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BRIEF REPORT

Uncovering continuous and transient monitoring profiles in event-based prospective memory

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Abstract The present study implemented response time distribution modeling to better characterize context-specific attention dynamics underlying task interference due to possessing a prospective memory intention. During a three-phase paradigm in which prospective memory cues appeared only in the final phase, prospective memory performance was better when participants were informed at encoding of the context in which cues were to appear than when participants were not informed. Additionally, task interference increased during the third phase when the cue context was previously specified. Ex-Gaussian parameter estimates revealed that task interference during the third phase was due to a greater relative frequency of longer latencies, rather than an overall increase in latencies across all trials, suggesting that participants relied primarily on transient, rather than continuous, monitoring processes to support cue detection. Functionally, variability in transient and continuous monitoring profiles was predictive of prospective memory cue detection. More generally, the results from the present study suggest that ex-Gaussian parameter estimation procedures may provide a fruitful avenue for better understanding how attention is differentially allocated to ongoing tasks, what processes might underlie monitoring behavior, and how this behavior is related to eventual intention fulfillment.

Keywords Prospective memory · Memory and attention · Ex-gaussian function · Response costs

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Temporal, contextual, or physical constraints often demand the delay of behavior until an appropriate opportunity affords itself. Remembering to fulfill this intended action is referred to as *prospective memory* (PM). Event-based PM refers to relying on environmental cues to trigger the retrieval of the intended action from long-term memory. Considerable research has investigated the attentional processes necessary for intention formation, cue detection, and retrieval of the intended action (McDaniel & Einstein, 2000). However, the extant research has primarily used measures of central tendency (e.g., mean response latencies) to make inferences about the attentional processes thought to support PM. Mean response latencies may not entirely capture the underlying dynamics involved in monitoring for intention-related information (Brewer, 2011). Thus, the present study sought to extend previous findings by analyzing response time (RT) distributions during ongoing task contexts that either did or did not have a PM intention associated with them.

In a typical event-based PM task, participants form an intention to perform a certain action upon encountering a specific perceptual or conceptual cue during a subsequent ongoing task. For example, participants may be instructed that they are going to later perform a lexical decision task (LDT) and that if, at any time, an animal word (e.g., *horse*) appears, they should press the "/" key after (or instead of) making their lexical decision. To examine cost to ongoing task performance as a result of possessing an intention, average RTs for noncue trials are compared between participants who do or do not possess an intention. Considerable research has demonstrated that RTs are longer for participants who possess an intention than for those who do not (referred to as either costs or task interference), suggesting that the slowing reflects additional capacity-consuming attentional processes necessary for detecting cues (Marsh, Hicks, Cook, Hansen, & Pallos, 2003; Smith, 2003). That is, if both the ongoing task and PM task draw on the same limited attentional resources, as more resources are devoted to cue detection, slowing should occur because fewer resources are available for ongoing task processing.

Currently, several complementary hypotheses have been developed to explain why task interference effects emerge in event-based PM tasks. In the retrieval mode and two-stage checking hypotheses (Guynn, 2003; Guynn, McDaniel, & Einstein, 2001), task interference arises from maintenance of a *retrieval mode* that treats ongoing task stimuli as potential PM retrieval cues or from checking each stimulus for intention-relevant details. The preparatory attentional and memory (PAM) theory posits that cue recognition requires the allocation of capacity-consuming preparatory attentional processes (e.g., Smith, 2003), whereas the attention allocation hypothesis states that participants are sensitive to the demands of the PM task at hand and adjust their attentional-allocation policies to optimize cue detection (Hicks, Marsh, & Cook, 2005). Critically, the underlying assumption of each of these theories is that participants *continuously* maintain capacity-consuming PM processes necessary to monitor for cues. Consequently, when participants possess an ill-specified (i.e., nonfocal) intention, general slowing should occur across all (or most) ongoing task trials. Alternatively, the periodic reminding view suggests that monitoring is *transient* and that intentions fade in and out of consciousness between the time that the intention is formed and when the cue is detected and, therefore, that slowing should occur only during the trials on which the intention is active (e.g., Dewitt, Hicks, Ball, & Knight, 2012; Einstein, McDaniel, Williford, Pagan, & Dismukes, 2003). Although theoretically these views differ in their presupposition of either continuous or transient monitoring profiles across ongoing task trials, mean RTs cannot necessarily arbitrate between RT profiles, due to the fact that equivalent increases in mean RTs can arise from *both* continuous and transient strategies.

