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# The Dynamic Interplay Between Bottom-Up and Top-Down Processes Supporting Prospective Remembering

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**Abstract**
Like many dual process theories in the psychological sciences, existing models of prospective memory (i.e., remembering to execute future intentions) emphasize the role of singular top-down or bottom-up processes that act in isolation. We argue that top-down and bottom-up processes are interconnected and dynamically interact to support prospective memory. We elaborate on this dynamic multiprocess framework by focusing on recent behavioral, neuroimaging, and eye-tracking research that demonstrated the dynamic nature of monitoring (top-down) and spontaneous retrieval (bottom-up) processes in relation to contextual factors, metacognition, and individual differences. We conclude that identifying how dual processes interact with environmental and individual difference factors is crucial for advancing understanding of cognition and behavior.

**Keywords**
prospective memory, spontaneous retrieval, involuntary memory, monitoring, metacognition, working memory, attention, aging, context

Dual process theory contends that thoughts and behaviors can be affected by top-down, controlled processes or bottom-up, automatic processes. The history of dual process theories can be linked back to William James (1890) but were later popularized in the fields of social and cognitive psychology to explain attitudes, reasoning, and decision-making (Barrett, Tugade, & Engle, 2004; Frankish & Evans, 2009). In some fields, dual process theories have become the source of spirited debate (e.g., Wixted, 2007). Our view is that dual process theories have been limited by taking an *isolation* approach rather than considering how top-down and bottom-up processes are interactive systems. In the present article, we will elaborate on how top-down and bottom-up processes interact *dynamically* to support *prospective memory*.

## An Overview of Prospective Memory

Remembering to execute delayed intentions, known as prospective memory, is integral to daily living (e.g., remembering to tell a friend happy birthday), workplace performance (e.g., remembering to submit a report to a supervisor), and health (remembering to take medication with dinner). The public often attributes prospective memory errors to a failure in top-down processes such as a lack of sufficient commitment or poor effort; by contrast, prospective memory researchers acknowledge that regardless of how intelligent and conscientious individuals are, they may still fail to remember to execute very important delayed intentions (Dismukes, 2012; Loft, 2014). Thus, models that rely solely on top-down processes are unlikely to adequately explain prospective memory.

## Dual Processes in Prospective Memory

In prospective memory, top-down processes involve repeated rehearsal of the intention and monitoring for cues that signal it is time to execute the intention. Relying on top-down processes for prospective memory tasks impairs performance on ongoing tasks because the two tasks compete for resource capacity. An everyday example

