggest at least two possible emerging areas of enquiry for future research: a link with the closely related field of prospection (i.e., thinking about the future), and "expectation prospective memory" (triggering of behaviour in the absence of awareness depending on contingencies learnt from the environment).

Prospective memory (PM) is commonly defined as the set of abilities that are used when remembering to perform an intended action, or thought, at some future point (Brandimonte, Einstein, & McDaniel, 1996). This type of memory is in constant use in everyday life in order to fulfil intentions ranging from the simple, such as remembering to take out the garbage when leaving home, to the more complex, such as remembering to organise a surprise party for a friend's birthday. This ability is critical to competent human functioning, so much so that previous studies have suggested that PM problems are the most frequent memory failures in everyday life (Kliegel & Martin, 2003). Relatively little experimental and theoretical investigation was conducted on this topic until the last 15 years. However, since then there has been a remarkable increase in number of research studies that have considered PM.

The nature of typical prospective memory paradigms

The majority of studies of the psychology of memory have focused on the phenomena related to learning and the reproduction of information or content, broadly referred to (mainly by prospective memory theorists) as *retrospective*

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memory (RM; Baddeley & Wilkins, 1984). In a typical retrospective memory experiment, the participant is asked to learn and remember certain material, such as a list of words. In the next stage either the experimenter or the presentation of an instruction, serves as an external cue, which encourages the participant to remember the material at the appropriate time. Since this type of remembering is always triggered by an external cue, it has been termed "cued remembering" (Levy & Loftus, 1984; Wilkins & Baddeley, 1978). By comparison, in a typical PM paradigm one is required to remember to perform intentions to be carried in the future without any obvious requirement from the environment regarding the appropriate execution time of these intentions. For this reason, remembering intentions is sometimes called 'uncued' (Levy & Loftus, 1984) or 'self cued' (Wilkins & Baddeley, 1978) remembering.

Different types of PM intentions, which vary along many dimensions, have been studied over the past twenty years (Kvavilashvili & Ellis, 1996). However, the most cited distinction between them contrasts event-based with time-based PM (e.g., Einstein & McDaniel, 1990; Park, Hertzog, Kidder, Morrell, & Mayhorn, 1997), both of which have been well studied. In event-based PM the environment can serve as an external cue to prompt the intention that was formed. For example, the sight of a convenience store might bring to mind the intention to replenish the milk. In time-based PM, an intention is formed to be executed either at a predetermined time, such as calling the dentist at 5pm, or after a specific period of time has elapsed, such as taking the cookies out of the oven before they get overcooked. One way to view the distinction between these two types of tasks is that time-based PM is more self-initiated whereas event-based PM is more environmentally cued (Block & Zakay, 2006). However, others claim that this distinction is not useful since in some naturalistic time-based situations one has access to external chronometers, which may serve as event-based cues (Graf & Grondin, 2006). Most published work has concerned itself with the cognitive processes associated with storing and realising event-based intentions (Cook, Marsh, & Hicks, 2005). As a result, the theories concerning event-based memory are more developed, as are the various laboratory techniques used in its study. Less studied forms of PM (in addition to time-based PM) are habitual PM (Meacham & Leiman, 1975), and activity-based PM (Kvavilashvili & Ellis, 1996). Habitual PM tasks are those where the action is performed repeatedly and in a routine manner. For example, remembering to take vitamins every day at 8pm. Activity-based PM, on the other hand, requires the intention to be retrieved and executed upon completing some other task. For example, remembering to call a friend after dinner.

For experimental purposes the characteristics of tasks involving PM have been simplified and are summarised below (adapted from Burgess, Scott, & Frith, 2003).

1. There is an intention, or multiple intentions (Kliegel, McDaniel, & Einstein, 2000), upon which to act.
2. The intended act cannot be performed immediately after the intention has been formed.
3. The intention is to be performed in a particular circumstance, called the "retrieval context" (Ellis, Kvavilashvili, & Milne, 1999). This can be marked by an external cue, in event-based paradigms, or a particular time, or certain duration, in time-based paradigms.
4. The delay period between creating the intention and the appropriate time to act (i.e., the "retention interval") is filled with an activity called the ongoing activity (Ellis et al., 1999).
5. Performance of the ongoing task prevents continuous, conscious rehearsal of the intention over the entire delay period. This is typically because the ongoing activity places a heavy demand on competing cognitive resources or the delay is too long.
6. The PM cue does not interfere with, or directly interrupt, performance of the ongoing task. Intention enactment is therefore self-initiated (Graf & Uttl, 2001) and, thus participants are required to recognise the PM cues or retrieval context themselves.
7. In most situations involving PM no immediate feedback is given in response to the participants' errors or other aspect of performance.

In 1990, Einstein and McDaniel developed a typical experimental paradigm for controlled laboratory-based studies on PM. In order to parallel a 'real life' situation as far as possible, participants are first engaged in an ongoing activity (e.g., indicate which of the 2 numbers presented on the screen is numerically bigger). In the second stage, while they are fully engaged with the ongoing activity, the PM instructions are introduced and participants are asked to try to remember to perform an unrelated action at some pre-specified point in the experiment (e.g., respond differently when both numbers are even). This paradigm allows one to measure performance by the proportion of trials in which participants correctly remembered to execute the PM task and the ongoing activity. Many variations of this paradigm were carried out in order to look at the different cognitive processes that form the basis of PM, including, for example, the length of the retention interval, the importance of the PM task, and the cognitive load of the ongoing activity.

