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Published online: 07 Feb 2018.

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Individual differences in episodic memory abilities predict successful prospective memory output monitoring

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ABSTRACT

Output monitoring refers to memory for one's previously completed actions. In the context of prospective memory (PM) (e.g., remembering to take medication), failures of output monitoring can result in repetitions and omissions of planned actions (e.g., over- or under-medication). To be successful in output monitoring paradigms, participants must flexibly control attention to detect PM cues as well as engage controlled retrieval of previous actions whenever a particular cue is encountered. The current study examined individual differences in output monitoring abilities in a group of younger adults differing in attention control (AC) and episodic memory (EM) abilities. The results showed that AC ability uniquely predicted successful cue detection on the first presentation, whereas EM ability uniquely predicted successful output monitoring on the second presentation. The current study highlights the importance of examining external correlates of PM abilities and contributes to the growing body of research on individual differences in PM.

Event-based prospective memory (PM) involves the remembering of deferred action plans by relying on environmental cues to trigger retrieval of previously formed intentions (Einstein et al., 2005). PM is particularly interesting because its success requires a delicate balance of both attention and memory control processes. The majority of extant research has focused on the attentional mechanisms underlying the *prospective component* of PM, which involves noticing the cue and becoming aware that an intended action should be initiated. However, relatively less research has focused on the memory mechanisms underlying the *retrospective component*, which involves remembering the contents of the intention and retrieving the action from long-term memory. The relative paucity of research examining the retrospective component of PM is largely by design, as laboratory studies typically hold retrieval demands constant by using tasks that involve execution of only a single action upon encountering PM cues. However, in many real-world scenarios, PM cues (e.g., a medicine bottle) are encountered multiple times and the appropriate action (e.g., do or do not take medication) differs depending on whether or not the intention has previously been fulfilled. In such instances, memory for past performance (i.e., *output monitoring*) becomes an important factor in determining the appropriate action to avoid repetition (e.g., over-medication) or omission (e.g., under-medication) errors (Einstein, McDaniel, Smith, & Shaw, 1998; Marsh,

Hicks, Hancock, & Munsayac, 2002). Despite the relevance of output monitoring to theories of PM, however, there is relatively little research on the topic. The current study, therefore, sought to examine the mechanisms underlying successful PM output monitoring using an individual differences approach assessing the relations between PM output monitoring, attention control (AC), and episodic memory (EM).

In a typical event-based PM task, participants establish an intention to perform a specific action upon encountering a specific cue during an ongoing task (e.g., press "/" key upon encountering animal words during an ongoing pleasantness rating task). However, in an event-based PM output monitoring task these cues are repeated throughout the ongoing task and participants are instructed to make one response (i.e., "first" key) upon noticing the first presentation and a *different* response (i.e., "repeat" key) any time a cue is repeated that *they remember having previously responded to* (Marsh et al., 2002, 2007). If they do not remember successfully responding to the first presentation, the appropriate response to the second presentation is the "first" response. Failures of output monitoring can, therefore, occur for two reasons. A *repetition error* occurs when a "first" response is made on both the first and second presentations (i.e., incorrectly believe no "first" response was made on first presentation). An *omission error* occurs when no response is made on the first presentation and a "repeat" response is made on the

second presentation (i.e., incorrectly believe a "first" response was made on first presentation). Returning to the medication example, a repetition error would result in over-medication, whereas an omission error would result in under-medication.

Much of the prior research investigating the cognitive processes involved in PM output monitoring has examined age differences in performance (Einstein et al., 1998; Marsh, Hicks, Cook, & Mayhorn, 2007; May, Manning, Einstein, Becker, & Owens, 2015; McDaniel, Bugg, Ramuschkat, Kliegel, & Einstein, 2009; Skladzien, 2010). The typical finding is that older adults are more likely to forget their original response leading to greater repetition errors than younger adults, whereas younger adults are more likely to erroneously believe they successfully responded to the first presentation leading to greater omission errors than older adults (Marsh et al., 2007; Skladzien, 2010). In both instances, these errors are thought to occur due to failures of source monitoring whereby participants are unable to distinguish between events that actually occurred versus those that were only imagined to occur (i.e., "did I actually respond or do I only think I did?"; Johnson, Hashtroudi, & Lindsay, 1993; Johnson, Raye, Foley, & Foley, 1981). Interestingly, using distinct picture targets or distinct responses that should facilitate source monitoring reduces repetition errors for younger adults, but not older adults (Marsh et al., 2007; Skladzien, 2010).[1] This suggests that in addition to deficits in source monitoring associated with increased age (Hashtroudi, Johnson, & Chrosniak, 1989; Henkel, Johnson, & De Leonardis, 1998), older adults may have difficulty in binding the action to the PM cue on the original presentation. Together, these findings suggest that EM abilities may in part underlie successful PM output monitoring.

