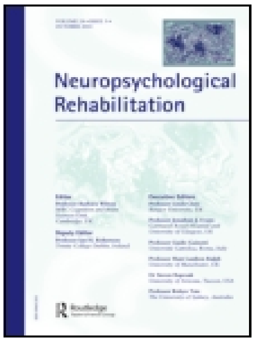

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Errorless learning of prospective memory tasks: An experimental investigation in people with memory disorders

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The term prospective memory (PM) refers to memory for future intentions. PM problems are frequent in people with cognitive impairment and, because they are central to the realisation of many everyday goals, are important in rehabilitation. Event-based PM tasks (EBPM) are environmentally-cued and have primarily mnemonic demands, whereas time-based PM tasks (TBPM) require self-initiated retrieval, and have greater executive demands. Errorless learning (EL) is an encoding method that results in superior retrospective memory compared with "errorful" learning (EF). As this EL advantage (ELA) likely stems from its reduced explicit memory demands, and there is no such advantage for executive tasks, a greater ELA for EBPM than TBPM was predicted. Fourteen adults with neurological memory impairment completed PM tasks under four counterbalanced conditions: EL of EBPM, EL of TBPM, EF of EBPM, and EF of TBPM. A significant ELA was observed for EBPM ($d = .63$), but not TBPM ($d = -.01$). These results extend the evidence for EL within cognitive rehabilitation, by showing for the first time that the method can benefit future action in addition to retrospective memory. The clinical implications are also

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clear: errorless learning techniques may be usefully employed to support completion of day-to-day EBPM tasks.

Keywords: Cognition; Rehabilitation; Treatment; Everyday abilities.

INTRODUCTION

Prospective memory

"Prospective memory" (PM) tasks involve remembering to act upon previously formed intentions. They are frequent in everyday life, and include remembering to pay the gas bill or take medication. Within Squire and Zola's (1996) taxonomy, PM is a subtype of episodic memory, but its future-oriented nature distinguishes it somewhat. Memories for intended future action are, for example, more accessible than memories for past actions (Goschke & Kuhl, 1993), and thinking about the future has greater frontal/executive demands than thinking about the past (Weiler, Suchan, Koch, Schwarz, & Daum, 2011). Recent research, however, has emphasised the overlap in the brain mechanisms underlying prospective and retrospective thought (Schacter, Addis, & Buckner, 2007). As no dissociations have been reported, the processes are unlikely to be supported by independent systems.

Completion of PM tasks involves a range of functions. Fish, Wilson, and Manly (2010) emphasised a cognitive hierarchy whereby memory for the intention is a prerequisite, yet insufficient to ensure success. Attentional and executive processes (i.e., those processes that guide behaviour towards goals; Kopp, 2012) are also required, to notice the retrieval cue, passage of time, or execution opportunity, retrieve and act upon the intention, and manage these processes within the context of concurrent activities that may distract from the goal. There are also metacognitive aspects of PM, including task-specific awareness of errors, performance evaluation, and more general insight into one's PM abilities (see Figure 1).

Within a limited capacity system in which different goals may compete for attention, holding onto a delayed intention could reduce available capacity for other activities taking place in the interim. In experiments this can be examined through relative performance of an activity (called the "ongoing task") with and without a second instructed PM element. Smith (2003) has argued from such studies that PM load invariably has a cost related to monitoring for the execution cue. However, Einstein et al. (Einstein & McDaniel, 1996; Einstein et al., 2005; Scullin, McDaniel, & Einstein, 2010) report that interference is determined by factors such as the similarity or relevance

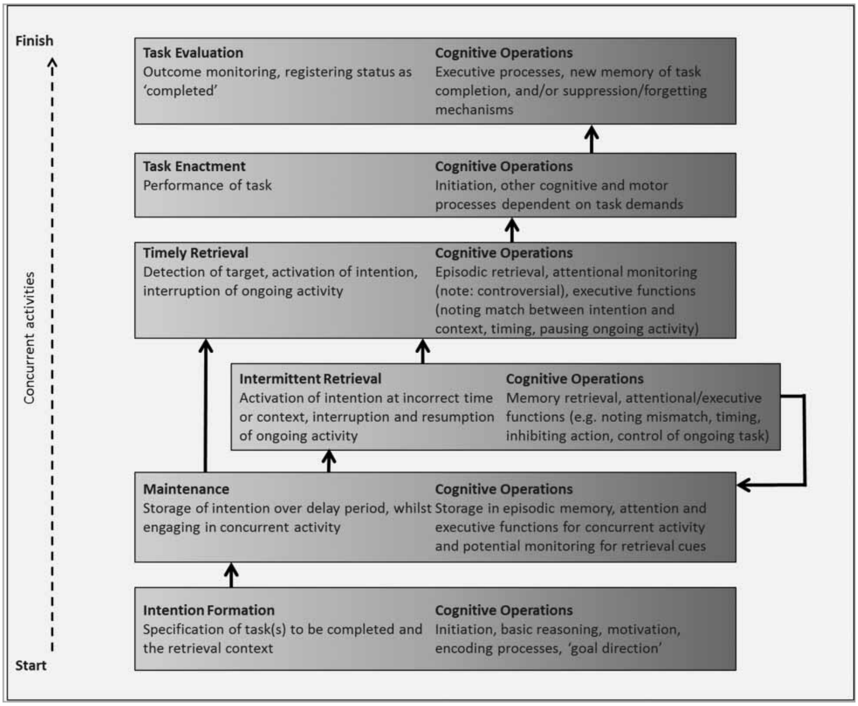

Figure 1. Schematic diagram showing stages involved in completion of prospective memory tasks and associated cognitive operations.

of the ongoing task to the PM task. When the PM task is particularly distinctive or familiar, little or no cost to the ongoing task may be apparent.

Einstein and McDaniel (1996) differentiated between event-based and time-based PM tasks (henceforth EBPM and TBPM). EBPM tasks are enacted in response to an external occurrence (e.g., posting a letter on passing a pillar box) and TBPM tasks are enacted at a particular time (e.g., attending an appointment at 1:30). Whilst clear distinctions can be difficult to draw in naturalistic tasks, this separation is useful in thinking about the cognitive processes required. The representation of a PM contains the action itself plus associated information (e.g., intending to contact the bank about a replacement card implies the content of the message and related information about banks, phones, e-mails, etc.). If the intention is well encoded, related content (e.g., a bank) may be sufficient to trigger the intention. In a pure TBPM task the only cues for execution are self-initiated (e.g., checking the clock, mentally calibrating the likely passage of time). If those processes are compromised, task execution is less likely, regardless of how well the intention has been encoded. In other words, in the first case a good representation of the intention may be sufficient for incidental triggering by events; in the second, a series of additional PM tasks (e.g., check the time) must also be enacted. These additional demands likely contribute to the disproportionate age-related decline in TBPM compared with EBPM (d'Ydewalle, Bouckaert, & Brunfaut, 2001). In line with this, neuroanatomical and neuropsychological analyses both in normal ageing (Gordon, Shelton, Bugg, McDaniel, & Head, 2011; McDaniel, Glisky, Rubin, Guynn, & Routhieaux, 1999) and in people with focal lesions following tumour resection (Burgess, Veitch, de Lacy Costello, & Shallice, 2000; Volle, Gonen-Yaacovi, de Lacy Costello, Gilbert, & Burgess, 2011) have reported that temporal lobe damage (particularly including the hippocampus) is associated with poor performance on EBPM tasks, and tasks with a minimal monitoring component (Gordon et al., 2011). Performance on tasks requiring monitoring (e.g., TBPM tasks, and EBPM where targets are difficult to detect), is in addition adversely affected by frontal lesions, more specifically to right frontopolar cortex (Volle et al., 2011).