Analyzing RT distributions may help to better address these hypotheses regarding how attentional processes are recruited to monitor for event-based PM cues. The ex-Gaussian function is a convolution of the Gaussian and exponential distributions. At each time point x, the ex-Gaussian distribution is described by the mean (μ) and variance (σ) of the Gaussian distribution, and the mean (and standard deviation) of the exponential distribution (τ). The sum of μ and τ produces the mean of the overall distribution, and the sum of their squared standard deviations ($\sigma^2 + \tau^2$) produces the variance. The sum of μ and τ estimates is approximately equal to the mean RT, because the sum of the true values of μ and τ is equal to the true mean of the ex-Gaussian distribution. An increase in μ leads to a distributional shift to the right, whereas an increase in τ leads to a positive distributional skew (see Balota & Yap, 2011, for more details on RT distribution analyses). Although it is important to note that ex-Gaussian parameters do not reflect an underlying cognitive process (Matzke & Wagenmakers, 2009), previous research has suggested that these parameters are affected more by some manipulations than by others. For example, interference effects due to response competition during various attention tasks have been associated primarily with an overall shift in the RT distribution (e.g., Spieler, Balota, & Faust, 2000), whereas goal neglect due to periodic lapses of attention has been associated primarily with a positive skew in the tail of the distribution (e.g., Schmiedek et al., 2007; Tse, Balota, Yap, Duchek, & McCabe, 2010; Unsworth, Redick, Lakey, & Young, 2010). Importantly, these results also suggest that theorizing of the underlying cognitive processes that contribute to ongoing task performance may be improved by investigating various components of the RT distribution.

To demonstrate the utility of RT distribution modeling in PM tasks, Brewer (2011) fit the ex-Gaussian function to RTs during an LDT prior to forming an intention (baseline block) and following formation of a nonfocal intention (intention block) to respond to the syllable “tor” (e.g., *doctor*). Brewer found that the task interference evident from mean RTs for the intention, relative to the baseline, block was due entirely to a change in the relative frequency of slow responses (τ) when possessing an intention (see also McBride & Abney, 2012). The increase in τ was interpreted as reflecting transient periods in which participants engaged monitoring processes. There was no difference in μ and, thus, no evidence that the task interference observed reflected an overall increase in monitoring throughout the entire ongoing task (i.e., regularly monitoring on ongoing task trials). These results demonstrated that RT distribution analyses can provide a better understanding of the attentional processes involved in task interference that cannot be found using traditional measures of central tendency. However, because there was no comparison group, the increase in τ could presumably reflect periodic lapses of attention, rather than increased focus on a subset of trials.

The present study

The purpose of the present study was to extend the findings from Brewer (2011) by fitting the ex-Gaussian function to RT distributions for PM conditions that differed in the contextual specificity of a nonfocal intention. We used a three-phase paradigm in which PM cues appeared only in the third phase and compared RTs between the first and third phases for participants who possessed an intention that was or was not specifically associated with the third phase (context linked and nonlinked conditions, respectively), as well as for participants who did not possess an intention (control condition). We utilized this approach because it has been demonstrated that linking an intention to a specific context (e.g., third phase) eliminates the necessity to monitor for cues during ongoing tasks (e.g., first phase) not associated with an intention (e.g., Knight et al., 2011; Marsh, Hicks, & Cook, 2006) and increases the rates of reporting strategic (i.e., continuous) search processes (as opposed to allowing the intention to "pop into mind") upon encountering the appropriate context (Meier, Zimmermann, & Perrig, 2006). Furthermore, when an intention is not linked to a specific context and expected cues fail to appear (e.g., first phase), participants may actually disengage monitoring processes. Thus, these findings suggest that participants with or without contextually linked intentions may engage different monitoring processes to support cue detection even though the cues to be encountered and intended action are identical across conditions.