Another potential source of variation in PM output monitoring is AC ability. First, it is generally assumed that attentional processes are needed to maintain an attention allocation strategy to support cue detection during tasks that do not orient attention to the relevant features of the PM cue (i.e., nonfocal tasks; Marsh, Hicks, Cook, Hansen, & Pallos, 2003). For example, Skladzien (2010) found better cue detection on the first presentation for younger than older adults (but see Marsh et al., 2007), which is consistent with the finding that older adults typically show age-related declines in nonfocal cue detection (Kliegel, Jäger, & Phillips, 2008). AC is also needed to inhibit ongoing task responses to check for PM targets and to shift between ongoing and PM tasks (Schnitzspahn, Stahl, Zeintl, Kaller, & Kliegel, 2013; Zuber, Kliegel, & Ihle, 2016). However, beyond cue detection for the first presentation, AC may also be involved in successful output monitoring. For example, for younger adults divided attention increases repetition errors (Sugimori & Kusumi, 2009), whereas more elaborative responses (i.e., vocalising to experimenter) reduce them (Marsh et al., 2002, 2007). Presumably, these manipulations affect attention devoted to the original encoding event that makes it more or less difficult on the second presentation to remember if the cue had previously been encountered. Interestingly, elaborative responses actually *increase* repetition errors in older adults. Marsh et al. (2007) suggested that elaborating the responses might heighten attention to the PM cues making them more memorable, but this produces strong retrieval competition for older adults making it more difficult to discern which items did or did not receive prior responses. In any manner, these findings suggest that attentional processes may also partly underlie successful output monitoring. However, because older adults have deficits in both AC (Braver & West, 2008; Zacks & Hasher, 1988) and EM (Hashtroudi et al., 1989; Henkel et al., 1998), it is not entirely clear whether attention, memory, or some combination of both abilities underlie successful output monitoring.

Current study

The purpose of the current study was to examine the joint contributions of EM and AC to successful PM output monitoring. The output monitoring task was a direct replication of Experiment 1 from Marsh et al. (2007) in which animal cues (e.g., cheetah) were presented during an ongoing pleasantness rating task. Participants were instructed to make one response (i.e., "first") during the first presentation of a PM cue and a different response (i.e., "repeat") on the second presentation of the same cue *only if* they remembered responding to it on the first occurrence. If they did not remember responding to it previously, they were to press the "first" key on the second presentation. To examine the role of EM and AC in successful output monitoring, the primary dependent variables (DVs) were correct responses on the second cue presentation (i.e., a "repeat" response following an original "first" response, or a "first" response following an original miss). Given the considerable research suggesting that cue-action binding and source monitoring abilities underlie successful output monitoring (Marsh et al., 2002; 2007; McDaniel et al., 2009; Skladzien, 2010), we expected EM ability to be associated with better output monitoring. Additionally, research suggests that attention devoted to the first occurrence of the cue may facilitate subsequent output monitoring (Marsh et al., 2002; Sugimori & Kusumi, 2009). Consequently, AC may also be associated with improved output monitoring.

Although not necessarily central to the current study, we were also interested in examining the role of EM and AC ability in overall cue detection (i.e., on the first presentation). Prior research suggests that when controlled attentional processes are needed to actively maintain the intention to support cue detection (i.e., nonfocal tasks), AC is integral for cue detection (Smith & Bayen, 2005). In this regard, it was predicted that AC ability would be predictive of cue detection on the first presentation given that the PM task is arguably nonfocal in nature. However, there is also evidence suggesting that EM ability is an

important predictor of cue detection (Salthouse, Berish, & Siedlecki, 2004; Unsworth, Brewer, & Spillers, 2012). For example, controlled retrieval processes are needed to remember the contents of the intention (Einstein & McDaniel, 1996) and when there is a sufficient delay between intention retrieval and action execution (Ball, Knight, Dewitt, & Brewer, 2013). Thus, it was predicted the EM may also be important in successful cue detection on the first presentation.

Method

Participants and cognitive ability battery

One hundred and sixty-eight undergraduate students were recruited from the research participant pool at the University of Georgia to participate in the study in exchange for partial class credit. Participants completed a battery of EM (i.e., delayed free recall, cued recall, gender source monitoring, location source monitoring) and AC (i.e., antisaccade, flanker, and psychomotor vigilance) tasks as well as PM output monitoring task.[2] Full task details can be found in previously published research from our laboratory (see Brewer & Unsworth, 2012).

EM tasks

Cued recall (C-Recall)
Participants attempted to recall 3 lists of 10 cue-target noun pairs studied for 2 s each. After a 16-s distractor task, participants were randomly provided with a cue for 5 s and they were instructed to enter the target using the keyboard. The DV for this measure was the proportion of targets recalled correctly.

Delayed free recall (DF-Recall)
Participants attempted to recall 6 lists of 10 nouns studied for 1 s each. After a 16-s distractor task, participants typed as many words as they could remember from the current list in any order they wished. Participants had 45 s for recall. The DV for this measure was the proportion of items recalled correctly.

Gender source recognition (G-Source)
Participants heard 30 nouns presented in either a male or a female voice. At test, participants were presented with 30 old and 30 new words and were required to indicate if the word was new or old and, if old, what voice it was spoken in via key press. Participants had 5 s to press the appropriate key. The DV for this measure was the proportion of correct gender responses.