Cognitive processes underlying prospective memory retrieval

In the last 15 years several theories have been proposed to account for the cognitive processes that support event-based PM retrieval in an attempt to discover how the cognitive system enables one to execute intended actions at the appropriate time. The main approaches are as follows:

Spontaneous retrieval theory

When Einstein and McDaniel (1990) started using the experimental design they had developed, they noticed that many participants were reporting that the PM intention "popped" into their mind while they were performing the ongoing task. In an attempt to explain how the environment can trigger the retrieval of associated memories, McDaniel, Robinson-Riegler, and Einstein (1998) described an 'automatic-associative' memory system. Their mechanism was directly linked to Moscovitch's (1994) automatic-associative subsystem mechanism. During the formation of an intention, an associative link is formed between the intention and the associated action related to this intention. This cue-action pairing exists with a certain level of activation. Unless rehearsal, or some other activity aimed to raise the activation level, occurs, the level of activation will gradually decay. However, if the cue produces enough interaction with the memory trace, then the system will deliver the information associated with the cue to a person's awareness. In other words, the aim of this mechanism is to mediate PM retrieval if the cue interacts sufficiently with the representation of the associated action in such a way that the associated action is transferred to awareness (McDaniel et al., 1998). Illustrating this model in an everyday life situation, one might consider when someone forms the intention of giving their flatmate a message. When forming the intention, an initial association is made between the flatmate, who serve as the PM cue, and the message, which is the intended action that is linked to the PM cue. If the association between the flatmate and the message is strong enough, when encountering the flatmate the cognitive system will reflexively deliver the intended message into the person's awareness.

To test this idea, McDaniel, Guynn, Einstein, and Breneiser (2004) manipulated the strength of the association between PM cue words. Some of the words were strongly associated, such as spaghetti/sauce, while others were weakly associated, such as spaghetti/church. They found that PM performance was better when the cue was strongly associated with the intentions (accuracy of 85%) compared with when the cue-response association was weak (accuracy of 56%). Similar findings were reported when the semantic context of the PM cue changed from encoding to retrieval, e.g., the PM cue word 'bat' was encoded in a specific context ('a baseball player will use a bat several times in a game') but retrieved in either the same ('a hard swing of the bat could lead to a home run') or different ('a bat is commonly classified as a bird because it flies') contexts (McDaniel et al., 1998, experiment 1). In addition, superior PM performance was found when the ongoing task involved deep semantic processing (e.g., generating adjectives) compared with shallower processing (e.g., generating rhymes, McDaniel et al., 1998, experiment 3). These findings suggest that under certain encoding conditions one can increase the likelihood of forming a strong cue-action association that, in turn,

will increase the chances of the cue to interact with the memory trace and the intention to be retrieved at the appropriate time. A last set of findings comes from self reports of participants while performing the PM task (e.g., Hicks, Marsh, & Russell, 2000). In one study, participants were tested in a PM experiment and were asked to indicate at various time points during the experiment what they were thinking about. Most often (around 69% of the time) participants reported thinking about the ongoing task, and less than 5% of the time reported thinking about the PM task (Reese & Cherry, 2002). This suggests that after the PM intention has been formed and the link between the PM cue and the intended action was made, participants were relying on appearance of the PM cue to activate the cue-action association in order to trigger the execution of the PM intention.

Preparatory attentional and memory processes theory

An alternative model was suggested by Smith (2003; Smith & Bayen, 2004) who proposed that PM retrieval occurs through the capacity-demanding attentional process of monitoring the environment. According to the preparatory attentional and memory processes (PAM) theory (Smith, 2003), successful event-based PM requires capacity-consuming preparatory processes. The preparatory processes are engaged in maintaining a state of readiness to perform a task, which involves some degree of monitoring of the environment for the occurrence of PM target events. More specifically, the preparatory processes are not automatic and therefore require the allocation of some of the limited cognitive resources away from the ongoing activity and towards preparation for the PM task. In addition to the preparatory processes, according to the PAM theory, RM processes are also involved in PM performance. RM processes are needed for discrimination between PM target and non target events, as well as for recollection of the intended action, processes that are likely to absorb attentional resources when the target is present. This suggestion follows previous findings showing that increasing the cognitive load of the ongoing activity influences the performance on PM tasks (e.g., Kvavilashvili, 1987). However, the most striking evidence supporting the attentional monitoring theory comes from studies comparing performance in an ongoing activity before any PM involvement with performance in the same ongoing activity after adding the PM requirement. According to this theory, preparatory attentional processes include nonautomatic monitoring of the environment for the PM cue, therefore, when a PM task is embedded in an ongoing task, a reduction in the resources available for the ongoing task is expected, even when the PM cue is not present. To test this idea, Smith (2003) asked participants to perform a lexical decision task as the ongoing activity. In this task a string of letters was presented and participants were asked to indicate

whether or not the string represents a word. In the second part, the PM instructions were added and, in addition to performing the ongoing activity task, participants were instructed to respond differently to several PM cues. It was found that speed in making the lexical decision in the ongoing activity trials was significantly slower in the second part, when the PM task was embedded, compared with similar trials in the first part, before the PM task was added. This decrement in performance of the ongoing task whilst maintaining an intention has variously been termed 'attentional cost', 'task interference' or (our favoured term) 'intention cost', and was to our knowledge first demonstrated by Burgess, Quayle, and Frith, 2001. Other studies using a variety of ongoing tasks and PM cues on different populations have yielded similar findings, providing further support for the role of preparatory attention in PM (e.g., Cook, Marsh, Clark-Foos, & Meeks, 2007; Einstein, McDaniel, Thomas, Mayfield, Shank, Morrisette et al., 2005; Gilbert, Gollwitzer, Cohen, Burgess, & Oettingen, 2009; Guynn, 2003; Loft & Yeo, 2007; Marsh, Hicks, & Cook, 2005; Marsh, Hicks, & Cook, 2006; Marsh, Hicks, Cook, Hansen, & Pallos, 2003; McCauley & Levine, 2004; Smith, Bayen, & Martin, 2010; Smith, Hunt, McVay, & McConnell, 2007; West, Bowry, & Krompinger, 2006; see Smith, 2008, p. 42-46 for review). Furthermore, the intention cost upon the ongoing activity has been found to positively correlate with PM performance (Smith, 2003; Smith & Bayen, 2004), and has also been found on trials preceding PM hits compared with trials preceding PM misses (West, Krompinger, & Bowry, 2005).