On the basis of the findings from Brewer (2011), we expected cost for context-linked intentions to be evidenced by an increase in τ, but only during the third phase. However, it is also possible that these participants engage more continuous monitoring processes, and thus, changes in cost across phases may additionally be associated with an increase in μ. In contrast, if participants disengage monitoring processes in the not-linked condition because cues fail to appear during the first phase, there may actually be a decrease in μ. Beyond examining changes in parameter estimates across varying contexts, we further extend the work by Brewer by examining whether changes in these parameter estimates are functionally related to PM performance.

Method

Participants

Undergraduate students from the University of Georgia volunteered in exchange for partial credit toward a research appreciation requirement. Each participant was tested individually in sessions that lasted approximately 30 min. One hundred twenty participants were randomly assigned to the two between-subjects conditions. Thirty additional participants were included as a control condition that performed the ongoing task but never received PM instructions. However, data are reported only for participants in the linked (n = 56), not-linked (n = 56), and control (n = 26) conditions in which model fits for parameter estimates were successful (described below).

Materials and procedure

Participants were informed that the experiment consisted of three distinct phases. In the first and third phases of the experiment, participants performed 105 trial LDTs in which 52 strings of letters were valid English words and 53 were pronounceable nonwords that were randomly presented during each phase. Participants were to determine whether or not each stimulus was a valid English word as quickly and accurately as possible. After the decision was made, a "waiting" message would appear to indicate to the participants to press the space bar to continue to the next trial. During the second phase of the experiment, participants were to complete a brief questionnaire. The questionnaire included questions about the participant's age and school status (e.g., year in school, major, number of enrolled classes, etc.) and took approximately 1 min to complete. Each experimental phase was clearly identified, so participants knew which phase they were about to begin.

After receiving ongoing task instructions, participants in the experimental conditions were additionally instructed to make a special keypress ("/") during the "waiting" message after responding to any animal word (e.g., "CHEETAH") during the LDT. The animal words *only appeared in the 3rd phase of the experiment* and were always presented on trials 25, 50, 75, and 100. The order in which the cues appeared was randomly selected for each participant. Critically, only half of the participants were instructed that the animal words were going to appear only in the 3rd and final phase (linked condition). The other half of the participants were under the impression that cues could appear in either LDT phase (not-linked condition). Following PM instructions, half of the participants in each condition were additionally asked to predict the percentage of cues they expected to respond to. After participants acknowledged that they fully understood the task instructions, they completed a 4-min distractor task and began the experiment.

Response time analyses

Standard RTs

Only correct (noncue) word trials within 2.5 standard deviations of each participant's mean were included for the analyses. We also excluded the two trials following cue presentation in the intention conditions because participants may have been still been engaging cue-related processes during these trials (e.g., Meier & Rey-Mermet, 2012). RTs were analyzed by calculating mean RTs during the ongoing task for each participant, separately for each phase.

Ex-Gaussian parameters

Ex-Gaussian analyses were performed on the same RTs using Quantile Maximum Probability Estimation (QMPE) software (Heathcote, Brown, & Cousineau, 2004) to obtain parameter estimates for each participant that best produced the observed data. Estimates of μ, σ, and τ were derived separately for phases 1 and 3 for each participant using the maximum possible number of quantiles (N−1). The model failed to converge for 4 participants in each condition. For all other participants, acceptable model fits were obtained within 30 iterations. Thus, only data from the 138 of the 150 participants for whom model fits were successful are included in the analyses.

Quantiles

Quantile plots allow for examination of the raw RT distribution across conditions without making assumptions about the underlying shape of the distribution (Andrews & Heathcote, 2001). Quantiles were separately computed for each condition by rank ordering raw RTs from shortest to longest for each individual (separately for each phase) and calculating the mean of the first 20 %, the second 20 %, and so forth. Additionally, we calculated the difference across quantiles from phase 1 to phase 3.