Picture source recognition (P-Source)
Participants were presented with 30 pictures in one of 4 different quadrants on the computer screen. At test, participants were presented with 30 old and 30 new pictures in the centre of the screen. Participants indicated if the picture was new or old and, if old, what quadrant it was originally presented in via key press. Participants had 5 s to press the appropriate key to enter their response. The DV for this measure was the proportion of correct quadrant decisions.

AC tasks

Antisaccade (Anti)
Participants were instructed to stare at a fixation point onscreen for a variable amount of time (200–2200 ms). A flashing white "=" was then flashed either to the left or right of fixation (11.33° of visual angle) for 100 ms. This cue was followed by the target stimulus (a B, P, or R) onscreen for 100 ms. The target was followed by masking stimuli (an H for 50 ms and an 8 which remains onscreen until a response is given). The participants' task was to identify the target letter by pressing a key for B, P, or R (the keys 1, 2, or 3). The target always appeared in the opposite location as the flashing cue. The DV for this measure was the proportion of correct responses.

Arrow flankers (Flanker)
Participants were presented with a fixation point for 400 ms followed by an arrow directly above the fixation point for 1700 ms. Participants indicated the direction the arrow was pointing (pressing the F for left pointing arrows or pressing J for right pointing arrows) as quickly/accurately as possible. On 50 neutral trials, the arrow was flanked by two horizontal lines on each side. On 50 congruent trials, the arrow was flanked by two arrows pointing in the same direction as the target arrow on each side. On 50 incongruent trials, the target arrow was flanked by two arrows pointing in the opposite direction as the target arrow on each side. All trial types were randomly intermixed. The DV for this measure was the proportion of correct responses.

Psychomotor vigilance task (PVT)
Participants were presented with a row of zeros on screen and after a variable amount of time the zeros began to count up in 1-ms intervals from 0 ms. Participants were to press the spacebar as quickly as possible once the numbers started counting up (roughly 75 total trials). After pressing the spacebar the response-time was left on screen for 1 s to provide feedback to the participants. Interstimulus intervals were randomly distributed and ranged from 1 to 10 s. The DV for this measure was the number of trials with RTs slower than 500 ms (reflecting an attentional lapse).

PM output monitoring task

Materials and procedure
The PM output monitoring task procedure was a direct replication of Experiment 1 from Marsh and colleagues (2007). The ongoing task consisted of rating 300 words

Table 1. Descriptive statistics for individual differences measures.

Measure	M	SD	Skew	Kurtosis
C-Recall	0.48	0.23	0.07	−0.96
DF-Recall	0.50	0.18	0.32	−0.20
G-Source	0.60	0.15	−0.34	0.13
P-Source	0.80	0.15	−2.23	6.63
Anti	0.49	0.14	0.42	−0.36
Flanker	0.97	0.06	−4.27	21.46
PVT	7.22	9.11	2.35	5.66

Note: C = cued; DF = delayed free, G = gender; P = picture; Anti = antisaccade; PVT = psychomotor vigilance task.

for pleasantness using a 5-point Likert scale. Eight animal words (e.g., cheetah) were used as the PM cues, with four of these words being randomly selected for each participant to repeat once during the ongoing task (resulting in a total of 12 presentations of animal words). The first cues were repeated later on in the sequence interspersed with four new cues that were not repeated as follows: 1, 2, 3, 4, 1, 2, 5, 6, 7, 8, 3, 4. Cues were presented every 25th trial of the ongoing task. There were 288 non-prospective trials in which 12 prospective trials were embedded.

Participants were given ongoing task instructions and were additionally informed that we were interested in their ability to remember to perform an action in the future. They were told that whenever an animal word was encountered for the first time during the pleasantness rating task, they should press the "/" key before making their pleasantness rating (referred to as "first" keypress). However, on any subsequent presentations of the same cue participants were to instead press the "=" key (referred to as "repeated" keypress) if they had successfully remembered to press the "/" key on the first encounter. If participants successfully responded to an animal on its first encounter and the "first" key was pressed again upon the second encounter, it means that participants forgot that they already responded earlier to that specific cue (i.e., repetition error). By contrast, if an animal word was missed the first time and the "repeated" key was pressed on the second encounter, it means that participants remembered encountering the cue, but erroneously believed that they responded on the first time (i.e., omission error). For the present purposes, we were interested in successful output monitoring performance, i.e., when participants remember that they already responded to that cue (they

pressed the "/" key) upon the first encounter and so they press the repeated key ("=") upon the second encounter. The experiment did not proceed until the participant acknowledged that they fully understood the instructions. Memory for the instructions was also assessed at the end of the experiment. Each participant was tested individually in sessions that lasted approximately 60 minutes.

Results

Unless stated otherwise, all analyses reported had *p*-values less than .05. Descriptive statistics for all EM and AC tasks can be found in Table 1. The correlations between these measures can be found in Table 2. Tasks within a construct were generally more highly correlated than tasks between constructs, indicating reasonable convergent and discriminant validity. A supplementary exploratory principal components factor analysis suggested that two factors accounted for the data (all other eigenvalues less than 1). Moreover, the rotated factor matrix indicated that the tasks within each construct of interest loaded similarly onto the same factor (e.g., the four EM tasks all loaded onto the first rotated factor and not the second). A principal components analysis was separately conducted on the EM and AC tasks to create constructs to assess individual differences in performance.