Critics of this theory claim that constant use of attentional resources directed towards the PM task would be too costly to allow competent functioning in everyday life activities (McDaniel & Einstein, 2007). Accordingly, they argue that this theory might relate to PM in specific situations where the predictability of the appearance of the PM cue is low (Marsh, Hicks et al., 2006) or where retention intervals are relatively short (Einstein et al., 2005).

The multiprocess theory

The contradictory findings supporting both attentional monitoring and spontaneous retrieval processes led McDaniel and Einstein (2000) to change their initial single-process model. According to their updated multiprocess model, PM retrieval can be supported by both attention-demanding monitoring and also by more automatic processes. Whether one will rely on a monitoring or spontaneous retrieval process depends on several factors such as the characteristics of the PM task, the ongoing task, and also the individual. In other words, they argue that the system that accomplishes PM retrieval is flexible and dependent on several mechanisms. The task conditions that are likely to favour each process are detailed below and summarised in Table 1 (p. 182).

1. The extent of attention directed from the ongoing activity to the PM cues

McDaniel and Einstein (2007) argue that spontaneous retrieval is more likely to occur when there is a large overlap between the information that is extracted from the PM cues at retrieval and the information that is considered about this cue during the encoding. This idea was taken from the transfer-appropriate processing explanation of RM effects (e.g., Morris, Bransford, & Franks, 1977) suggesting that memory performance is determined by the relationship between how information is initially encoded and how it is later retrieved. In 2005, Einstein et al. (experiment 2) asked college students to complete a category verification task and also to form an intention to make a PM response each time they encountered a specific word (e.g., the word "dormitory"). In another condition, they asked participants to make a PM response each time they encountered a word containing a specific syllable (e.g., the syllable "tor") while performing the category verification task. Accuracy for cue detection was dramatically different with greater accuracy in the condition where a specific word was used as the PM cue (93%) compared to the condition where a syllable was used as the PM cue (61%). In addition, task interference to the ongoing activity was found when a syllable was used as the PM cues but not when a specific word was used as the PM cues. The findings led them to distinguish between *focal cues* and *nonfocal cues*. Focal cues were defined as "PM cues that overlap with the information constellation relevant to performing the ongoing task" and nonfocal cues as "cues that are present in the environment but not part of the information being considered by the person" (McDaniel, Einstein, & Rendell 2008, pp. 141-160). Further support for the suggestion that the "focality" of the ongoing activity can influence the retrieval processes in PM tasks has been given by subsequent studies (Brewer, Knight, Marsh, & Unsworth, 2010; Scullin, McDaniel, & Einstein, 2010; Scullin, McDaniel, Shelton, & Lee, 2010). Importantly, a potential problem has been highlighted in applying the distinction between focal versus nonfocal *a priori*, which results in confusion in the classification of some task conditions (e.g., Smith, 2010).

2. Cognitive load of the ongoing activity

According to the multiprocess theory (McDaniel & Einstein, 2000), the demand on resources required by the ongoing activity is another essential factor that influences the dominance of either monitoring or spontaneous retrieval processes. More specifically, it states that a decrease in resources available for monitoring should interfere with PM performance mainly on tasks involving nonfocal PM cues. For example, Marsh, Hancock, and Hicks (2002) manipulated the demand of the ongoing activity task and found that participants who were asked to switch randomly between two ongoing tasks

showed poorer PM performance when the PM cue was nonfocal, than those performing a single task. Similar results were found when using PM cues that were focal to the ongoing activity task (Einstein, Smith, McDaniel, & Shaw, 1997).

3. Saliency of the PM cue

Distinctive PM cues should produce a higher level of PM performance compared with nondistinctive cues (McDaniel & Einstein, 2000). Support for this is found when using uppercase letters as PM cues, as opposed to lower case letters in the ongoing activity task (Brandimonte & Passolunghi, 1994, experiment 2) and when using unfamiliar distinct cue words (e.g., the word "bole") than familiar non distinct cue words (e.g., the word "belt"; Einstein & McDaniel, 1990, experiment 2; McDaniel & Einstein, 1993). However, Smith et al. (2007, experiments 1 and 2) showed that using perceptually or semantically salient PM cues resulted in task interference to the ongoing activity, contradicting the predictions of the multiprocess account.

4. Association between the PM cue and the intended action

A further factor that affects cognitive processing during retrieval of PM is the strength of the association between the cue and the associated action. More specifically, spontaneous retrieval is likely to be dominant when the cue and the action are highly associated. However, when the relationship between the cue and the action is not very strong, processing of the cue is less likely to result in reflexive retrieval of the intended action and therefore monitoring of the environment for the cue is more likely to be dominant (McDaniel et al., 2004). Loft and Yeo (2007) looked at the relationship between the ongoing task performance and PM performance under conditions of low and high cue-response association and found response cost on ongoing trials preceding PM hits compared with PM misses under the low association condition but not under the high association condition. Other studies showed improved performance when manipulating pre-exposure to PM cues between participants (Guynn & McDaniel, 2007) or within participants (Mantyla, 1993), suggesting that pre-exposure to the PM cues benefited from high cue-action association promoting reflexive retrieval processes.

5. Importance of the prospective memory intention

The multiprocess account states that PM intentions of high importance, especially nonfocal ones, will produce better PM performance (McDaniel & Einstein, 2000). This suggestion follows previous findings showing higher PM performance under conditions in which successful performance of the PM

task has been emphasised (e.g., Ellis, 1998; Kvavilashvili, 1987, experiment 2; Meacham & Singer, 1977). Kliegel, Martin, McDaniel, and Einstein (2001) extended this prediction, claiming that task importance is relevant only in event-based tasks and not in time-based ones. However in a later study Kliegel, Martin, McDaniel, and Einstein (2004) demonstrated that task importance can impact performance on some event-based PM tasks, especially when the task required strategic allocation of attentional monitoring resources (see Einstein et al., 2005, experiment 1, for similar results).