Errorless learning in memory rehabilitation

Errorless learning (EL) is "a teaching technique whereby people are prevented, as far as possible, from making mistakes while they are learning a new skill or acquiring new information" (Wilson, 2009, p. 89). One way of achieving EL is to use fading cues. To illustrate, a person may be told that a photograph is of "Anne Smith". He or she would then be asked to avoid guessing, and given a strong cue such as "Anne Smit . . . ". Over successive trials the cues are systematically reduced (Anne Smi . . . Anne Sm . . . , etc.) until recall is successful from the photo alone. Baddeley and Wilson (1994) found that participants with severe memory impairment learned more items from word lists under errorless learning compared with an errorful control, and demonstrated in a series of case studies an EL advantage (ELA) for learning object names, novel face–name associations, new facts, names of rehabilitation ward staff, items of orientation information, and methods for programming memory aids. These findings have been independently replicated (Squires, Hunkin, & Parkin, 1997; Tailby & Haslam, 2003), and a meta-analysis of eight studies comprising 168 participants reported a large effect size (where $d = .87$, 95% CI: 0.1–1.64; Kessels & de Haan, 2003). More recently, ELAs have been reported for learning virtual reality routes (Lloyd, Riley, & Powell, 2009), verbal learning in children with brain injury (Haslam, Bazen-Peters, & Wright, 2012), and learning face–name associations in early-stage Alzheimer's disease and other dementias (Bier et al., 2008; Clare et al., 2000; Clare, Wilson, Carter, Hodges, & Adams, 2001; Haslam, Moss, & Hodder, 2010).

Some studies comparing EL with other methods of promoting learning (e.g., Dunn & Clare, 2007; Haslam, Hodder, & Yates, 2011) have found no ELA, or an EL disadvantage relative to spaced retrieval (SR) (Landauer & Bjork, 1978), a method in which information is recalled over expanding intervals. Middleton and Schwartz (2012) cautioned that error-minimising procedures, if associated with a reduction in retrieval practice[1], could be detrimental. However, the guidance has always been to incorporate EL within an active learning paradigm (Wilson, Baddeley, Evans, & Shiel, 1994), which would likely be one that maximises successful retrieval opportunities. Further, some of the studies reporting negative findings suffered from methodological confounds related to retrieval intervals or required effort/ engagement that would unduly favour comparison conditions. Overall, it appears there are strong empirical grounds that, *all other factors being equal*, EL procedures are likely to improve retrieval in people with memory impairments, relative to errorful methods.

The dominant view of the errorless learning advantage (ELA) is that espoused by Baddeley and Wilson (1994), and Page, Wilson, Shiel, Carter, and Norris (2006). They argue that as people with amnesia lack the explicit memory required to build up rich, contextual representations, they rely upon implicit memory when learning. When errors are made during learning, one needs to remember the correct response, the error, and identity of each. This is a more contextual representation, of the type impoverished in amnesia. People with amnesia are therefore more likely to have difficulty in distinguishing between correct and erroneous information that has previously been encountered. This increases the probability that an error will interfere with the correct information, be repeated and be consolidated. Consistent with this, Page et al. (2006) reported equivalent ELAs for participants with moderate and severe memory impairments, despite greater preserved explicit memory in the former. In slight contrast, Anderson and Craik (2006; see also Anderson, Guild, Cyr, Roberts, & Clare, 2012) found a reduced ELA in healthy young adults (i.e., those with good explicit memory), relative to healthy older adults (i.e., those with somewhat reduced explicit memory). In accounting for this they argued, as had Baddeley and Wilson, that prior errors caused more interference for those more reliant on implicit memory. In contrast, retention of the instances of negative feedback on errors in those with good explicit memory may help elaborate the learning process.

In line with both the suggestion that errors may help elaborate learning in those with intact systems but compromise it in people with capacity limitations, in a healthy population fMRI study, EL was associated with

[1]Retrieval practice is an established principle associated with improved performance (Roediger & Payne, 1982).

reduced frontoparietal activity compared with errorful conditions (Hammer, Templemann, & Münte, 2013). Similarly Hammer, Mohammadi, Schmicker, Saliger, and Münte (2011) reported that experimentally-induced reductions in neural firing within left dorsolateral prefrontal cortex (PFC) impaired memory performance after errorful but not EL. Both findings imply that the PFC and functions it supports have a role in EF that is absent/substantially reduced in EL.

In summary, neuropsychological studies indicate that people with compromised explicit memory are adversely affected by errors made during learning, and that implicit memory is sufficient to produce an ELA. The neuroimaging and neurostimulation studies suggest that EF has greater frontal/executive demands than errorless learning, and it seems likely that these relate to the identification and rejection of prior errors.

Applying errorless learning to prospective memory tasks

Approaches to the rehabilitation of PM have included retraining using repetitive exercises (Sohlberg & Raskin, 1996; Sohlberg, White, Evans, & Mateer, 1992a, 1992b), group-based strategy training programmes (Kinsella et al., 2009; Shum, Fleming, Gill, Gullo, & Strong, 2011), and use of external memory aids to remind the person of intended tasks at the appropriate time intervals (Kim, Burke, Dowds, Boone, & Park, 2000; Svoboda, Richards, Leach, & Mertens, 2012; Wilson, Emslie, Quirk, Evans, & Watson, 2005). There is also evidence that supporting individual cognitive components of PM tasks can improve performance. For example, Fish et al. (2007) found that supporting executive monitoring processes improved performance on an everyday PM task. A small group of studies has also examined the impact of learning strategies on PM performance. McKitrick, Camp, and Black (1992) found that learning PM task content (to check a noticeboard to identify one's daily tasks), with spaced retrieval led to improved performance of the task relative to baseline in four people with Alzheimer's disease (AD). Two further controlled studies have found that the same method leads to improved PM in people with early AD relative to a simple repetition control learning procedure, and that elaborated encoding (simply practising the PM task prior to the spaced retrieval condition), further improved subsequent performance (Kinsella et al., 2007; Ozgis, Rendell, & Henry, 2009). It stands to reason that an intention clearly stored in memory is more likely to be acted upon than an incorrectly stored or weakly remembered intention. In these studies, post-test memory for PM task instructions was not assessed, and so EL may have improved PM performance relative to EF by decreasing the likelihood of intentions being forgotten before the retrieval opportunity was presented. These findings are hence relatively uncontroversial, albeit with important clinical applications.

More recently, Grilli and McFarland (2011) found that self-imagery during encoding resulted in better PM performance than verbal repetition during encoding, even when PM task instructions were recalled in all conditions post-test. This suggests that encoding strategies may have benefits that extend beyond the initial stages of intention formation, to the timely retrieval and enactment stages of PM tasks.

Aims and hypotheses

In the current preliminary study, people with neurological memory impairment undertook two types of PM task (EBPM and TBPM), each under two encoding conditions (EL and EF learning). It was predicted that EL, through minimising interference with an implicit trace of the intention and/or reducing explicit memory demands, would be associated with more accurate retrieval and *execution* of that intention than intentions encoded with errors. Crucially, the prediction was that this would be the case *despite the intention being adequately retained* (in the sense of being accurately reported post-test) in both conditions. A second prediction concerned a differential effect of encoding condition on EBPM and TBPM tasks. Based on the model outlined above, EBPM tasks provide strong environmental cues linked to the stored intention. Improvements in the encoding of the intention after EL should allow the participants to recognise these cues and recall the associated intended action more reliably than after EF learning. TBPM tasks also require adequate retention of the intention but do not provide environmental cues and so require additional monitoring and self-initiated action. If EL enhances encoding of the intention but does not improve monitoring capacity, a less prominent or even absent EL advantage would be expected.