PM and output monitoring performance

As described in the Method section, there were a total of eight PM cues, four of which were repeated once during the ongoing task. "PM performance" refers to proportion of cues detected on the first presentation (out of eight), whereas "output monitoring performance" refers to performance on the second presentation of the four cues *conditional on whether or not the cue was successfully responded to on the first presentation*. It should be noted, however, that conditional scores could not be calculated for participants who detected (*N* = 19) or missed (*N* = 36) all four cues on the first presentation (e.g., performance cannot be conditionalised on having originally made a successful "first" response if no "first" response was ever made). That is to say, only participants who displayed some variable performance on the first presentation (i.e., detected one and

Table 2. Correlations for episodic memory and attention control measures.

Variable	C-Recall	DF-Recall	G-Source	P-Source	Anti	Flanker	PVT
C-Recall	1.00						
DF-Recall	.50**	1.00					
G-Source	.30**	.23**	1.00				
P-Source	.28**	.29**	.26**	1.00			
Anti	.10	0.14+	.15*	0.14+	1.00		
Flanker	.10	.16*	.17*	.34**	.18*	1.00	
PVT	.05	0.15+	.25**	.16*	.29**	.25**	1.00

Note: C = cued; DF = delayed free, G = gender; P = picture; Anti = antisaccade; PVT = psychomotor vigilance task. PVT was reverse scored here such that higher values reflect better attention control.

**p < .01.
*p < .05.
+p < .07.

missed three, detected two and missed two, or detected three and missed one) could be included in the analyses assessing output monitoring performance. We, therefore, imputed means for these missing values based on the overall sample mean.[3]

Participants successfully responded to approximately half of the cues (M = .47, SE = .02) on the first presentation (i.e., PM performance). Figure 1 represents performance for repeated cues dependent on whether or not it was originally responded to on the first presentation (i.e., output monitoring performance). On the left half of Figure 1, from left to right the bars reflect the proportion of trials where participants originally detected the cue on the first presentation and then on the second presentation correctly pressed the "repeat" key (i.e., successful output monitoring), incorrectly pressed the "first" key (i.e., repetition error), or failed to detect the cue (i.e., miss). On the right half of Figure 1, from left to right the bars reflect the proportion of trials where participants missed the cue on the first presentation and then on the second presentation correctly pressed the "first" key (i.e., successful output monitoring), incorrectly pressed the "repeat" key (i.e., omission error), or failed to detect the cue (i.e., miss). Results suggest that although overall the output monitoring task was performed effectively, there were substantial individual differences in performance.

Relationship between individual differences constructs and performance

Correlations between overall cue detection (on first presentation), output monitoring performance (on second presentation), and the constructs of interest (EM and AC) can be found in Table 3. Replicating previous work, EM and AC constructs were correlated with each other (Unsworth,

Brewer, & Spillers, 2009). Additionally, both EM and AC were generally positively related to overall cue detection and successful output monitoring performance.

To examine the unique contribution of EM and AC ability to performance, we conducted a regression analysis with these measures predicting successful performance. For output monitoring, we collapsed across both "correct" measures (i.e., "first"-"repeat" and miss-"first" trials; see "Average" section of Table 3). As can be seen in Table 4, only AC ability uniquely predicted overall cue detection (i.e., first presentation), whereas only EM ability uniquely predicted overall successful output monitoring (i.e., second presentation).

General discussion

Previous research has shown that a variety of cognitive functions underlie prospective remembering. Specifically, the prospective component (e.g., noticing the cue) of PM seems to be driven by AC and other executive functioning abilities (e.g., shifting between different tasks and monitoring of the environment; Brewer, Knight, Marsh, & Unsworth, 2010; Schnitzspahn et al., 2013; Zuber et al., 2016), whereas the retrospective component (e.g., remembering the retrieval context and appropriate target action) seems to be primarily driven by EM abilities (Einstein & McDaniel, 1990, 1996; Smith & Bayen, 2006). In the current study, both the prospective and retrospective components were differentially influenced by individual differences in cognitive abilities. In particular, AC uniquely predicted successful cue detection on the first presentation while EM uniquely predicted successful output monitoring on the second presentation. These findings not only support previous theoretical assertions about the joint roles of attention and memory in PM abilities (Ball et al., 2013; Brewer
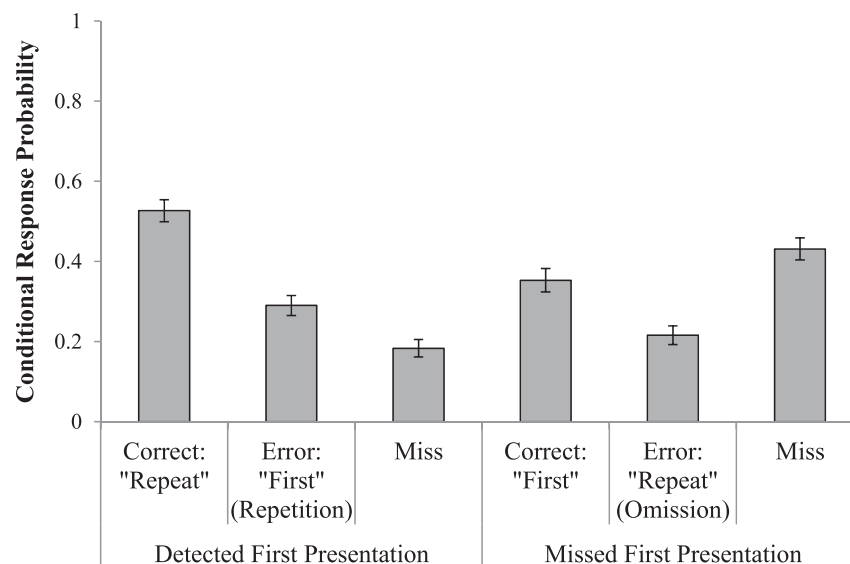