6. Length of prospective memory retention interval

In the retrospective memory literature, longer retention intervals quite predictably lead to a higher forgetting level (Linton, 1978). For PM, however, the dynamics determining forgetting seem less straightforward. Loftus (1971) reported poorer performance after longer, compared with shorter, delays. Similarly, Meacham and Leiman (1982) reported greater decline in performance after a 5-to 8-day delay compared with a 1-to 4-day delay, in the absence of external memory aids. Finally, Brandimonte and Passolunghi (1994, experiment 1) showed a decreased in PM performance when the retention interval increased from 0 (i.e., no delay condition) to 3 minutes and proposed that forgetting in PM task occurs primarily within the first 3 minutes after encoding. According to the multiprocess account, when the PM cues are nonfocal, a decline in PM performance is expected when the retention intervals are increased (McDaniel & Einstein, 2007). The results of some studies supported this prediction (e.g., Einstein et al., 2005, experiment 2). However, other studies did not find any difference between short and long retention intervals (e.g., Einstein, Holland, McDaniel, & Guynn, 1992; Guynn, McDaniel, & Einstein, 1998), or found the opposite pattern of results such that a longer retention interval produces better PM performance (Hicks et al., 2000, experiments 1A, 1B and 3).

7. Planning

Burgess and colleagues (e.g., Burgess, Veitch, Costello, & Shallice, 2000; see Burgess et al., 2008 for review) have demonstrated that what one does during encoding, or planning, can affect the performance of retrieval of PM. In other words, planning during encoding has an important consequence for the successful retrieval of PM intentions. The multiprocess theory predicts that good planning at encoding will prompt spontaneous retrieval processes during PM performance (McDaniel & Einstein, 2000). In one form of planning, the instructions provide specific information about the context in which the PM cues will appear (Marsh, Hicks et al., 2006). A different aspect of planning was tested by Kliegel et al. (2000), who asked young and old participants to

remember to perform a single PM task while engaged in a range of processes that included executing a series of multiple intentions (Six Element Test, SET; Burgess, Alderman, Emslie, Evans, Wilson, & Shallice, 1996; Shallice & Burgess, 1991). Even though participants were specifically asked to plan aloud how they would perform the task, only 54.1% of the participants remembered to execute the PM task on time and only 50% of the steps indicated in the plans were subsequently followed. This suggest that despite having a formulated plan concerning the different components involved in the PM intention, execution of the intention did not necessary followed the intended plan.

Table 1
A summary of the task conditions which according to the multiprocess theory
(McDaniel & Einstein, 2007) favour spontaneous retrieval or monitoring processes.

	Factors	**Task conditions favouring spontaneous retrieval approach**	**Task conditions favouring monitoring approach**
Task conditions related to the ongoing activity	The extent of attention directed from the ongoing activity to the PM cues	Focal cues	Nonfocal cues
	The cognitive load of the ongoing activity	Lower cognitive load of the ongoing activity task	Higher cognitive load of the ongoing activity task
Task conditions related to the PM cue	The salient of the PM cue	Distinctive cues	Non-distinctive cues
	The association between the PM cue and the intended action	Strong cue-action association	Weak cue-action association
Others	Importance of the PM task	Low importance of the PM task	High importance of the PM task
	Length of PM retention interval	Long retrieval intervals	Short retrieval intervals
	Planning	Extensive planning	Poor planning

Prospective memory and aging

Craik (1986) suggested that performance in memory tasks in general is influenced by an interaction between external factors, such as environmental support and the type of operation required, such as self-initiated activity. Specifically, Craik hypothesised that age-related differences should increase with the amount of self-initiated activity necessary to accomplish a memory task and should decrease with the amount of environmental support provided. In Craik's view, PM is characterised by the greatest need for self-initiated activity and the lowest degree of environmental support when compared with RM tasks such as free recall or recognition. Thus, larger age-related impairments are expected in PM than in RM. However, findings from extensive work that

was done on how age effects PM within the older population indicate that the picture is more complex than one might think at first (see Henry, MacLeod, Phillips, & Crawford, 2004, for a meta-analytic review).

Age-related effects were initially investigated in laboratory studies that used time- and event-based PM tasks, (e.g., Einstein, McDaniel, Richardson, Guynn, & Cunfer, 1995), where no age-related effect was found in the event-based task; however, older participants performed significantly worse in the time-based task, a finding which was in accordance with Craik's prediction. Subsequent studies supported this finding (e.g., Cherry & LeCompte, 1999; Cherry, Martin, Simmons-D'Gerolamo, Pinkston, Griffing, & Gouvier, 2001; Einstein & McDaniel, 1990; Marsh, Hicks, Cook, & Mayhorn, 2007; Reese & Cherry; 2002). A good example is that of d'Ydewalle, Bouckaert, and Brunfaut (2001), who tested 48 younger participants (aged 18-25 yrs) and 48 older participants (aged 60-86 yrs). The ongoing task was an arithmetic test, which aimed to use more executive resources with increasing complexity of the arithmetic operation. They found that time-based prospective memory among older adults was much poorer when the complexity of the ongoing task was increased. An age-related impairment was also obtained when the pacing of the event-based prospective memory task was high, which they interpret as being due to general slowing due to age.

However, some studies have reported age-related effects in event-based PM tasks (e.g., Maylor, 1993; Maylor, 1996; Maylor, 1998; Maylor, Smith, Della Sala, & Logie, 2002; Park et al., 1997; Smith & Bayen, 2006; West & Craik, 1999; West & Craik, 2001; Zimmerman & Meier, 2006), so age effects may not be restricted to time-based PM. One potential explanation for these differences is related to the design of these experiments. An analysis of the studies that failed to find an age-related effect shows that the majority of researchers adjusted, that is, reduced, the difficulty of the ongoing task for older participants (Kvavilashvili, Kornbrot, Mash, Cockburn, & Milne, 2009).