The specific hypotheses were that within a group of participants with episodic memory disorders: (1) There will be an ELA for EBPM that is greater than any ELA for TBPM, and (2) any ELA will occur without any associated detrimental impact on other aspects of PM performance (e.g., reduced accuracy or timing of responses to the ongoing task).

To test the specified hypotheses, a 2×2 factorial within-subjects design was employed, crossing the factor of encoding condition (Errorless, Errorful), with that of PM task type (EBPM, TBPM).

METHOD

Ethical approval and other administrative procedures

The study was approved by the relevant ethics committee (NHS Research Ethics Service Camden and Islington branch, REF 12/LO/0310), Research and Development Department at King's College London, and the Psychological Medicine Clinical Academic Group of King's Health Partners.

Participants

Participants were recruited from the Neuropsychiatry and Memory Disorders Service of the South London and Maudsley NHS Trust. This is a combined general neuropsychiatric and specialist memory disorders service providing assessment and treatment of conditions associated with memory or other cognitive impairment. Potential participants were screened according to the following criteria:

- Aged 18–70 years. This upper age limit was used as PM is thought to decline more substantially in the general population after this age, with more variability (Kvavilashvili, Kornbrot, Mash, Cockburn, & Milne, 2009), and including people with age-related as well as neurologically-based memory problems could complicate the interpretation of the results.
- Neurologically-based non-progressive memory impairment defined as memory functioning at least 1.5 *SD* below IQ (see below for details).
- Fluent in written and spoken English, without documented learning disability, and with a current IQ over 70, due to the significant verbal reasoning demands of the experimental task (in particular the ongoing task, see below).

Over a nine-month period, 17 patients met these criteria. Three did not take part; one for health reasons, and two because they could not be contacted. This left a final sample of 14. All participants gave written informed consent to participate.

The 14 participants (12 males, 2 females) had a mean age of 53.93 years (*SD* 8.27, range 38–69), and an average of 11.86 years of education (*SD* 2.19, range 9–17). Occupational classifications from the Office for National Statistics (ONS) categorised two participants as previously engaged in higher managerial or professional positions, six in intermediate occupations (e.g., clerical or service roles), and six in routine or manual occupations. Eight participants were currently unemployed and in receipt of disability benefits, two had retired from work on medical grounds, two had retired prior to the onset of their memory difficulties, and two were in part-time employment. According to ONS ethnicity classifications, 12 participants were White British, one Black African, and one Black Caribbean.

In six cases, the memory disorder resulted from cerebrovascular disease, in three cases cerebral hypoxia, two cases had temporal lobe epilepsy, and one had a head injury and small vessel disease. In the remaining two cases, the precise aetiology was uncertain; in one case it was either a stroke or hypoxia secondary to status epilepticus, and in the other case, there was neurological damage in the context of chronic poorly-controlled diabetes.

Measurement of memory impairment

Standard tests used routinely within the clinic were used to establish the 1.5 *SD* discrepancy between intellectual ability and memory functioning. The tests used varied slightly, but there were always results from recall and recognition tests of visual and verbal memory, using aggregate scores. We used existing clinical data as recent test results were available for the vast majority of patients, it considerably reduced the burden of participation, and minimised the risk of inflated scores linked with practice.

The current sample included people with a history of dyslexia, non-native speakers of English, and people with additional executive difficulties, which can complicate the measurement of estimated premorbid and current intellectual functioning. A pragmatic decision was made to use the most appropriate measures of intellectual ability on a case-by-case basis. The estimated Full-Scale IQ score (FSIQ) from the National Adult Reading Test (NART; Nelson & Willison, 1991) was used in three cases, the Wechsler Test of Adult Reading (WTAR; Wechsler, 2001) in one case, and from the Test of Premorbid Functioning (TOPF; Wechsler, 2011a) in two cases. The two-subtest FSIQ score from one of two versions of the Wechsler Abbreviated Scale of Intelligence (WASI-II; Wechsler, 2011b; WASI; Weschsler, 1999) was used in four cases, and the Matrix Reasoning *T*-score alone in four cases.

Memory performance was measured with the overall memory score from the Doors and People battery (Baddeley, Nimmo-Smith, & Emslie, 1994) in 12 cases, the composite verbal score in one case, and a composite from the story recall and figure recall subtests from the BIRT Memory and Information Processing Battery (BMIPB; Coughlan, Oddy, & Crawford, 2007) in one case[2].

The group memory versus IQ standard deviation mean difference was -2.55 (*SD* 0.69, max -1.67, min -4.0). The group's intellectual functioning was consistent with the population mean ($M\ z = .27$, $SD = 0.81$, max 1.67, min -0.75), and their memory functioning was relatively impaired ($M\ z = -2.26$, $SD = 0.69$, max -3, min -1.33). Note that two participants' memory scores would be classified as in the borderline range (9^{th} centile).

As would be expected in a mixed-aetiology group such as this, participants' impairments were not restricted to the domain of memory. Indeed, five participants had borderline scores on at least one test of executive function. Further detail on the sample is presented in Appendix 1.

[2]These deviations were due to differences in the test batteries in one case, and due to sparing of visual recognition memory in one case.

Design

The study was a 2 (encoding condition: Errorless Learning, Errorful Learning) × 2 (PM task type: Time-based, Event-based) factorial experiment. A within-subjects design was adopted as this reduces the variance stemming from individual difference factors that would necessitate substantially larger sample sizes, impracticable for this relatively rare patient group. All participants therefore took part in all four experimental conditions: Errorless Learning of an Event-based PM task, Errorless Learning of a Time-based PM task, Errorful Learning of an Event-based PM task, and Errorful Learning of a Time-based PM task. To minimise practice effects, parallel PM tasks were developed (PM task versions A, B, C, D; A and C being Event-based, and B and D being Time-based). Learning condition was counterbalanced on a between-session basis, so that half of the participants underwent Errorless Learning first, and half underwent Errorful Learning first. PM task type was crossed to control for order effects, with the restriction that only one Time-based and one Event-based task occurred per session. This partial counterbalancing approach was adopted as full counterbalancing may have lead to contamination of the encoding conditions. Specifically, switching between the instructions to “Only respond if you’re sure you’re right” versus “If you’re not sure, have a guess” within one session may have made it difficult to control the presence or absence of errors in the later part of the session.

Procedure

Participants were informed that the aim of the study was to investigate the effects of different learning methods on memory but, to minimise potential bias, any information regarding the specific experimental hypotheses was withheld. They completed each of the four experimental tasks in either one or two sessions. The original intention was to separate each session with a one-week interval; however, a number of participants requested one longer session rather than two shorter ones (e.g., to reduce inconvenience of making two journeys to the clinic). This meant that seven participants completed all tasks in one day (the sessions were separated by a break of at least 30 minutes), and seven in two sessions separated by one week.

Each experimental condition included four distinct phases:

1) Encoding: Presentation of instructions with vanishing cues (VC), in 3–5 cycles separated by a distracter digit span task, until the participant reached the criterion of correctly recalling the instruction, after completing the distracter digit span task, and without any prompts.

2) Delay: Completion of questionnaires for set 4-minute period[3].
3) PM task: Duration 16.5 minutes.
4) Post-test questions: These assessed memory of the instructions for both the PM and ongoing tasks.