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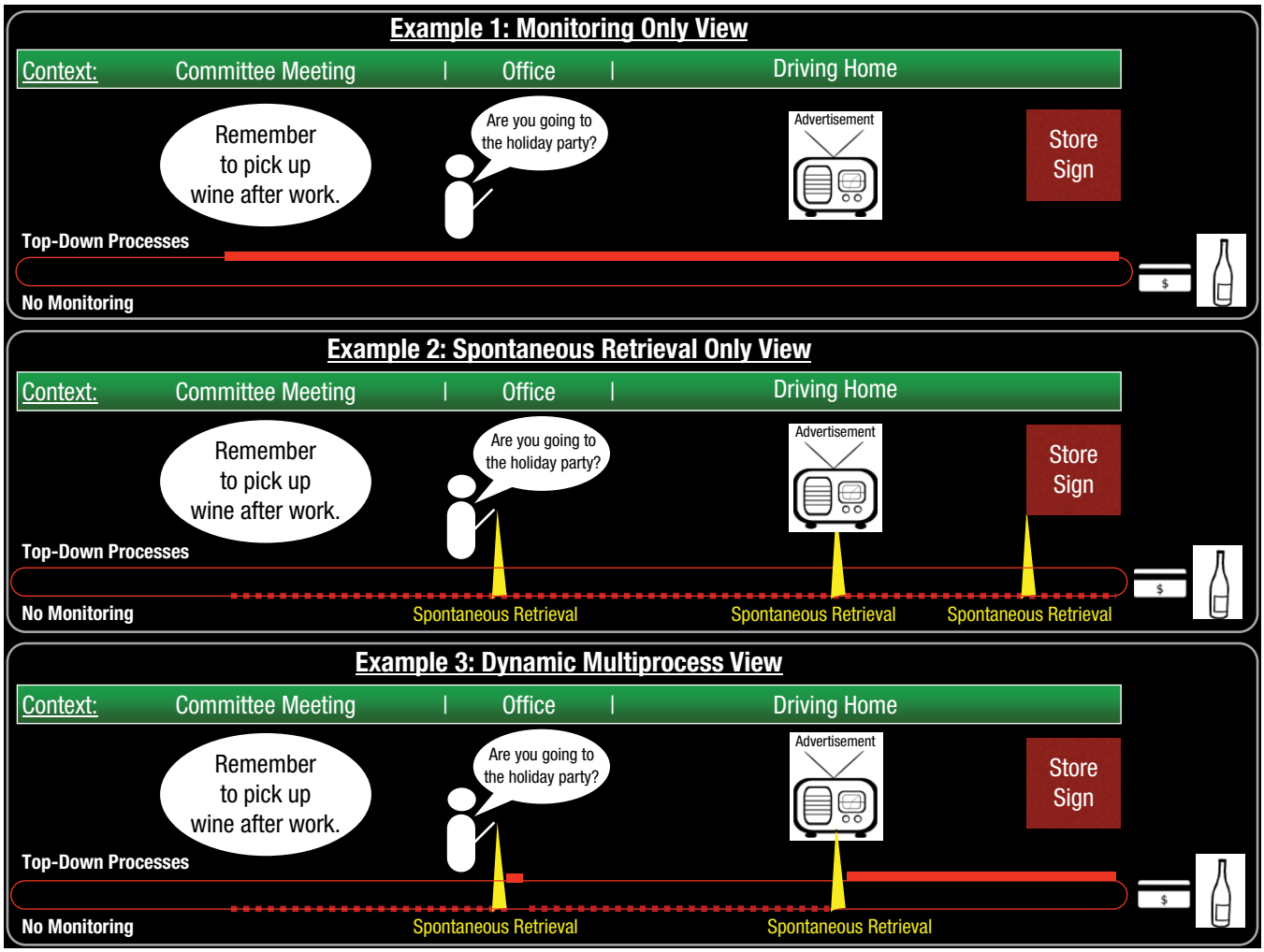


**Fig. 1.** Illustration of top-down monitoring processes operating in isolation (Example 1), bottom-up spontaneous retrieval processes operating in isolation (Example 2), and dual processes operating dynamically (Example 3). For each example, the prospective memory intention is to remember to pick up a bottle of wine for a holiday party. Top-down processes (monitoring for cues and rehearsing the intention) are represented by bolded red lines. Though monitoring at a time proximal to when the intention can be performed improves the probability of remembering to execute that intention, monitoring is effortful and always exacts a cost to ongoing task performance (contributing to the committee meeting and driving performance). In the absence of monitoring (dashed red lines), the DMPV argues that environmental cues (friend asking about the party, radio advertisement for wine) can elicit spontaneous retrieval and that spontaneous retrieval. Following the spontaneous retrieval, people will sustain monitoring if the intention can soon be performed.

illustrated in Figure 1 (Example 1), would be sitting in a curriculum committee meeting and forming the intention to later pick up a bottle of wine for a holiday party that night. If one is rehearsing the intention ("pick up wine, pick up wine") or monitoring for cues ("when will the committee chair conclude this meeting?"), one will contribute poorly at the meeting.

Top-down prospective memory processes can be objectively measured in the laboratory (Smith, 2003). Participants learn to perform a simple, binary-choice *ongoing task* such as determining if words refer to a living object. Then participants are given the *prospective memory* task of remembering to press a designated key (e.g., "Q") whenever they encounter a target item (e.g., the word "orange"). Top-down processes such as monitoring are revealed by an increase in *ongoing task cost*, which is slowed reaction time (or lower accuracy) on the living judgment task when a prospective memory demand is present relative to when no such demand is present.

Consistent with dual process theories of retrospective memory (Jacoby, 1991) and cognitive control (Braver, Gray, & Burgess, 2007), bottom-up processes can also support prospective memory. As detailed in the involuntary autobiographical memory literature (Berntsen, 2010), external cues often cause memories

to "pop" into mind without conscious effort. Returning to the example of remembering to pick up a bottle of wine after work, one might not rehearse the intention all day, but instead hear a radio advertisement on the drive home about new legislation allowing wine to be sold in Tennessee grocery stores, which spontaneously elicits retrieval of the related intention (see Fig. 1, Example 2). *Spontaneous retrieval* has been mechanistically attributed to strong cue–intention associations formed during encoding and the ability to fully process the cue during test phases (Einstein & McDaniel, 2005). An advantage of the spontaneous retrieval view is it can support prospective memory without sustained top-down processes, but a disadvantage is that weak retrieval cues will fail to elicit spontaneous retrieval and the prospective memory intention will go unfulfilled. Furthermore, because spontaneous retrieval is reflexive and cue-*dependent*, processing a strong retrieval cue at an inappropriate time can lead to prospective memory false alarms and commission errors such as accidentally "double dosing" on one's medication (Scullin, Bugg, & McDaniel, 2012).