Figure 1. Output monitoring performance conditional on whether or not the first presentation of the cue was detected. Error bars reflect standard errors.

Table 3. Correlations between overall cue detection, output monitoring performance, and individual differences constructs.

					Detected first presentation			Missed first presentation			Average		
		EM	AC	PM	Correct: "Repeat"	Error: "First" (Repetition)	Miss	Correct: "First"	Error: "Repeat" (Omission)	Miss	Correct	Error	Miss
	EM	1.00											
	AC	.31**	1.00										
	PM	0.15+	.21**	1.00									
Detected first presentation	Correct: "Repeat"	.18*	.08	.21**	1.00								
	Error: "First" (Repetition)	−.03	.00	.02	−.66**	1.00							
	Miss	−.20**	−.11	−.29**	−.52**	−.31**	1.00						
Missed first presentation	Correct: "First"	0.14+	.17*	.31**	.13	−.09	−.06	1.00					
	Error: "Repeat" (Omission)	.00	.02	.09	−.02	−.03	.06	−.47**	1.00				
	Miss	−.15+	−.19*	−.40**	−.12	.12	.01	−.67**	−.35**	1.00			
Average	Correct	.21**	.17*	.35**	.73**	−.49**	−.37**	.77**	−.33**	−.54**	1.00		
	Error	−.02	.01	.08	−.50**	.72**	−.19*	−.39**	.67**	−.15+	−.59**	1.00	
	Miss	−.24**	−.22**	−.49**	−.41**	−.09	.63**	−.56**	−.24**	.79**	−.65**	−.23**	1.00

Note: EM = episodic memory; AC = attention control; PM = overall cue detection on first presentation. Average = the mean performance for correct, error, or miss trials averaged over "detected" and "missed" trials on the first presentation.
**$p < .01$.
*$p < .05$.
+$p < .07$.

Table 4. Summary of regression analysis for variables predicting successful prospective memory and output monitoring performance.

Variable	ID measure	β	t	sr	R^2	Sig.
First presentation					0.053	0.011
	Episodic memory	0.090	1.13	0.086		
	Attention control	0.185	2.32*	0.176		
Correct (average)					0.058	0.007
	Episodic memory	0.179	2.25*	0.170		
	Attention control	0.114	1.43	0.108		

Note: Average = the mean performance for correct, error, or miss trials averaged over "detected" and "missed" trials on the first presentation.
*$p < .05$.

et al., 2010), but also illustrate the value of independently investigating the prospective and output monitoring components of PM. Our results seem to be especially critical as this is the first study that allowed for a direct, within-subjects comparison of individual differences in these two components.

The results of the current study replicate previous findings showing that both EM and AC were interrelated (Unsworth et al., 2009) and that both were positively associated with cue detection when output monitoring was not required (i.e., on first cue presentation; Salthouse et al., 2004; Unsworth et al., 2012). Notably, however, only AC uniquely predicted performance. This finding is consistent with previous research showing that nonfocal cue detection is better for those with greater attentional capacity, which is needed to maintain the intention, inhibit ongoing task responding to check for PM cues, and to shift between the ongoing and PM task (Brewer et al., 2010; Schnitzspahn et al., 2013; Zuber et al., 2016). The current results support theories of PM that suggest that successful cue detection is determined by both attentional mechanisms needed for monitoring for cues along with retrieval mechanisms needed for retrieving previously planned target behaviours (e.g., Smith & Bayen, 2004).

More central to the current study, we also examined the relative contributions of AC and EM abilities to successful output monitoring. As with overall cue detection, our results showed that both AC and EM were associated with successful output monitoring. These findings were anticipated given that previous research has demonstrated that successful output monitoring requires binding of cue-action associations in memory during original presentation and retrieval of the original action (i.e., source monitoring) on the second presentation (Marsh et al., 2007; Skladzien, 2010). Additionally, with more attention devoted toward the cue during initial presentation the better the encoding and subsequent retrieval of the cue-action associations should be (Marsh et al., 2003). Importantly, however, and in contrast to overall cue detection, only EM abilities uniquely predicted successful output monitoring. These findings suggest that regardless of the attentional

processes involved, once an intention is realised the ultimate fate of output monitoring involves whether or not controlled retrieval processes are successful in accessing and monitoring the source of contextual information associated with a previous encounter with the cue.