At the end of the study, participants were given a brief verbal summary of the study's aims and reimbursed for their travel costs where appropriate at a flat rate of £10 per session.

Encoding procedures. In both errorless and errorful learning conditions participants learned the instructions for one of the PM tasks as a single sentence, e.g., "Press the red (blue) key when you see the word 'tigers' ('hammers')", or "Press the blue (red) key every other minute, starting at 1:00 (2:00)". Initially, the experimenter stated the task instructions for the ongoing task, and demonstrated it for approximately five trials. The participant then practised for a similar duration. This process was then repeated for the PM task, but without making specific reference to the target word or time interval (e.g., "Every now and then you'll have to do a different task, and for that task you press this button. We'll go through the details in a moment.").

The PM task instruction was then learned using one of two vanishing cues procedures along with prompts from the experimenter (see Figure 2 for a summary).

Errorless learning. The PM instruction sentence was displayed on a laptop monitor in white point 20 Arial font lettering on a black background. The participant was asked to read it aloud. The instruction sentence was then displayed with the final word deleted, it being replaced by blank underlining approximate to the missing word's length. The participant was again asked to read it aloud, and to fill in the gaps, but *only if they were sure they knew the answer*. They were instructed that if they were unsure of the response, they would be provided with a clue leading to the correct answer. To facilitate an active approach within the task, clues for certain words were in the form of descriptions (e.g., for the word "tigers", the description was "They're wild animals, a type of big cat that has stripes, the name has six letters and it starts with T"). Similar descriptions were also given for the other categories (hammers, red, blue, 1:00, 2:00) when relevant. This procedure continued, removing one word at a time, until the sentence could be recited in response to a series of blank lines representing each word. A brief distracter task was

[3]Note that this delay is somewhat shorter than that used with healthy subjects in the experimental literature, which are often 10–15 minutes, but it is consistent with the few studies of PM in people with memory impairment.

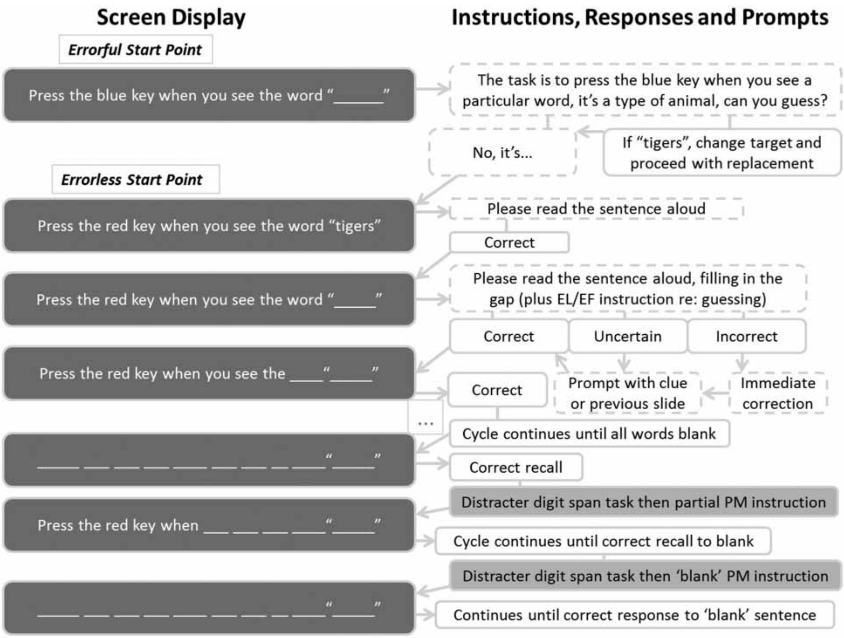

Figure 2. Flow chart detailing procedures for errorless and errorful encoding.

then completed, specifically 10 trials of a digit span task. This served to prevent continuous rehearsal of the task instruction. The vanishing cues procedure then resumed, with the first five words of the instruction displayed initially for the participant to complete, before words were again progressively removed. The digit span task was then repeated, and the vanishing cues procedure resumed, beginning with only the placeholders remaining. If at any point the participant was not confident in producing a correct response, a greater proportion of the sentence was displayed, before the process of progressive fading began again.

Errorful learning. The errorful learning procedure mirrored the errorless learning procedure, apart from the following characteristics. Firstly, a "forced error" was elicited by asking participants to initially guess the target word/ number. A second error was elicited by updating the stated colour of the key with which to make the PM response between the first instruction screen (which also included the blank lines for the target word), and the second, entirely correct, instruction screen (see Figure 2, and note that only one coloured response key was actually available during the PM task). Finally, guessing was encouraged within the instructions, rather than being discouraged. Aside from these manipulations, the previously outlined vanishing cues procedure was followed. If at any point a spontaneous error was made, the procedure reverted to the previous display, and the whole instruction was repeated. This was to ensure that exposure to the correct information was equivalent between the encoding conditions.

Common to both conditions, when participants either made errors or gave "Don't know" responses, corrective feedback was immediately provided. This took the form of either an easy question that elicited the correct response, or the direct provision of the correct information. This increased the number of times that correct information was repeated, over and above the standard presentations within the instruction slides.

The criteria for completing the encoding phase was accurate recall of the instruction in response to the blank sentence placeholders only, after a minimum of three VC cycles. The number of trials needed to meet the learning criterion was recorded, along with any errors made.

Measures

Prospective memory paradigm. The PM paradigm involved an attentionally demanding ongoing task with a further PM task to be performed on an infrequent basis. The task ran on a Dell Latitude D520 laptop computer. Throughout, participants responded using one of four clearly labelled keys located towards the lower right of the laptop keyboard. The leftmost was marked with a clock-face symbol. When pressed, this displayed the time elapsed from the start of the task. Adjacent to this was the PM response key, marked with either a red or blue sticker depending on the task version. To the right of this, there were two keys marked "T" and "F", with which true/false responses to the ongoing task were made. See Figure 3 for an illustration of the task.

The ongoing task was the same for all four versions of the paradigm. It was based upon the Speed of Comprehension test from the Speed and Capacity of Language Processing Test (SCOLP; Baddeley, Emslie, & Nimmo-Smith, 1992), also known as the "Silly Sentences Test"[4]. Participants were presented with a series of sentences, and asked to judge whether each was true (e.g., "apples are fruit", "desks can be bought in shops") or false (e.g., "beef steaks are fruit", "physicists can be bought in shops"). There were 404 such sentences (202 true and 202 false in content), presented serially in a random order, in a white sans serif font approximately 10 mm in height against a black background. The task was self-paced, with participants being instructed to respond as quickly as possible, whilst avoiding errors.

[4]This name refers to the occasionally comical nature of the false sentences in particular, which were created by mixing up the beginning and end of true sentences.