Another controversial aspect is related to the environmental context of this experiment. Younger adults tend to outperform older adults in laboratory-based PM tasks (e.g., d'Ydewalle, Luwel, & Brunfaut, 1999; Maylor, 1993; Maylor, 1996; Rendell & Craik, 2000; Vogels, Dekker, Brouwer, & de Jong, 2002). However, when using real-life conditions in naturalistic settings, a different pattern emerges. Some studies did not find any difference between young and old adults (West, 1988) while others showed that older adults outperform younger adults in naturalistic tasks (e.g., Bailey, Henry, Rendell, Phillips, & Kliegel, 2010; Devolder, Brigham, & Pressley, 1990; Moscovitch, 1982; Rendell & Thomson, 1993; Rendell & Thomson, 1999). Together, the discrepancy in these findings has been referred to as the *age PM paradox* (Rendell & Craik, 2000), remaining a puzzle for applied developmental

research (Rendell, McDaniel, Forbes, & Einstein, 2007). Trying to resolve these contradictory findings, it has been argued that young and old adults may differ in their motivation to complete PM tasks successfully outside the laboratory (Patton & Meit, 1993; Rendell & Craik, 2000). A recent support for this was given when incentives were found to affect younger but not older adult participants' PM performance (Aberle, Rendell, Rose, McDaniel, & Kliegel, 2010, experiment 2), suggesting that young adults might not be sufficiently motivated in naturalistic settings, but when highly motivated, younger but not older adults outperform their normally motivated counterparts.

The cognitive neuroscience of prospective memory

Neuropsychological studies

Extensive work from the last decade has targeted possible impairments in event- and time-based PM functioning across a range of different neuropsychological populations. Impairments have been found when, for example, testing patients with Parkinson's disease (Costa, Peppe, Caltagirone, & Carlesimo, 2008; Katai, Maruyama, Hashimoto, & Ikeda, 2003; Kliegel, Phillips, Lemke, & Kopp, 2005; although see Altgassen, Zöllig, Kopp, Mackinlay, & Kliegel, 2007 for different findings), high-functioning children and adolescents with ASD (Jones, Happé, Pickles, Marsden, Tregay, Baird et al., 2011; Rajendran, Law, Logie, van der Meulen, Fraser, & Corley, 2010; Zinke, Altgassen, Mackinlay, Rizzo, Drechsler, & Kliegel, 2010; although see Brandimonte, Filippello, Coluccia, Altgassen, & Kliegel, 2011 for different results), patients with bipolar disorder (Lee, Xiang, Man, Au, Shum, Tang et al., 2010), patients with obsessive-compulsive disorder (Racsmany, Demeter, Csigo, Harsanyi, & Nemeth, 2011), and patients with schizophrenia (Altgassen, Kliegel, Rendell, Henry, & Zöllig, 2008; Henry, Rendell, Kliegel, & Altgassen, 2007; Kondel, 2002; Kumar, Nizamie, & Jahan, 2005).

Several studies have shown impaired event- and time-based PM performance in adults with traumatic brain injury (TBI) (Carlesimo, Casadio, & Caltagirone, 2004; Fortin, Godbout, & Braun, 2002; Groot, Wilson, Evans, & Watson, 2002; Kinsella, Murtagh, Landry, Homfray, Hammond, O'Beirne et al., 1996; Kliegel, Eschen, & Thöne-Otto, 2004; Knight, Harnett, & Titov, 2005; Knight, Titov, & Crawford, 2006; Mathias & Mansfield, 2005; Potvin, Rouleau, Audy, Charbonneau, & Giguère, 2011; Roche, Fleming, & Shum, 2002; Shum, Valentine, & Cutmore, 1999; Umeda, Kurosaki, Terasawa, Kato, & Miyahara, 2011; for review see Shum, Levin, & Chan, 2011). PM impairments have also been found in children with TBI (e.g., McCauley & Levin, 2004; McCauley, Pedroza, Chapman, Cook, Hotz, Vásquez et al., 2010b; McCauley, Pedroza, Chapman, Cook, Vásquez, & Levin, 2011;

McCauley, Wilde, Merkley, Schnelle, Bigler, Hunter et al., 2010a; Ward, Shum, McKinlay, Baker, & Wallace, 2007). This is commonly attributed to the fact that the retrieval of PM intentions appears to be subserved by prefrontal and temporal regions, brain structures which are particularly vulnerable to a TBI. Some researchers have looked at ways to improve PM performance and found that reminders (McCauley & Levin, 2004), monetary rewards (McCauley, McDaniel, Pedroza, Chapman, & Levin, 2009) and compensatory training (Shum, Fleming, Gill, Gullo, & Strong, 2011) improve performance in event-based PM tasks in children with both mild and severe TBI.

Other studies have examined patients with other form of neurological problem, e.g., stroke patients (Brooks, Ross, Potter, Jayawardena, & Morling, 2004), and people with frontal lesions from a variety of causes (e.g., Cockburn, 1995). In general, they tend to demonstrate impaired performances on both time- and event-based PM tasks compared with the matched control group. However there are more specific findings in patients with particularly circumscribed lesions. Volle, Gonen-Yaacovi, de Lacy Costello, Gilbert, and Burgess (2011) compared the performance of 45 patients with focal brain lesions with 107 control participants in event- and time-based PM tasks, accompanied by a series of secondary tasks that examined the basic aspects of attention and speed, response inhibition, problems remembering multiple instructions, and task switching. They found that lesions in the right polar prefrontal region, approximating Brodmann area (BA) 10, were specifically associated with a deficit in the time-based PM task. This could not be attributed to impairments in performance of the secondary tasks, and therefore was associated solely with PM performance. In addition, the fact that the impairment was seen only in the time-based task suggests that time- and event-based PM might be supported, at least in part, by distinct brain regions.

Neuropsychological investigations have suggested that other brain regions also support PM performance. For instance, the involvement of temporal lobe structures in PM was examined when 13 patients with lesions in the left temporal lobe plus a matched control group were tested on time-based PM tasks (Palmer & McDonald, 2000). Significant impairments were found in the patients group compared with the controls participants in all of the time-based tasks (e.g., "every 15 minutes tell the experimenter what you are working on", "at a pre-specified time tell the experimenter that the testing should almost be finished").