Results

Prospective memory performance

PM performance and descriptive statistics for all other measures are reported in Table 1. The proportion of successfully fulfilled intentions across conditions (linked vs. not-linked) were submitted to a between-subjects analysis of variance (ANOVA). Consistent with previous research (Cook, Marsh, & Hicks, 2005; Meier et al., 2006; Nowinski & Dismukes, 2005), context linking served to improve performance, $F(1, 110) = 3.97$, $p < .05$, $\eta_{p2} = .035$.

Ongoing task performance

As was mentioned previously, half the participants in each experimental condition made predictions on how well they were going to do in remembering to fulfill the intended action. However, all reported analyses are collapsed across the prediction factor because it did not interact with any variables of interest. Thus, for all cost analyses (i.e., standard and ex-Gaussian), mean RTs or parameter estimates (μ, τ, or σ) were submitted to a 2 (phase: phase 1 vs. phase 3) by 3 (condition: linked vs. not-linked vs. control) mixed-factorial ANOVA. Family-wise error rates from multiple comparisons were corrected by reporting Bonferonni-adjusted p values.

Standard RT analyses

The analysis of mean RTs failed to find an effect of phase or condition, $F(1, 135) < 1.0$ and $F(2, 135) < 1$, respectively. However, there was an interaction of phase and condition, $F(2, 135) = 20.44$, $p < .001$, $\eta_{p2} = .232$. This interaction primarily reflects that, relative to phase 1, RTs in phase 3 were longer for the linked condition, $t(55) = 4.82$, $p < .001$, $d = 0.645$, shorter for the control condition, $t(25) = 3.21$, $p = .01$, $d = 0.668$, and marginally shorter for the not-linked condition, $t(55) = 2.33$, $p = .07$, $d = 0.315$. Group analyses revealed no RT difference during phase 1, $F(2, 135) = 1.85$, $p = .16$, but a significant difference in phase 3, $F(2, 135) = 3.73$, $p < .05$, $\eta_{p2} = .052$. The phase 3 group difference reflects that relative to the control condition, latencies were longer for the linked condition, $t(80) = 2.53$, $p = .03$, $d = 0.60$, but did not differ for the not-linked condition, $t(80) = 1.70$, $p = .19$.

Ex-Gaussian analyses

The analysis of the μ parameter revealed an effect of phase, $F(1, 135) = 6.20$, $p < .05$, $\eta_{p2} = .044$, but no effect of condition, $F < 1.10$. However, there was an interaction of phase and condition, $F(2, 135) = 6.77$, $p < .01$, $\eta_{p2} = .091$. This interaction primarily reflects that, relative to phase 1, in

Table 1 Mean reaction times (RTs), ex-Gaussian parameters, and prospective memory performance across conditions (standard errors in parentheses)

Phase	Condition	Mean RT	μ	σ	τ	Cue detection
Phase 1:						
	Linked	678 (16)	539 (9)	46 (3)	152 (11)	
	Not-linked	719 (14)	555 (9)	46 (3)	166 (9)	
	Control	706 (23)	531 (14)	49 (5)	177 (18)	
Phase 3:						
	Linked	727 (16)	536 (9)	40 (3)	193 (12)	.83 (.04)
	Not-linked	698 (13)	533 (9)	45 (3)	167 (9)	.71 (.04)
	Control	661 (17)	516 (10)	60 (6)	146 (14)	–
Phase 3 – Phase 1:						
	Linked	49 (10)	8 (6)	−6 (3)	42 (10)	
	Not-Linked	−21 (9)	−22 (6)	−1 (4)	2 (9)	
	Control	−46 (14)	−15 (11)	2 (8)	−32 (14)	

phase 3 μ decreased for the not-linked condition, $t(55) = 4.12$, $p < .001$, $d = 0.551$, but did not differ for the linked or control conditions, $ts < 1.36$, $ps > .49$. Group analyses revealed only a marginal μ difference in phase 1, $F(2, 135) = 2.40$, $p = .10$, and no difference in phase 3, $F(2, 135) < 1.0$.