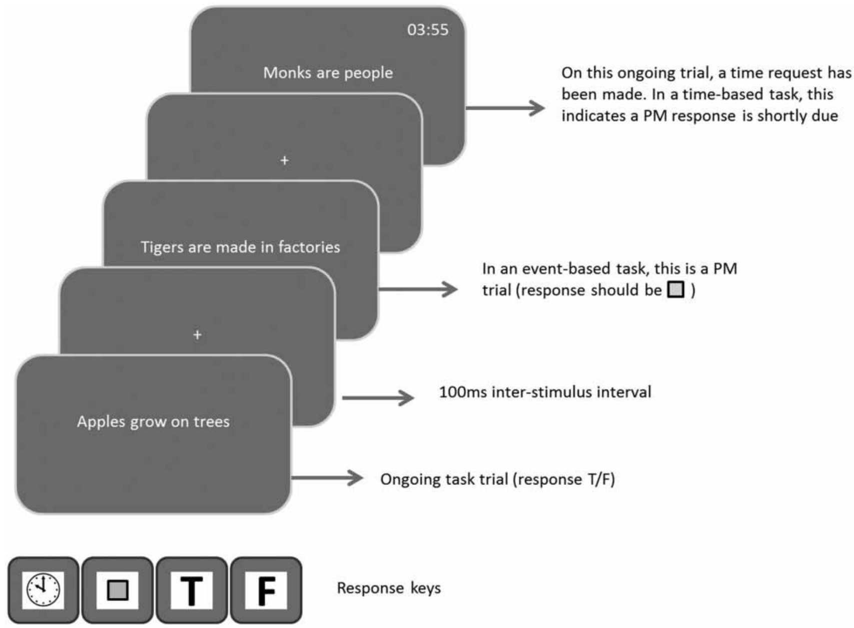

Figure 3. Illustration of the trial sequence and response format of the PM task. Note that examples of both event-based and time-based tasks are included, although in reality these would not occur within the same sequence.

The outcome measures were the number of sentences rated, the percentage correct responses, and median response times for both correct responses and errors.

There were four versions of the PM task; two event-based, and two time-based. To facilitate comparisons between the tasks, they were constructed such that each lasted 16.5 minutes and perfect performance necessitated eight responses. The instruction sentences each contained 10 words, and instructions for clock-monitoring were included in all conditions although this was a task-relevant activity for TBPM only.

The EBPM task was to press the designated key when a designated word appeared within a sentence (Either: "Press the red key when you see the word 'tigers'", or "Press the blue key when you see the word 'hammers'"). The target word appeared at pseudorandom intervals, the order of which was fixed for all participants (PM trials in Task A occurred on the trial subsequent to each of the following minute:second time-points: 1:25, 2:17, 4:12, 6:09, 7:38, 9:12, 11:23, and 12:07; and in Task C at 1:55, 3:46, 7:43, 8:16, 9:25, 11:14, 12:36, and 13:30). The outcome measures were correct and erroneous PM responses. Response times were recorded but not further analysed due to the low number of trials.

The TBPM task was to press the designated key every other minute, starting at 1:00 (version B), or at 2:00 (version D). Time-checking behaviour served a more obvious purpose in this time-based condition, which is to assist in accurate timing of the PM response. The timing and frequency of time-check responses was recorded, but not used in the analysis. PM responses within a window of 45 seconds either side of a target time were scored as correct.

Post-test questions: At the end of each task participants were asked to recall the instructions for both the ongoing and PM tasks. In the event of erroneous or "Don't know" responses, cued recall was tested (i.e., "You had another task to do too… to press a different button… which one was it… and when were you meant to do that?" etc.).

Background neuropsychological measures. In addition to the IQ and memory tests, additional measures of naming/semantic memory (Graded Naming Test; McKenna & Warrington, 1983) were available for 10 participants, and measures of executive functioning (letter and category fluency, Hayling & Brixton tests; Shallice & Burgess, 1997) for all but one. Participants also completed the Prospective and Retrospective Memory Questionnaire (Smith, Della Sala, Logie, & Maylor, 2000), the Hospital Anxiety and Depression Scale (Zigmond & Snaith, 1983), and the European Brain Injury Questionnaire (Teasdale et al., 1997). The results were not used in the analyses but are presented in Appendix 1, to assist in the characterisation of the sample.

Power calculation

Power calculations for the primary analyses of the main effect of encoding method on event-based PM performance, and the interaction between encoding and PM task type, were conducted using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007). The calculations were guided by the effect size reported by Kinsella et al. (2007), where the effect size for spaced retrieval was $d = 1.25$. This exceeds Cohen's (1992) threshold of $> .8$ for a "large" effect size. As this study used a different encoding technique, a more conservative $d = 0.8$ was carried forward for use in the calculation. On this basis, a sample of 12 participants gives 83% power to detect an effect significant at the 5% level in a one-tailed paired *t*-test. There was no existing clinical study comparing encoding procedures for different PM tasks on which to base a power analysis for the interaction effect. The final sample of 14 gave 88% power to detect large-sized effects, but only 46% power to detect a medium-sized interaction. Therefore, the statistical analyses were restricted to the two paired *t*-tests that examined the effects of interest, rather than the full factorial ANOVA.

Planned statistical analyses

The planned statistical analyses aimed to: (1) examine the effectiveness of the experimental manipulation in prompting and minimising errors as appropriate, (2) ensure that exposure to the correct information was equivalent between the encoding conditions, (3) to examine the impact of errors during learning on subsequent EBPM and TBPM accuracy (the primary analysis), and (4) to identify any impact of encoding condition or task type on ongoing task performance.

The approach was to initially inspect the distributions of raw data for all dependent variables of interest, by means of boxplots, Q-Q plots, and variance estimates. Where the distributions were approximately normal, parametric statistical tests were used, otherwise, non-parametric equivalents were employed. The differences between conditions were then examined using Analysis of Variance, *t*-tests, or their parametric equivalents. Effect sizes were also computed.

RESULTS

Preliminary analyses concerning the effectiveness of the experimental manipulations

This section presents results from a series of analyses conducted to determine the effectiveness of the experimental procedures in manipulating error rates and teaching PM task content, which are both essential for the interpretation of the subsequent experimental results. Analyses are presented for error rates and exposure to correct information during learning, and retrospective recall of task instructions, across the encoding and PM task type conditions. For summary data see Table 1.

The data included counts of infrequent events with limited variance and non-normal distributions. Non-parametric tests were therefore used throughout these preliminary analyses.

The occurrence of errors during learning. The errorful learning conditions were designed to elicit at least two "forced" errors, not present in the errorless learning conditions. The encoding conditions additionally varied in their inclusion of instructions to avoid versus encourage guessing, hence additional spontaneous errors could also occur. A Friedman's two-way Analysis of Variance by ranks for related samples confirmed that the error rates differed between the four conditions, $\chi^2(3) = 39.3$, $p < .001$. Follow-up pairwise comparisons confirmed there were more errors in the errorful compared with errorless conditions, for EBPM tasks ($z = -4.245$, $p < .001$), TBPM tasks ($z = -3.952$, $p < .001$), and EB-TB task pairs

TABLE 1
Rates of errors and prompts by encoding condition and task type

	Errorless Encoding		*Errorful Encoding*	
Condition / Measure	*EBPM* M (SD)	*TBPM* M (SD)	*EBPM* M (SD)	*TBPM* M (SD)
Total errors	0 (0)	0.143 (.363)	2.571 (1.016)	2.357 (.497)
Spontaneous errors	0 (0)	0.143 (.363)	0.571 (1.016)	0.357 (.497)
Prompts	.429 (.646)	0.214 (.426)	0.071 (.267)	0.500 (.650)
Exposure to correct information	.429 (.646)	0.357 (.497)	0.643 (1.15)	0.786 (.975)
Retrospective recall	13 correct spontaneously, 1 after prompt	All correct spontaneously	All correct spontaneously	12 correct spontaneously, 2 after prompt

($z = -4.245, p < .001$, and $z = -3.952, p < .001$). Within encoding conditions, error rates were equivalent for the EBPM and TBPM task comparisons, both for the errorless ($z = .488$, $p = .770$), and errorful ($z = 0.0$, $p = 1$) pairs. This shows that the encoding manipulation was successful in producing errors in the errorful conditions compared with the errorless conditions. This can be taken as evidence that the paradigm was effective in reducing, if not completely eliminating, errors (two were made in the errorless conditions, and 14 in the errorful); and that the error rates between event-based and time-based PM tasks were similar.