Prior research examining age differences in output monitoring suggests that younger adults commit more omission errors, whereas older adults commit more repetition errors. This could suggest that output monitoring failures could reflect biases in responding rather than source monitoring failures, per se. That is, younger and older adults may have different biases to respond "repeat" based on metacognitive assessments of their own memory ability, with overconfidence leading to greater omission errors (liberal bias) and underconfidence leading to greater repetition errors (conservative bias; see Touron & Hertzog, 2004 for evidence of age differences in memory confidence). Interestingly, however, in the current study, there was little difference between error types as a function of EM ability, suggesting that metacognitive biases may have been similar across individuals. Notably, PM cues were semantically related and required the same response, which likely exacerbated source confusion problems. Thus, one possibility for the better output monitoring for high EM ability individuals in the absence of differences in biases is that they were better able to resolve proactive interference from semantically related items (similar to high working memory capacity individuals; Kane & Engle, 2000; Unsworth, Spillers, & Brewer, 2012). Future research could examine this idea by examining whether distinctive cues (or responses) are particularly beneficial for low EM ability individuals.

Interestingly, considerable research has recently investigated the cognitive mechanisms underlying a related type of PM error. Commission errors are studied by having participants perform an "active phase" in which they respond to PM cues followed by a "finished phase" in which the PM intention is cancelled and participants are told they should no longer respond to cues. Despite the cancelled instructions, participants often accidentally respond (i.e., commit a commission error) when cues are presented in the finished phase (Bugg & Scullin, 2013; Schaper & Grundgeiger, 2017). These errors are thought to occur due to failures of inhibiting execution of a prepotent response following spontaneous retrieval of the PM intention (Scullin, Bugg, & McDaniel, 2012). While it is possible that similar processes may underlie repetition errors, output monitoring paradigms typically use nonfocal cues that do not typically elicit spontaneous retrieval of intentions. Furthermore, Marsh et al. (2002) found that repetition errors occurred because participants forgot their original response, suggesting a failure of EM rather than a failure of AC (i.e., inhibition). Thus, while commission and repetition errors appear similar on the surface, we believe that different processes may underlie the two. Of course, it is possible that commission errors could in part reflect a failure of source monitoring during the context verification (Marsh, Hicks,

& Watson, 2002) stage of intention retrieval (i.e., "am I in active phase or finished phase?"), in which case a common mechanism may contribute to both error types. Future research is needed to further elucidate common and distinct processes underlying these error types.

Lastly, it could be argued that output monitoring failures observed in the current study could simply reflect failures to understand instructions[4] or difficulties in encoding the correct PM response during the first presentation rather than EM failures, per se. While this is possible, we ensured that participants fully understood the instructions at both the beginning and end of the task. Additionally, prior research (which this study was based on) assessed participants' memory for cues by including a prompt after any "first" response asking if the cue had previously been presented (Marsh et al., 2002). Following successful responding to PM cues on the first presentation, 100% of "first" responses on the second presentation were because participants remembered seeing the cue but forgot their original response. Following misses on the first presentation, 84% of "first" responses on the second presentation were because participants remembered seeing the item but (correctly) remembered not responding to it. In both cases, participants therefore remembered seeing the item before but believed they had not responded to it previously. Although we did not include such a prompt, we can reasonably assume output monitoring errors in the current study primarily reflect difficulties at retrieval during the second presentation rather than problems with understanding instructions or encoding the correct PM response during the first presentation.

Beyond the theoretical significance of the current study, these results also highlight the importance of accounting for individual differences in output monitoring that may have critical behavioural consequences in naturalistic settings. For example, laboratory-based repetition errors might index how often a person forgets that they have already taken medication and inappropriately re-administer another dose (resulting in over-medication), whereas omission errors may index an individual's propensity to erroneously believe that they have previously taken the medication when they did not (resulting in under-medication). The results from the current study suggest that individuals with EM deficits may be particularly susceptible to over- or under-medicate in everyday situations. Notably, however, the effect sizes in the current study were fairly small, which likely has to do in part with the small number of cues presented that is inherent to PM research (Kelemen, Weinberg, Alford, Mulvey, & Kaeochinda, 2006; McDaniel & Einstein, 2007). Furthermore, there are likely other contextual, task-based, and individual differences factors that are important for successful memory performance (i.e., output monitoring; see Jenkins, 1979; Roediger, 2008). Future research should, therefore, increase the number of cues, use multiple assessments of output monitoring to increase the reliability of these measures, collect additional cognitive ability factors, and examine the degree of context-specificity in these relations. Of course, given that the cues in the current study were semantically related and required the same response suggests that this paradigm may most aptly reflect situations where the same intention (take a medicine) needs to be retrieved and performed in response to different but related PM cues (i.e. multiple different medicine bottles) only a few times a day. However, research suggests that 34% of older adults are taking three or more prescribed medications (Park and Kidder, 1996), each of which may require different actions, temporal sequences, and frequencies (e.g., taking with food twice daily versus taking with water three times). Therefore, while we admit that the present paradigm might not apply to all event-based PM tasks, we believe that the present experiments have important practical implications. Future research should, therefore, examine strategies that can reduce the incidence of output monitoring failures that could have detrimental effects for individuals with EM deficits.