Event-related brain potentials

There are few studies that have explored the neural correlates of processes associated with encoding of PM. In three studies, age-related differences were explored using a similar paradigm in which the encoding of the PM

intentions was embedded in a continuous ongoing activity (West, Herndon, & Covell, 2003; West & Ross-Munroe, 2002; Zöllig, Martin, & Kliegel, 2010) and in one study a paradigm was used in which individuals encoded short action phrases that were not part of an ongoing activity (Leynes, Marsh, Hicks, Allen, & Mayhorn, 2003). Findings from the former studies have consistently revealed three modulations of event-related potentials (ERPs) that have been shown to differentiate ongoing activity trials from intention formation trials: a late positivity complex (LPC), fronto-polar slow waves (FPSW), and temporo-parietal slow waves (TPSW). The LPC reflects positivity over the parietal region of the scalp and negativity over the lateral frontal regions with a peak around 600 ms. after stimulus onset and reflects a difference between later-retrieved (i.e., PM hit responses) and later-unretrieved (i.e., PM miss responses) intention trials. The FPSW reflects a sustained negativity over the frontal-polar region of the scalp and lasts approximately from 500 to 1000 ms. after stimulus onset. This phenomenon was shown to exist in young adults but not in old ones (West, Herndon et al., 2003; Zöllig et al., 2010). Finally, the TPSW reflects greater positivity in later-retrieved intention trials than in later-unretrieved intention trials, only in old adults, beginning at 800 ms. after stimulus onset and lasting for the remainder of the ERP.

Similar to findings from studies of the neural correlates of encoding of PM intentions, researchers who looked at retrieval processes in PM have consistently reported three components of modulations of the ERPs associated with PM (West, Herndon, & Crewdson, 2001; West & Krompinger, 2005; West & Ross-Munroe, 2002). The first is N300, representing negativity over the occipital-parietal region starting around 300 ms. after stimulus onset. This modulation represents differences between PM and ongoing activity trials. The second modulation is frontal positivity, reflecting positivity over the midline frontal region which, similarly to the N300, represents differences between PM and ongoing activity trials. This ERP modulation starts at around 200 ms. after stimulus onset and lasts for several hundred milliseconds. The N300 and frontal positivity are thought to reflect processes that are related to the processing of event-based PM intentions that go beyond the specific characteristic of the PM intention or the demand of the ongoing activity (West, 2007; West et al., 2001; West & Krompinger, 2005; West & Ross-Munroe, 2002). The last modulation associated with retrieval of PM is parietal positivity, representing sustained positivity over the parietal region of the scalp between 400 and 1200 ms. after stimulus onset; it distinguishes PM cue trials from ongoing activity trials (West & Wymbs, 2004). It is assumed to reflect 3 functionally and temporally distinct components of the ERP associated with the detection of low probability intentions (West, Herndon et al., 2003; West & Wymbs, 2004; West, Wymbs, Jakubek, & Herndon, 2003), the recognition of the PM cues (called parietal old-new effect; West, 2007; West, Carlson, &

Cohen, 2007a; West & Krompinger, 2005; West, McNerney, & Travers, 2007b) and the configuration of the PM task set (Bisiacchi, Schiff, Ciccola, & Kliegel, 2009; West et al., 2001; West, Wymbs et al., 2003).

Positron emission tomography

Four studies have so far used positron emission tomography (PET) to explore the neuroscience PM. (Burgess et al., 2001; Burgess et al., 2003; Okuda, Fujii, Ohtake, Tsukiura, Yamadori, Frith, et al., 2007; Okuda, Toshikatsu, Yamadori, Kawashima, Tsukiura, Fukatsu et al., 1998). These add weight to the neuropsychological findings suggesting some kind of frontal lobe involvement in PM. More specifically, the findings highlight a consistent relation between the activation of the rostral prefrontal cortex (rPFC) and performance on a variety of PM tasks. For example, Burgess et al. (2003) showed that two rostral prefrontal regions show activation during PM tasks. Medial anterior PFC shows a decrease in cerebral blood flow when people are maintaining an intention, and relatively greater regional cerebral blood flow when performing the ongoing task only, with no intention to maintain. On the other hand, lateral rostral PFC shows an increase in cerebral blood flow during performance of PM tasks, but relatively less when performing the ongoing task only. These findings have been found in other PET studies (Burgess et al., 2001; Okuda et al., 2007; Okuda et al., 1998), and agree well with findings from fMRI as well (see Burgess, Gonen-Yaacovi, & Volle, 2011 for review). They seem to represent a "standard pattern" of activation within this region for event-based PM tasks. The situation for time-based tasks however seems on present evidence to be more complex (Okuda et al., 2007).

Functional magnetic resonance imaging

As mentioned above, further support for the role of rFPC in PM has been obtained from fMRI studies. A meta-analysis of the overlapping regions of activation from all the fMRI studies of PM tasks reveals that performance during PM tasks, relative to the ongoing tasks, tends to be associated with activations in rPFC (Burgess et al., 2011). This general finding is supported by all studies where paradigms have been used where the performance in an ongoing task was compared directly with that in a PM task (den Ouden, Frith, Frith, & Blakemore, 2005; Gilbert, 2011; Gilbert et al., 2009; Hashimoto, Umeda, & Kojima, 2010; Haynes, Sakai, Rees, Gilbert, Frith, & Passingham, 2007; Okuda et al., 2007; Okuda, Gilbert, Burgess, Frith, & Simons, 2011; Poppenk, Moscovitch, McIntosh, Ozcelik, & Craik, 2010; Reynolds, West, & Braver, 2009; Simons, Schölvinck, Gilbert, Frith, & Burgess, 2006).

More specifically, activations in lateral rPFC are most often associated with maintaining a delayed intention (den Ouden et al., 2005; Gilbert, 2011; Gilbert et al., 2009; Okuda et al., 2011; Reynolds et al., 2009; Simons et al., 2006), a finding which is in agreement with other suggested theories regarding the role of lateral rPFC (e.g., Christoff & Gabrieli, 2000; Koechlin, Basso, Pietrini, Panzer, & Grafman, 1999). In addition, activation in medial rPFC during an ongoing or control task tends to be higher than during a PM task (Hashimoto et al., 2010; Okuda et al., 2007; Simons et al., 2006).