Exposure to correct information across encoding conditions and PM tasks. To examine any differences in the exposure to correct information between the encoding conditions, a composite measure of "prompts plus spontaneous errors" was created and used as the dependent variable in non-parametric analyses as above. A Friedman test indicated there were no differences in exposure rates between the four conditions, $\chi^2(3) = 2.130$ $p = .546$, see Table 1 for descriptive statistics.

Retrospective memory for PM task content. All participants were able to provide accurate information regarding PM and ongoing task content at the end of each testing condition. The majority reported this information in response to a general request to describe the task instructions. Two participants, however, required additional prompting to recall the precise details; one for the EF-TBPM condition, and one for both the EF-TBPM condition and the EL-EBPM condition. This prompting took the form, "You had another task to do too, to press a different button, which one was it? And when were you to press it?" These data were categorised into a binary "remembered unprompted" versus "remembered with prompt" variable, and entered into a Cochran's Q test for related samples. The test statistic was not significant, $Q(3) = 4.714$, $p = .194$, suggesting that there were no systematic differences in retrospective memory recall between the conditions. Furthermore, this indicates that all participants retained the details of both the ongoing and PM tasks, and by implication, any PM task failures did not result from low-level failures of retrospective memory for task content.

Primary analysis: The impact of encoding condition on prospective memory accuracy

This study's primary hypothesis was that there would be an interaction between encoding condition and PM task type. With a final N of 14, the study was not sufficiently powered to detect interaction effects within a Repeated Measures ANOVA any smaller than $d = 0.8$. The analysis therefore prioritised the two contrasts of primary interest, firstly that of EBPM performance between the errorless and errorful encoding conditions, and secondly of the errorless learning advantage (ELA) for the EBPM task compared with the TBPM task (equivalent to testing the interaction). These contrasts were assessed with paired t-tests and effect size calculations[5]. See Table 2 for summary data.

PM accuracy as a function of encoding condition and task type. A one-tailed t-test for paired samples confirmed the hypothesised difference in EBPM performance between the two encoding conditions, $t(13) = 2.274$, $p = .021$. After errorful encoding, the PM accuracy rate was 42.0%, whereas after errorless learning, PM accuracy was 66.1%. The effect size Cohen's d, calculated using Morris and DeShon's (2002) method for dependent data, was 0.63, which is considered to be a medium-sized effect (Cohen, 1992).

A paired t-test of the ELA difference scores, equivalent to testing the interaction between encoding and task type, did not reach the threshold for statistical significance, but it did indicate a trend in the predicted direction, $t(13) = 1.514$, $p = .077$. EBPM performance was 24.1% better after errorless learning conditions than after errorful learning, whereas the equivalent errorless learning "advantage" for TBPM was −0.01%. Cohen's d for this comparison was 0.41, considered small–medium. These results are illustrated in Figure 4.[6]

[5]Parametric tests were used as they are sufficiently robust to deviations from the normal distribution to the extent that would be expected within a sample of this size, and with a range of scores from only 0–8 converted to proportions, no scores can be considered outliers.

[6]As half of the participants underwent testing on one day and half on two days, we compared the ELAs for these two groups. No differences were apparent. Specifically, these analyses took the form of a nonparametric comparison of the ELA for EBPM between the one-session and two-session groups (one-session mean .196, SD .227, two-session mean .286, SD .534; Mann-Whitney $U = 23$, $p = .902$), and an equivalent comparison for the Time-based PM ELA (one-session mean −.046, SD .558, two-session mean .033, SD .360; Mann-Whitney $U = 29.5$, $p = .535$).

TABLE 2
Descriptive statistics for PM performance and the errorless learning advantage

PM Type	*Encoding condition*	*Mean*	SD	SE
EBPM	Errorless	.661	.378	.101
	Errorful	.420	.472	.126
TBPM	Errorless	.615	.442	.118
	Errorful	.621	.476	.127
EBPM	ELA	.241	.397	.106
TBPM	ELA	−.006	.453	.121

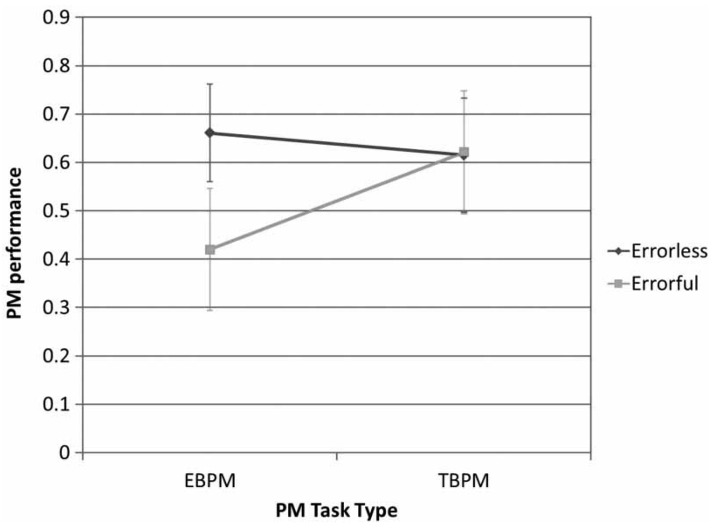

Figure 4. Mean EBPM and TBPM accuracy in errorless and errorful conditions. Error bars show standard errors.

Ongoing task performance across the experimental conditions

In much the same way that increases in performance accuracy frequently occur at the detriment to speed of performance, it is conceivable that differences in performance of the PM task may occur at the expense of performance on the ongoing task, reflecting, for example, a change in performance strategy. Given the difference in EBPM performance between the two encoding conditions previously identified, it is important to examine any associated impact of encoding or PM task type on ongoing task performance. The variables of ongoing task accuracy, number of trials, median RT and RTSD for each condition were all approximately normal, with approximately equal

TABLE 3
Descriptive statistics for ongoing task variables according to experimental condition

	Errorless M *(SEM) 95% CI*		*Errorful* M *(SEM) 95% CI*	
	EBPM	*TBPM*	*EBPM*	*TBPM*
Accuracy	94.87% (1.61) *CI: 91.39–98.36*	96.13% (.65) *CI: 94.73–97.54*	95.84 (1.14) *CI: 93.38–98.30*	95.82% (.81) *CI: 94.06–97.57*
N Correct	258.36 (27.09) *CI: 199.84–316.87*	253.43 (25.64) *CI:198.03–308.83*	260.72 (26.38) *CI: 203.74–317.69*	248.14 (25.52) *CI: 193.02–303.27*
Median Correct RT	2411.75 (306.61) *CI: 1749.35– 3074.15*	2611.68 (346.44) *CI: 1863.24–3360.12*	2502.46 (352.28) *CI: 1741.53–3263.40*	2694.36 (394.01) *CI: 1843.15–3545.56*
Correct RTSD	1710.17 (308.89) *CI: 964.74–2230.25*	1490.76 (247.27) *CI: 956.56–2024.961*	1597.50 (292.89) *CI: 964.74–2230.25*	1556.05 (285.26) *CI: 939.80–2172.31*

variance. As such, the data were deemed suitable for analysis within the General Linear Model. As there were no hypotheses regarding the effects of the experimental factors on ongoing task measures, the four measures were included in a repeated measures Multivariate Analysis of Variance (MANOVA). This analysis allowed for the detection of "overarching" effects that apply across some or all of the four dependent variables (i.e., the multivariate effects), in addition to effects on each individual dependent variable (i.e., the univariate effects). A repeated measures MANOVA was conducted on the dependent variables from the ongoing task of accuracy, number completed, median RT, and RTSD, with the within-subjects factors of encoding (Errorless, Errorful), and PM Task (TBPM, EBPM). The multivariate test showed no overall effect of encoding, $F(4, 10) = .171$, $p = .948$, $\eta\rho^2 = .064$, nor of PM task, $F(4, 10) = 1.714$, $p = .223$, $\eta\rho^2 = .407$, nor any interaction, $F(4, 10) = 1.314$, $p = .329$, $\eta\rho^2 = .345$. None of the associated univariate tests was significant. The descriptive statistics are shown in Table 3. This analysis suggests that the previously outlined effects of encoding on PM accuracy were not at the detriment of ongoing task performance.