Notes

1. Slightly different results have been found using a habitual PM intention paradigm in which the same cue/target action is required multiple times throughout the ongoing task. For example, distinctive responses reduce time-based repetition errors for older adults (McDaniel et al., 2009), and emotionally salient cues reduce event-based repetition errors for older adults (May et al., 2015). Likewise, divided attention increases repetition errors for older adults but has little influence on younger adults in the habitual PM task (Einstein et al., 1998; McDaniel et al., 2009).
2. As part of a larger study, participants also completed a battery of working memory tasks. However, in the current study we focus only on the EM and AC constructs that have previously been associated with output monitoring abilities.
3. Similar results were found when examining conditionalised performance on the reduced sample of participants with variability in early cue detection and when using imputed means to account for participants with no variability in early cue detection. Taken together, the outcome of these analyses did not depend on how we dealt with conditionalisation of performance for individuals with no variability.
4. For example, repetition errors could occur because participants remembered previously responding to the cue but simply forgot they needed to press a different ("repeat") response on the second presentation, whereas omission errors could occur because participants remembered not responding to the cue but thought the appropriate response was to press the "repeat" key (since it was the second time encountering it).

Funding

References

Ball, B. H., Knight, J. B., Dewitt, M. R., & Brewer, G. A. (2013). Individual differences in the delayed execution of prospective memories. *Quarterly Journal of Experimental Psychology*, *66*(12), 2411–2425.

Braver, T. S., & West, R. (2008). Working memory, executive control, and aging. *The Handbook of Aging and Cognition*, *3*, 311–372.

Brewer, G. A., Knight, J. B., Marsh, R. L., & Unsworth, N. (2010). Individual differences in event-based prospective memory: Evidence for multiple processes supporting cue detection. *Memory and Cognition*, *38*(3), 304–311.

Brewer, G. A., & Unsworth, N. (2012). Individual differences in the effects of retrieval from long-term memory. *Journal of Memory and Language*, *66*(3), 407–415.

Bugg, J. M., & Scullin, M. K. (2013). Controlling intentions. *Psychological Science*, *24*(12), 2463–2471.

Einstein, G. O., & McDaniel, M. A. (1990). Normal aging and prospective memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*, 717–726.

Einstein, G. O., & McDaniel, M. A. (1996). Retrieval processes in prospective memory: Theoretical approaches and some new empirical findings. In M. Brandimonte, G. O. Einstein, & M. A. McDaniel (Eds.), *Prospective Memory: Theory and Applications* (pp. 115–141). Mahwah, NJ: Lawrence Erlbaum Associates.

Einstein, G. O., McDaniel, M. A., Smith, R. E., & Shaw, P. (1998). Habitual prospective memory and aging: Remembering intentions and forgetting actions. *Psychological Science*, *9*(4), 284–288.

Einstein, G. O., McDaniel, M. A., Thomas, R., Mayfield, S., Shank, H., Morrisette, N., & Breneiser, J. (2005). Multiple processes in prospective memory retrieval: Factors determining monitoring versus spontaneous retrieval. *Journal of Experimental Psychology: General*, *134*(3), 327–342.

Hashtroudi, S., Johnson, M. K., & Chrosniak, L. D. (1989). Aging and source monitoring. *Psychology and Aging*, *4*(1), 106.

Henkel, L. A., Johnson, M. K., & De Leonardis, D. M. (1998). Aging and source monitoring: Cognitive processes and neuropsychological correlates. *Journal of Experimental Psychology: General*, *127*(3), 251.

Jenkins, J. J. (1979). Four points to remember: A tetrahedral model of memory experiments. In L. S. Cermak, & F. M. Craik (Eds.), *Levels of Processing in Human Memory* (pp. 429–446). Hillsdale, NJ: Erlbaum.

Johnson, M. K., Hashtroudi, S., & Lindsay, D. S. (1993). Source monitoring. *Psychological Bulletin*, *114*, 3–28.

Johnson, M. K., Raye, C. L., Foley, H. J., & Foley, M. A. (1981). Cognitive operations and decision bias in reality monitoring. *The American Journal of Psychology*, *94*(1), 37–64.

Kane, M. J., & Engle, R. W. (2000). Working-memory capacity, proactive interference, and divided attention: Limits on long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*(2), 336.

Kelemen, W. L., Weinberg, W. B., Alford, H. S., Mulvey, E. K., & Kaeochinda, K. F. (2006). Improving the reliability of event-based laboratory tests of prospective memory. *Psychonomic Bulletin & Review*, *13*(6), 1028–1032.