When considering the findings for activations in either medial or lateral rPFC in event-based tasks, some regions (but certainly not all, see below) seem remarkably insensitive to task-related performance details such as the form of stimulus material presented, the nature of the ongoing task, and the level of difficult in detecting the PM cues (Burgess et al., 2001; Burgess et al., 2003; see also Simons et al., 2006). This idea follows the use of "conjunction-type" designs (Burgess et al., 2003) where several tasks are used that differ along many dimensions (e.g., the type of ongoing task, the stimulus material, the question being answered, the PM cues etc.) and then at the analysis stage one looks for activations that are common across all the tasks. For other regions within the rPFC there does seem to be functional specialisation for different components, forms, and types of PM. For example, Gilbert et al. (2009) contrasted brain activity that supports the retrieval of PM in 2 conditions that differed only in the pre-task instructions provided to participants. In a "cued condition", participants were asked to produce a specific response whenever a PM cue appeared. The task instruction was "if the same letter is on both sides, then I will press the middle button", i.e., emphasising a close link between the intended action and the PM cue. By contrast, in a "self-initiated condition", the instruction took the form of: "if the same letter is on both sides, then I can score 5 points", emphasising the reward goal of the task rather than the specific action to be made in response to the PM target. Even though all other aspects of the paradigm were identical, differences in rPFC were found during the PM task even just with these small changes in instruction format. Responding to PM intentions in the self-initiated condition was associated with greater activation in lateral rPFC, whereas responding to PM intentions in the cued condition was associated with greater activation in medial rPFC. Other factors that may affect rPFC during PM are variations in implicit cues (Hashimoto et al., 2010), the nature of the PM intention (Haynes et al., 2007) and the characteristic of the intention retrieval (Simons et al., 2006).

Other activations outside rPFC are also commonly associated with PM performance. More specifically, there is frequent activation of BA7 and BA40 during PM tasks. Activation within one or both of these regions is almost as common as activation within rPFC (e.g., Burgess et al., 2001; den

Ouden et al., 2005; Eschen, Freeman, Dietrich, Martin, Ellis, Martin et al., 2007; Gilbert et al., 2009; Hashimoto et al., 2010; Okuda et al., 2011; Poppenk et al., 2010, Reynolds et al., 2009; Simons et al., 2006). Evidence from electrophysiological methods also suggests a possible link between PM performance and tempo-parietal regions (see West, 2011 for review). It is likely that sub-regions within BA40 & 7 support different processes associated with PM. For instance, Poppenk et al. (2010) found angular gyrus activations (BA7) for one condition (hits > misses) but also superior parietal lobe (BA7) for the opposite contrast (misses > hits). Another example is from Hashimoto et al. (2010), who found activations in the inferior region of the inferior parietal lobe (BA40) when comparing performance in the control condition compared with the PM condition, but at the same time, activations in more superior regions on the inferior parietal lobe (BA40) were found during PM blocks.

Another region often associated with PM performance is the anterior cingulate cortex (BA32; Hashimoto et al., 2010; Okuda et al., 2011; Reynolds et al., 2009; Simons et al., 2006). It seems that, similarly to BA40 & 7, different subregions support different components of PM; however, the findings so far are not as strong and consistent as the findings related to rPFC or parietal lobe. For example, Okuda et al. (2011) reported activations in the right anterior cingulate cortex during PM performance in one condition (expand > contract) and also activations in another section of this region in the opposite condition (contract > expand).

Putting the future into prospective memory

The neuroscience of prospective memory has been progressing especially rapidly over the last ten years or so, but is still in its infancy. This review has attempted to cover the main recent empirical findings in a field which is becoming increasingly coherent. So the time is right to consider where within PM the newest developments may occur. Two of these will be considered here.

The first concerns "prospection". While the growth of PM as an area of enquiry this has been happening, there has been a parallel development of a new and strongly related field: the cognitive neuroscience of "episodic future thinking" or "mental time travel" (e.g., Atance & O'Neill, 2001; Boyer, 2008; see Burgess et al., 2011 for review). There are many different terms for this kind of mental phenomenon, which we will refer to as "prospection" (Burgess et al., 2011) since that was a rather neater and previously existing term for it. Prospection refers to the mental experience of imagining the future, especially in a goal-driven way. Curiously perhaps, given that prospective memory and prospection are so obviously related in that they deal with future

thoughts and actions rather than the traces of past ones, each of these fields has developed almost completely independently, thus far. However, in the last few years there have been exciting developments in understanding prospection (e.g., Addis, Pan, Vu, Laiser, & Schacter, 2009; Schacter, Addis, & Buckner, 2007; Schacter, Addis, & Buckner, 2008; Szpunar, Watson, & McDermott, 2007; Weiler, Suchan, & Daum, 2010; Williams, Ellis, Tyers, Healy, Rose, & MacLeod, 1996), and there is one point in particular that might be made when thinking about the future of future thinking and how it relates to prospective memory.

This point is that, as with studies of prospective memory, rostral PFC activations appear to be found very commonly in neuroimaging studies of prospection. Indeed, Burgess et al. (2011) reviewed 13 studies of prospection, and found that all but one reported activation in rostral PFC, which is a roughly comparable level of consistency that one finds with studies of prospective memory. This common activation need not reflect a common processing component to prospection and maintaining an intention (the assertion that common activations reflect common processing across tasks is known in the field of neuroimaging as a "reverse inference", and is generally thought to be precarious). However, if it does, what might that be?