Most theory-based prospective memory research has aimed to isolate whether participants relied on monitoring versus spontaneous retrieval. We contend that this "either/or" *isolation approach* is misguided because it ignores the diversity of daily prospective memory challenges and advances in cognitive process dynamics found in related fields (e.g., Braver et al., 2007). Therefore, we developed the dynamic multiprocess framework (Scullin, McDaniel, & Shelton, 2013), which principally argues that monitoring and spontaneous retrieval are interconnected—not isolated—processes that are fluidly moderated by environmental and individual difference factors (see also Gilbert, Hadjipavlou, & Raoelison, 2013). Recent behavioral, neuroimaging, and eye-tracking research on contextual and individual difference factors in young and older adults has provided empirical support for the dynamic multiprocess framework's view (DMPV).

## The Dynamic Multiprocess Framework

According to the DMPV, retrieval of future intentions is not dependent on *either* a spontaneous retrieval *or* a strategic monitoring process; rather, there is a fluid interaction between these mechanisms and environmental factors (Fig. 1). The initial empirical test of the DMPV used a laboratory task in which participants were given multiple ongoing task contexts without instructions of which context the prospective memory target would appear. Consistent with our prediction that participants would be unlikely to continuously sustain (unrewarded) monitoring over a long task (Scullin, McDaniel, Shelton, & Lee, 2010), monitoring was absent in the 50 trials preceding the first appearance of the target word *horse*, but some participants were able to spontaneously retrieve their intention. The fascinating subsequent effect was that participants then engaged monitoring for the remainder of the ongoing task context (in which a second target word *table* later appeared). At the end of that context, participants disengaged monitoring, as if they were "starting over."

As illustrated in Figure 1 (Example 3), monitoring and spontaneous retrieval may dynamically interact to support memory for picking up a bottle of wine after work. During the curriculum committee meeting in which the intention is initially formed, one might encode a strong external cue as a reminder (e.g., bright red sign on the drive home). Because she has established a strong cue, she does not engage top-down processes during the rest of the curriculum committee meeting. On the drive home, an environmental cue spontaneously brings to mind the intention, which leads her to rehearse the intention and monitor for the street exit. Thus, for the same prospective memory intention, the DMPV states that individuals use both top-down and bottom-up cognitive processes, which are interconnected and fluidly engaged.

## Context and Prospective Memory Dynamics

Just as scuba divers remember words better if they were encoded and retrieved in the same context of being underwater or on land (Godden & Baddeley, 1975), providing specific details at encoding about the upcoming context of a prospective memory target bolsters retrieval of the future intention (Brewer & Marsh, 2010). In prospective memory, environmental contexts serve as bottom-up retrieval cues that trigger top-down monitoring processes for the specific moment to execute the intention. For example, individuals may spontaneously retrieve an intention (pick up wine) upon reaching the context in which they can execute an intention (grocery store), but if their monitoring is interrupted (unexpectedly encounter a friend), prospective memory forgetting becomes highly probable (Einstein, McDaniel, Manzi, Cochran, & Baker, 2000).

Providing contextual information at encoding boosts the probability of remembering to execute future intentions (Chen et al., 2015). Consistent with claims of the DMPV, when college-aged participants were told that the prospective memory targets would only appear in a specific ongoing task context, they increased their monitoring selectively to that context (Cohen, Gordon, Jaudas, Hefer, & Dreisbach, 2017; Marsh, Hicks, & Cook, 2006). By using contextual cues, participants can minimize overall monitoring costs (Smith, Hunt, & Murray, 2016) and even modify their reliance on monitoring

and spontaneous retrieval on a trial-by-trial basis (Kuhlmann & Rummel, 2014; Lourenço & Maylor, 2014).