DISCUSSION

Summary of results

This study investigated the impact of PM task encoding errors on subsequent performance of time-based and event-based PM tasks. We identified that, in a group of people with neurological memory impairment, event-based PM performance was significantly better when task instructions had been encoded under errorless learning conditions than errorful learning conditions. This errorless learning advantage had a moderate effect size ($d = 0.63$). In contrast, there was no ELA for the time-based PM task. The interaction between encoding condition and PM task type was not statistically significant in this small sample, but there was a clear trend, and the effect was of a small to moderate size ($d = 0.41$). Furthermore, this effect occurred without any detrimental effect on ongoing task performance, which may have been expected if participants had, for example, prioritised the PM task over the ongoing task in the errorless learning conditions. In addition, we successfully manipulated error rates during encoding, whilst maintaining equivalent exposure to correct information in both conditions, and ensuring successful post-test retrieval of the task instructions.

The present finding of a beneficial effect of EL on EBPM is consistent with earlier studies of retrospective memory (e.g., Baddeley & Wilson, 1994), and it extends them by showing that this technique, known to be effective for memory, can have subsequent effects on intentional behaviour. The finding that there was no ELA for TBPM is also in line with the hypotheses, but is rather more difficult to interpret, as null results can of course stem from a lack of statistical power, or use of an insensitive task. However, there are several observations that speak against these explanations. The EB and TB tasks were balanced in the number of actions required, and for the number of words in the instruction sentence. Their demands in terms of encoding (i.e., information to be remembered) and performance (i.e., the response required, the number of responses required) were therefore very similar. Furthermore, when EB and TB PM scores were collapsed across encoding conditions, accuracy was clearly at an equivalent level, and with very similar variance. Therefore, it does not seem likely that any simple measurement confound precluded detection of an ELA within the TBPM task. Along with the near-complete overlap in TBPM scores in the errorless and errorful learning conditions, this suggests at the very least that if an ELA could be detected for the TBPM task given a sufficiently large sample, then it would be significantly smaller than the ELA for EBPM. Nonetheless, the present results should be considered preliminary in nature.

The results in relation to models of prospective memory

PM tasks are composed of a series of stages, from encoding through retrieval to performance and evaluation. This study focused on experimental manipulation of a factor at the encoding stage to examine any later impact at the retrieval stage. This approach is frequently taken in the PM literature, where data from participants who do not remember the PM task instructions at the end of the test are often excluded from subsequent analyses, as it is assumed that this failure to report the task instructions represents a task failure at the lowest level of the hierarchy. Failures at these lower levels are likely very important in determining success or failure on PM tasks in everyday life, and if PM task instructions are more likely to be stored after errorless than errorful encoding procedures, then of course it is more likely that they would be subsequently acted upon (i.e., if a task is not learned it cannot later be performed). The question that this study addressed, however, was whether there would be an impact of errors made during learning at higher-level stages of PM, specifically at retrieval and the action initiation stages. The primary result, that PM performance was better after errorless learning than errorful learning for EBPM, supports the idea that differences in the encoding stage can have benefits at higher-level stages of retrieval and/or action initiation. It may well be the case that in more naturalistic settings, without the need to ensure adequate post-test retrieval across experimental conditions, the benefits of EL would be even larger.

The trend towards an interaction between encoding condition and task type is consistent with the multi-process model of PM. If the same retrieval processes were required in both TBPM and EPBM, then no such differential effect would be expected. However, this is not to say that the result provides any strong evidence against the competing Preparatory Attention and Memory model, as there were no "no PM task" conditions that would speak to the issue of whether simply holding an intention in mind is sufficient to reduce ongoing task performance.

The results in relation to research on errorless learning

Evans et al. (2000) stated that EL was likely to show benefits relative to EF learning in conditions that facilitate implicit retrieval, but not explicit recall of novel associations. Other studies have also concluded that the ELA is mediated by implicit rather than explicit memory processes (e.g., Anderson & Craik, 2006; Page et al., 2006). It could be argued that the retrieval process involved in our EBPM task is "implicit" (as a previously-learned external cue is presented for the participant to act upon), whereas the retrieval process involved in the TBPM task is more "explicit" (as the participant learns a task instruction but has to retrieve of his or her own accord). Thus, the present results apprear consistent with the literature. However, the event versus time distinction is not absolute, and neither is their reliance upon implicit versus explicit retrieval or mnemonic versus executive processes. If one were to create TBPM tasks that involved environmental cues, for example, then an ELA would be expected. Similarly, in an EBPM task with a target that required self-initiated monitoring to detect, no ELA would be expected. So far, the present results appear to tally with the literature.

Recent neuroimaging and neurostimulation studies in healthy volunteers have identified that the errorless learning is associated with reduced PFC activation compared with errorful learning (Hammer et al., 2013), and that temporary disruption of left PFC functioning impairs memory after errorful but not errorless learning (Hammer et al., 2011). If the ELA stems from circumnavigating the frontal demands of errorful memory retrieval, it follows that provided other factors (e.g., presentation time, elaboration, retrieval practice) are held constant, there should be an ELA for *any* memory task where successful retrieval involves screening out errors. The present results are not consistent with this prediction, as no ELA was evident for the TBPM task. However, we should keep in mind that the neuroimaging studies to date have only examined cued recall tasks, and future research will likely offer more precisely delineated predictions.

Given these neuroimaging results, would an ELA also be expected for executive or attentional tasks? It is conceivable that as errorless learning reduces the frontal demands of memory retrieval tasks, there would be a certain "freeing up" of frontal resources to be allocated to more purely attentional or executive demands. However, the frontal structures involved in episodic memory retrieval would not necessarily overlap with those involved in attentional or executive tasks, and not with PM tasks, which are most closely associated with anterior prefrontal cortex (Burgess et al., 2000). Therefore, it seems sensible to conclude that EL would be unlikely to benefit performance of executive or attentional tasks. Indeed, we saw no such effect in the present study.

Limitations and suggested modifications in future research

This study had limited statistical power to detect small or medium-sized effects. It is important to note that even though this study is preliminary, the results, and in particular the effect sizes generated, are informative and provide a good basis for subsequent work. The sample size is also comparable with many other similar studies (e.g., $n = 16$ in Baddeley & Wilson, 1994; $n = 12$ in Grilli & McFarland, 2011; $n = 10$ in Dunn & Clare, 2007).