One possibility is raised by Benoit, Gilbert, Frith, and Burgess (2011). Their study aimed to see whether functional imaging data is consistent with the idea that the "rostral PFC attentional gateway" is involved in performance of prospective memory paradigms. The rostral PFC attentional gateway is a hypothetical cognitive mechanism proposed by the "gateway hypothesis" of rostral PFC function (e.g., Burgess, Dumontheil, & Gilbert, 2007). This asserts that a principal purpose of rostral PFC is to control differences in attending between "stimulus-independent thought" (i.e., our inner mental life) and that involved in preferential attending to the external world ("stimulus-oriented attending"). Benoit et al. (2011) used a factorial design, crossing prospective memory (PM vs. no-PM) with mode of attending (stimulus-oriented (SO) vs. stimulus-independent (SI)), the latter of which has previously been shown to activate rostral PFC (see Burgess et al., 2007 for review). The purpose of the experiment was to determine whether the foci of activations in PM were the same as those activated by SI/SO attention changes. They found that parts of mrPFC were jointly recruited during (i) mere ongoing task activity versus additional engagement in a PM task, and (ii) stimulus-oriented versus stimulus-independent processing. This is congruent with the notion that some of the processes mediating PM performance can be characterised by relative differences in these attentional modes as proposed by the gateway hypothesis. At the same time, the PM contrast was consistently associated with more dorsal peak activation than the stimulus contrast, perhaps reflecting engagement of additional processes. Burgess et al. (2011) argue that this

same "attentional gateway" might also be used in engaging prospection, because it requires drawing one's attention away from the current environment and creating an "inner mental world". Currently, it seems possible that the currently larger topic of prospective memory may in the future be viewed as perhaps the most developed sub-class under the broader heading of "prospection". Key to this is the very special role that rostral PFC (and other PFC structures) seem to play in enabling people to engage in imaginative thought, aspects of which are critical to creating intentions for future acts (prospective memory), and considering the potential consequences of them (prospection).

A second possible future development point within the field of prospective memory concerns the role of awareness and "cognitive control" in the maintenance and remembering of delayed intentions. As this review outlines, it is clear that most theorists regard there as being both automatic- and controlled-type processing underpinning the maintenance and execution of a delayed intention. However, it seems to be generally assumed (but rarely examined) that the participant is broadly "aware" of the contingencies affecting their behaviour. But this assumption is challenged by a recent study by Okuda et al. (2011), who developed a PM task where the intervals between prospective memory targets were manipulated in a predictable alternating cycle of expanding and contracting target intervals. "Expanding" means that the number of ongoing trials between PM targets was increasing, and "contracting" means that the number of ongoing trials between targets was decreasing. Okuda et al. (2011) found that the participants' behaviour changed in accordance with these changing target intervals. Prospective memory performance (measured by responses to PM targets) was faster and more accurate in the expanding target interval phase, at the cost of less accurate and slower performance on ongoing trials. But in the contracting phase the opposite pattern was found: faster and better ongoing trial performance but poorer PM performance.

Remarkably however, although the participants' behaviour was affected, the changes in target intervals, they were completely unaware of them – in the sense that when asked none of them reported being aware of any pattern in target interval, or of any change in their behaviour. Nevertheless, fMRI detected a trade-off effect in activations in the anterior medial prefrontal cortices that mirrored the changes in participant behaviour. We found activation increases in response to the PM targets that was accompanied by deactivation to the ongoing trials in the expanding phase as compared with the contracting phase. The opposite pattern was observed in the anterior cingulate cortex.

These patterns of behaviour and BOLD signal changes are not easy to explain according to the "monitoring" or "spontaneous retrieval" frameworks. The medial rostral PFC activations are probably not indicators for

some form of deliberate, conscious "monitoring" or "working memory" operation, because participants were unable to report their behaviour changes or the changes in target intervals. Similarly, the consistency of the relation between the changes in target interval and PM performance is also difficult to explain by a simple "spontaneous retrieval" account, since it is entirely predictable and seems to be cued by the experimental context and not just the PM target. It seems possible instead that what has been detected here may be the neural signature of a process which effects automatic (i.e., unconscious) coordination of attentional resources between ongoing task performance and a delayed intention.

Moreover, this kind of effect may not be restricted just to PM situations. Blais, Harris, Guerrero, & Bunge (2012) have shown a similar effect using a Stroop task. They examined the size of the congruency (i.e., Stroop) effect according to the proportion of congruent trials given. Their paradigm demonstrated the well-known phenomenon where the proportion of congruent trials had a marked behavioural effect upon performance (where reaction times are slower when incongruent trials are less frequent). But, critically, they asked participants about the relative proportion of congruent/incongruent trials. They found that the proportion by congruency interaction was unrelated to participants' awareness of the actual frequencies. So here again, we have a situation where behaviour is being governed by contingencies even though participants are unaware of them (in the sense of being able to report them). It seems very likely on the evidence of these very recent papers therefore, that there may be processing at work in PM situations which has only just been started to be considered – perhaps one might think of it as "expectation prospective memory" – i.e., where regularities in the environment (e.g., temporal or proportional) set up expectations akin perhaps to priming within the cognitive system at a level which is not routinely available for self-report.

Conclusion

The past 15 years have seen a huge increase in experimental research targeted at understanding prospective memory. By 1996 there were only 45 published experimental studies on PM (Kvavilashvili & Ellis, 1996). However, from 1996 until 2005, over 285 published papers appeared (McDaniel & Einstein, 2007). This rate of increase is in turn increasing. We have attempted to summarise the main conclusions from the theoretical and empirical work that has been carried out in this emerging field. As contrasted with 20 years ago, we now have some degree of agreement about what constitutes a PM paradigm. Moreover, whereas in the early years it was not clear whether the term "prospective memory" described a variety of behaviours supported by a variety of different processing resources, or the operation of a particular construct (or

limited set of them), these days most theorists would take the former position. The prevalent current theories highlight the importance of different factors upon behaviour and processing, such as the characteristics of the ongoing task and the PM cue, on determining the types of processes that support retrieval of PM and the likelihood of PM success. Remarkably however, given the complexity and multiplicity of these findings, neuropsychological and neuroimaging investigations have suggested that there is a particular part of the brain (rostral prefrontal cortex, approximating Brodmann area 10) that is involved in a wide range of PM situations, presenting hope that there may be a common processing resource that might provide a meeting point for understanding the processing underpinning PM. Finally, we suggest that two promising future developments for the field of prospective memory might be integration with the findings from prospection more broadly, and also the consideration of "expectation prospective memory" – the triggering of PM responses without awareness in response to contingencies detected in the environment.

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