Metacognitive processes (i.e., awareness of one's own thinking and performance) may be a key mediator in the influence of context on prospective memory dynamics. For example, if one is aware that a retrieval cue will be a strong reminder, then one should monitor less because that cue can trigger spontaneous retrieval of the intention. Alternatively, if one is aware that there will be weak or no external cues, then one should monitor more because spontaneous retrieval will be ineffective. Lourenço, Hill, and Maylor (2015) captured both of these patterns by giving participants a strong or weak retrieval cue at encoding, and then during testing altered expectations for some participants by presenting a weak retrieval cue. Participants who expected the prospective memory task to be easy (strong retrieval cue) showed minimal or no monitoring; however, when the weak retrieval cue was presented, participants increased their reliance on monitoring, possibly due to realizing the improbability of spontaneous retrieval occurring. Thus, metacognitive processes during both encoding and testing affect the interplay of monitoring and spontaneous retrieval.

## Individual Differences and Prospective Memory Dynamics

Given the strong evidence for individual differences in bottom-up and top-down processes in the field of attention control (e.g., Barrett et al., 2004), one might expect similar outcomes for prospective memory dynamics. For example, an individual difference factor might lead to more efficient use of top-down monitoring processes, or alternatively, an individual difference factor might increase the likelihood of generating external cues to improve the probability of a spontaneous retrieval.

One widely studied individual difference factor is working memory capacity (Barrett et al., 2004). Brewer, Knight, Marsh, and Unsworth (2010) found that participants with high (relative to low) working memory capacity performed better on a prospective memory task with weak retrieval cues even though the overall ongoing task cost was similar across working memory groups. The DMPV's explanation is that participants with high working memory capacity effectively engaged monitoring at the appropriate moments and disengaged monitoring at times when the cues were unlikely to appear.

A second widely studied individual difference factor is personality. The public may believe conscientiousness to be key to whether someone completes a prospective memory task (e.g., if the father were conscientious he would have remembered to drop his son off at daycare), but laboratory research has found only modest correlations with prospective memory performance ($r = .10$ in Smith, Persyn, & Butler, 2015). Apparently, individuals with high conscientiousness do not monitor any more than those with low conscientiousness, but they do encode the prospective memory targets more strongly (resulting in better retrospective memory, and theoretically, a greater probability of spontaneous retrieval).

A third individual difference factor concerns effective planning. By planning to leave an external retrieval cue, individuals can increase the probability of a later spontaneous retrieval (and/or the timeliness of initiating monitoring). For example, Gilbert (2015) developed a laboratory-based task that allowed participants to use—or not use—a strategy to "offload" their intentions to the environment by setting a visual reminder. Some individuals utilized the offloading strategy whereas others did not, demonstrating individual differences in how people chose to approach the task. Of particular interest to the DMPV, when some participants anticipated that the task demands were increasing, they switched from relying on only monitoring to setting reminders that would enable spontaneous retrieval of their future intention (which can also lead to highly efficient, temporary monitoring). The difference between Gilbert's finding of increasing reliance on spontaneous retrieval and Lourenço et al.'s (2015) finding of increasing monitoring as task difficulty expectations increased is likely explained by internal locus of control. Participants in the Lourenço et al. study did not have the opportunity to control their external retrieval cue and so exerted more control over their situation by increasing monitoring. These two studies demonstrated that people can flexibly shift between a bottom-up and top-down approach to completing future intentions depending on contextual and individual difference factors.

We should be clear that people do not make a conscious choice to spontaneously retrieve their intention at the moment of retrieval (that would be a controlled process); rather, the choice to use a planning strategy suggests that people want to reduce effort toward or the difficulty of an intention. Of course individuals might mistakenly select a poor retrieval cue (e.g., a road sign that is only visible from some directions), just as individuals might mistakenly monitor more than needed (Rummel & Meiser, 2013; Scullin, McDaniel, & Einstein, 2010). According to the DMPV, selecting a weak retrieval cue or monitoring more than necessary could be due to individual differences in metacognitive processes during encoding or the testing interval.