The inclusion criteria for this study were broad, reflecting our intention to study a clinically representative group of people with memory problems, in whom rehabilitation techniques in question were likely to be clinically applied. As a result, the sample was heterogeneous in terms of age, aetiology, and time since injury. We also used individually tailored test batteries for the background assessment. These factors add a degree of complexity to the interpretation of the results (e.g., we do not know if the ELA may be more robust in particular aetiological groups or within more restricted age ranges). However, one would predict such heterogeneity to increase statistical variation and reduce power to detect statistical differences. As such these methods were conservative in relation to the hypotheses – if the ELA for EBPM and trend towards an interaction in the ELA between EBPM and TBPM were present in this small, varied group, the effects may be stronger or more robust in more closely defined groups. Additionally, the majority of our participants were male (12 males, 2 females); this balance is thought to be coincidental, as the general referral pattern of the service is more balanced.

We also intended to separate the two encoding conditions by one week to avoid any carry-over effects of the guess/don't guess instructions, but in seven cases testing was completed in one day. However, we compared the ELA in these two groups for both types of PM task, and found no suggestion of any difference. Further, the analysis of spontaneous error rates during encoding suggests this deviation from protocol did not result in any significant contamination of the two learning conditions. This is also useful for planning future studies.

Finally, the study used a rather artificial laboratory task to measure PM performance over brief timescales, and a rather artificial method of provoking errors. These were necessary first steps in examining the impact of errors during learning on PM performance, and ideally future studies would improve upon this aspect of the design by measuring the effects of naturalistic learning errors (or studying self versus experimenter-generated errors as described in Lubinsky, Rich, & Anderson, 2009) on performance on more naturalistic PM tasks (e.g., telephone calls, as in Fish et al., 2007).

Clinical applications of the results

These results indicate that errorless learning methods may be helpful in promoting action in addition to improving learning. This is an important finding, as PM tasks are part and parcel of everyday life, and are often very challenging for people with cognitive impairment. Many rehabilitation goals directly concern PM tasks (e.g., remembering to take medication) and many further will have implicit PM components (e.g., managing finances). There are various possibilities regarding how EL methods could be used clinically to improve PM performance. For example:

1. Facilitating performance on specific PM tasks: For event-based PM tasks that are not reliably completed, distil them to their simplest instruction, and teach these instructions using errorless methods. A selection of examples may be: When I clean my teeth I will remember to take my tablets; Before I go upstairs to bed I will lock the front door; When I have something to eat, I will also drink a glass of water; As I leave the house, I will say to myself, "Have I got my keys?".
2. Establishing new behaviours, and replacing unwanted behaviours: Specify and teach a clear goal, e.g., When I finish dinner I will have an apple for dessert.
3. Enhancing performance on procedural tasks with PM components: When focusing on activities of daily living in rehabilitation, prompting and fading of instructions over time are well-known effective

approaches, but the inclusion of error minimisation techniques within these approaches may improve learning further and/or facilitate acting upon PM sub-goals.

4. Promoting effective interactions with people with memory impairment: It is always helpful to remember that using error-minimising processes (i.e., communicating clearly), perhaps particularly when giving instructions but also in more general interactions, will likely have better outcomes than approaches that incorporate errors (e.g., giving confused or revised instructions). This sort of reminder may be particularly helpful to staff and family members unused to being with people with memory impairment.

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APPENDIX 1

Demographic, medical, neuropsychological and questionnaire data for each participant, and group summaries where relevant

							IQ	*Memory*		*PRMQ*		*HADS*		*EBIQ (vs Brain Injury Group)*		*EBIQ (vs Control Group)*	
ID	*Sex*	*Age*	*Yrs Educ*	*Age at Onset*	*Aetiology*	*Scan report summary*	*Z-score*	*Z-score*	*IQ-memory discrep.*	*Pro*	*Retro*	*Anx*	*Dep*	*Cog*	*Core*	*Cog*	*Core*
1	M	49	13	24	Head injury/ alcohol	Steno-occlusive disease, M1 MCA	0	−1.67	−1.67	<-3.0	−1.50	−0.6	−0.7	−0.50	−0.24	−1.66	−1.05
2	M	52	11	28	Diabetes	Prominent ventricles and subarachnoid spaces, posterior fossa volume loss	1	−1.58	−3	−2.25	−2.67	−2.3	−2.3	−1.03	−2.20	−2.40	−3.40
3	M	69	12	65	SVD	Mild−moderate small vessel disease	0.25	−1.67	−1.58	+1.20	0.9	−2.3	−0.2	0.76	0.83	0.08	0.23
4	M	60	11	57	Stroke	Left PCA stroke, volume loss L fusiform and peri-hippocampal gyri and posterior hippocampus	−0.25	−1.67	−2	−0.4	−0.33	−0.6	−0	0.04	0.50	−0.91	−0.17
5	M	61	9	48	Stroke and SVD	L thalamic and cerebellar atrophy	−0.33	−3	−1.67	−0.60	0.100	0	−0.7	−1.03	0.34	−2.40	−0.36
6	M	45	17	44	Hypoxia	Multiple infarcts, L frontal, temporal and parietal	1.67	−2.33	−4.34	−0.60	+0.55	−0.1	−0	0.22	0.75	−0.66	0.13
7	M	55	11	46	Hypoxia	Not available	0.55	−2.33	−2.55	<-3.0	−2.67	−2.3	−2.3	−2.46	−2.93	−4.38	−4.28
8	F	65	16	52	TLE	High signal over left superior and middle temporal gyri	1.67	−1.33	−2.67	−0.40	−0.5	0	−0.2	−0.32	0.25	−1.41	−0.46
9	M	51	11	48	Stroke	Bilateral inferior cerebellar infarcts	−0.75	−3	−1.58	−2.75	−0.9	−1.3	−1.1	−0.32	0.17	−1.41	−0.56

(*Continued*)

APPENDIX 1
Continued

							IQ	Memory		PRMQ		HADS		EBIQ (vs Brain Injury Group)		EBIQ (vs Control Group)	
ID	*Sex*	*Age*	*Yrs Educ*	*Age at Onset*	*Aetiology*	*Scan report summary*	*Z-score*	*Z-score*	*IQ-memory discrep.*	*Pro*	*Retro*	*Anx*	*Dep*	*Cog*	*Core*	*Cog*	*Core*
10	M	52	11	40	Epilepsy/ stroke	Bilateral hippocampal sclerosis	−0.5	−3	−1.5	+0.60	−3.00	−2.3	−0.7	−2.11	−1.95	−3.89	−3.11
11	M	59	11	55	Stroke	R parietal infarct, R hippocampal atrophy, frontal grey matter volume loss	0.75	−3	−2.75	−2.75	−2.50	−0.9	−2.3	−2.64	−2.28	−4.63	−3.50
12	M	47	11	40	Hypoxic	Cerebellar atrophy, hippocampal atrophy	−0.75	−3	−1.58	+1.00	0.1	+1	−0.2	0.58	1.40	−0.17	0.91
13	M	52	10	50	Stroke	Two infarcts, affecting L occipital and medial posterior temporal lobes bilaterally, and R thalamus	0.67	−1.33	−3.34	<-3.0	−1.9	−1.6	−1.9	−1.75	−1.71	−3.39	−2.81
14	F	38	12	35	Temporal lobe epilepsy	Not available	−0.25	−2.67	−2.42	−1.25	−0.1	+1	−0.6	0.04	−0.15	−0.91	−0.95
						Group M	*0.27*	*−2.26*	*−2.05*	*−0.78*	*−1.73*	*−0.88*	*−0.94*	*−0.75*	*−0.52*	*−2.01*	*−1.38*
						Group SD	*0.81*	*0.69*	*1.43*	*1.47*	*1.37*	*1.18*	*0.89*	*1.12*	*1.40*	*1.55*	*1.67*