Kliegel, M., Jäger, T., & Phillips, L. H. (2008). Adult age differences in event-based prospective memory: A meta-analysis on the role of focal versus nonfocal cues. *Psycholgy & Aging*, *23*(1), 203–208.

Marsh, R. L., Hicks, J. L., Cook, G. I., Hansen, J. S., & Pallos, A. L. (2003). Interference to ongoing activities covaries with the characteristics of an event-based intention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*(5), 861.

Marsh, R. L., Hicks, J. L., Cook, G. I., & Mayhorn, C. B. (2007). Comparing older and younger adults in an event-based prospective memory paradigm containing an output monitoring component. *Aging, Neuropsychology, and Cognition*, *14*, 168–188.

Marsh, R. L., Hicks, J. L., Hancock, T. W., & Munsayac, K. (2002). Investigating the output monitoring component of event-based prospective memory performance. *Memory and Cognition*, *30*(2), 302–311.

Marsh, R. L., Hicks, J. L., & Watson, V. (2002). The dynamics of intention retrieval and coordination of action in event-based prospective memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *28*(4), 652.

May, C. P., Manning, M., Einstein, G. O., Becker, L., & Owens, M. (2015). The best of both worlds: Emotional cues improve prospective memory execution and reduce repetition errors. *Aging, Neuropsychology, and Cognition*, *22*(3), 357–375.

McDaniel, M. A., Bugg, J. M., Ramuschkat, G. M., Kliegel, M., & Einstein, G. O. (2009). Repetition errors in habitual prospective memory: Elimination of Age differences via complex actions or appropriate resource allocation. *Aging, Neuropsychology, and Cognition*, *16*(5), 563–588.

McDaniel, M. A., & Einstein, G. O. (2007). *Prospective memory: An overview and synthesis of an emerging field*. Thousand Oaks, CA: Sage.

Park, D. C., & Kidder, D. P. (1996). Prospective memory and medication adherence. In M. Brandimonte, G. O. Einstein, & M. A. McDaniel (Eds.), *Prospective memory: Theory and applications* (pp. 369–390). Mahwah, NJ: Lawrence Erlbaum Associates.

Roediger, H. L. (2008). Relativity of remembering: Why the laws of memory vanished. *Annual Review of Psychology*, *59*, 225–254.

Salthouse, T. A., Berish, D. E., & Siedlecki, K. L. (2004). Construct validity and age sensitivity of prospective memory. *Memory & Cognition*, *32*(7), 1133–1148.

Schaper, P., & Grundgeiger, T. (2017). Commission errors in delay-execute prospective memory tasks. *Quarterly Journal of Experimental Psychology*, *70*(8), 1423–1438.

Schnitzspahn, K. M., Stahl, C., Zeintl, M., Kaller, C. P., & Kliegel, M. (2013). The role of shifting, updating, and inhibition in prospective memory performance in young and older adults. *Developmental Psychology*, *49*(8), 1544.

Scullin, M. K., Bugg, J. M., & McDaniel, M. A. (2012). Whoops, I did it again: Commission errors in prospective memory. *Psychology and Aging*, *27*(1), 46–53.

Skladzien, E. M. (2010). Age differences in output-monitoring accuracy. *Aging, Neuropsychology, and Cognition*, *17*(2), 240–256.

Smith, R. E., & Bayen, J. (2006). The source of adult age differences in event-based prospective memory: A multinomial modeling approach. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *32*(3), 623–635.

Smith, R. E., & Bayen, U. J. (2004). A multinomial model of event-based prospective memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *30*(4), 756.

Smith, R. E., & Bayen, U. J. (2005). The effects of working memory resource availability on prospective memory. *Experimental Psychology*, *52*(4), 243–256.

Sugimori, E., & Kusumi, T. (2009). Limiting attentional resources influences performance and output monitoring of an event-based prospective memory task. *European Journal of Cognitive Psychology*, *21*(1), 112–128.

Touron, D. R., & Hertzog, C. (2004). Distinguishing age differences in knowledge, strategy use, and confidence during strategic skill acquisition. *Psychology and Aging*, *19*(3), 452.

Unsworth, N., Brewer, G. A., & Spillers, G. J. (2009). There's more to the working memory capacity—fluid intelligence relationship than just secondary memory. *Psychonomic Bulletin & Review*, *16*, 931–937.

Unsworth, N., Brewer, G. A., & Spillers, G. J. (2012). Variation in cognitive failures: An individual differences investigation of everyday attention and memory failures. *Journal of Memory and Language*, *67*, 1–16.

Unsworth, N., Spillers, G. J., & Brewer, G. A. (2012). Working memory capacity and retrieval limitations from long-term memory: An examination of differences in accessibility. *Quarterly Journal of Experimental Psychology*, *65*(12), 2397–2410.

Zacks, R. T., & Hasher, L. (1988). Capacity theory and the processing of inferences. In L. Light, & D. Burke (Eds.), *Language, Memory, and Aging* (pp. 154–170). New York: Cambridge University Press.

Zuber, S., Kliegel, M., & Ihle, A. (2016). An individual difference perspective on focal versus nonfocal prospective memory. *Memory & Cognition*, *44*(8), 1192–1203.