## Normal Aging and Prospective Memory Dynamics

Nearly all studies on prospective memory dynamics have used college students, but much prospective memory research now focuses on changes with normal aging. The data are mixed on whether healthy older adults can dynamically deploy top-down and bottom-up prospective memory processes. According to the view that older adults' metacognitive ability is preserved (Hertzog, Kidder, Powell-Moman, & Dunlosky, 2002), and the view that spontaneous retrieval is relatively preserved with aging (Mullet et al., 2013), one might expect healthy older adults to be able to selectively monitor during contexts in which prospective memory cues are expected. Indeed, Kominsky and Reese-Melancon (2017) found older adults to be able to strategically increase monitoring at comparable levels to young adults when contextual cues were provided. Their findings are striking when compared to the broader evidence that older adults have difficulty sustaining top-down monitoring processes over long intervals due to their limited working memory capacity (McDaniel, Einstein, & Rendell, 2008; Rose, Rendell, McDaniel, Aberle, & Kliegel, 2010). The DMPV can explain these various results by including a role for (age-preserved) spontaneous retrieval in eliciting temporary monitoring.

Other evidence suggests an age-related change in prospective memory dynamics. For example, when a retrieval cue is processed outside of the context in which the prospective memory task should be performed, young adults will spontaneously retrieve their intention but use top-down control to suppress making a false alarm or commission error. By contrast, older adults typically fail to exert top-down control and may make double the number of commission errors as young adults (Scullin et al., 2012). An exacerbating issue for older adults may be increased difficulty in balancing ongoing task demands, which results in poorer top-down controlled processes (Kvavilashvili, Cockburn, & Kornbrot, 2013; Shelton et al., 2011).

## Methodological Innovations to Study Prospective Memory Dynamics

The interest in prospective memory dynamics has spurred the incorporation of new methodologies. Behavioral studies now go beyond the simple binary-choice response-time approach (e.g., Abney, McBride, Conte, & Vinson, 2015), but in this section, we will focus on studies using neuroimaging and eye tracking. The traditional approach to using neuroimaging to investigate prospective memory is with a "block" design in which the blood oxygen level dependent (BOLD) response is averaged across all ongoing trials during prospective memory blocks relative to control blocks. By contrast, McDaniel, LaMontagne, Beck, Scullin, and Braver (2013) conducted a mixed block/event-related design to capture transient activity during prospective memory blocks. Of interest to the DMPV, the analyses revealed increases in *both* widespread frontoparietal networks that are associated with top-down processes *and* increases in ventral parietal regions that are associated with bottom-up processes (for converging evidence using event-related potentials, see Cona, Bisiacchi, & Moscovitch, 2014).

Another promising approach is to use eye-tracking to directly assess within-trial dynamics in monitoring, their relation to contextual cues, and the functional importance of these dynamics to prospective memory performance. Shelton and Christopher (2016) used a complex version of the living judgment task as an ongoing task in which participants visually searched an array to count the number of living objects. Participants in the prospective memory condition were told that in addition to the living judgment task they should also look for a particular target item (e.g., apple) that would be presented outside of the array, in the upper right corner of the screen. Eye fixations on the upper right corner of the screen, therefore, represented strategic monitoring (a control condition only showed rare fixations on this segment of the screen). Notably, embedding images within the ongoing task that were semantically related to the target (e.g., banana) affected participants' prospective memory processes. Consistent with the DMPV, fixating on contextual cues spontaneously elicited retrieval of the intention, and immediately prompted a cue-driven monitoring process.

## Conclusions

Many domains of psychology have embraced the utilization of top-down and bottom-up cognitive processes, but existing dual process models are typically static, isolation models in which either top-down processes or bottom-up processes are engaged. Our view is that complex behaviors, such as prospective memory, cannot be captured by singular cognitive processes that operate in isolation. The DMPV advances the literature by emphasizing the fluidity and interconnectedness of top-down and bottom-up processes, with the domain of remembering to execute delayed intentions as one important example.

### Recommended Reading

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D. Reisberg (Ed.), *The Oxford handbook of cognitive psychology* (pp. 267–282). Oxford, England: Oxford University Press. Describes how top-down and bottom-up processes support prospective memory during encoding, storage, and retrieval stages and connects this work to a broader cognitive control framework.

Dismukes, R. K. (2012). (See References). Covers the diversity of everyday tasks that require prospective memory functioning.

Kliegel, M., McDaniel, M. A., & Einstein, G. O. (Eds.). (2008). *Prospective memory: Cognitive, neuroscience, developmental, and applied perspectives*. New York, NY: Taylor & Francis. Provides a comprehensive review of prospective memory, including a chapter on the influential role of context.

Scullin, M. K., McDaniel, M. A., & Shelton, J. T. (2013). (See References). Formally outlines and tests the dynamic multiprocess framework.

Shelton, J. T., & Christopher, E. A. (2016). (See References). Presents a new eye-tracking paradigm designed to isolate the monitoring process.

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## Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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