The analysis of the τ parameter revealed no main effects, Fs < 1. However, there was an interaction of phase and condition, $F(2, 135) = 9.15$, $p < .001$, $\eta_{p2} = .192$. This interaction primarily reflects that, relative to phase 1, in phase 3 τ increased for the linked condition, $t(55) = 4.26$, $p < .001$, $d = 0.57$, marginally decreased for the control condition, $t(25) = 2.31$, $p = .09$, $d = 0.387$, and did not differ for the not-linked condition, $t < 1$. Group analyses revealed no τ difference during phase 1, $F < 1.1$, but a significant difference during phase 3, $F(2, 135) = 3.63$, $p < .05$, $\eta_{p2} = .051$. The phase 3 effect reflects that, relative to the control condition, τ was larger for the linked condition, $t(80) = 2.32$, $p = .05$, $d = 0.551$, but did not differ for the not-linked condition, $t(80) = 1.36$, $p = .36$.

The analysis of the σ parameter failed to reveal an effect of phase or condition or an interaction between the two, Fs < 1.0. The null effects are not entirely surprising, since previous research has failed to reveal differences in σ (e.g., Brewer, 2011).

Quantile plots

Figures 1a and b display the best-fitting estimated quantiles (lines) superimposed on the empirical quantiles (data points and standard errors). The minimal divergence between the estimated and empirical quantiles suggests that the data were well fit by the ex-Gaussian distribution. Figure 1c displays the difference across phases (phase 3 − phase 1) for the empirical quantiles, which is largely consistent with the ex-Gaussian analyses. The decrease in RTs for the not-linked condition is consistent with a distributional shift, since the magnitude of the effect (although small) remained largely invariant across the entire distribution. In contrast, although there was a small increase and decrease across phases for all items in the linked and control conditions, respectively, the changes in RTs are consistent with a distributional skew, since the magnitude of the effect was disproportionately greater for the slowest trials. However, further research is needed to determine whether the small differences between the linked and control conditions in the faster quantiles found here may additionally reflect meaningful changes in continuous monitoring strategies evidenced by distributional shifting.

Functional cost analyses

To examine whether there is a functional relationship between PM performance and costs, we computed correlations between PM performance and the change in mean RTs (e.g., phase 3 RT − phase 1 RT) and the ex-Gaussian parameter estimates across phases. In the linked condition, although PM performance was not correlated with the change in mean RTs ($r = -.07$, $p = .59$) or σ ($r = .01$, $p = .95$), performance was positively correlated with μ ($r = .29$, $p = .03$) and marginally negatively correlated with τ ($r = -.27$, $p = .06$). In contrast, although in the not-linked condition PM performance was positively correlated with the change in mean RTs ($r = .26$, $p = .05$), it was not correlated with μ ($r = .16$, $p = .24$), σ ($r = .18$, $p = .19$), or τ ($r = .17$, $p = .20$). A simultaneous regression analysis of PM performance on the three parameter estimates revealed that in the linked condition ($R^2 = .135$), only the change in μ was a significant predictor of successful PM, $t(52) = 2.05$, $p < .05$, whereas in the not-linked condition ($R^2 = .14$), only the change in τ was predictive of PM success, $t(52) = 2.11$, $p < .05$.

Discussion

Although considerable research has investigated the cognitive processes that underlie cost during event-based PM tasks, relatively little research has examined how regularly these processes operate during the ongoing task. The results from the present study suggest that the regularity of engaging capacity-consuming PM processes differs across conditions of varying contextual specificity and demonstrate that linking an intention to a future context can affect the continuous and transient monitoring RT profiles that support intention fulfillment. Thus, ex-Gaussian analyses may provide a fruitful avenue toward better understanding how attention is differentially allocated to the ongoing task, what processes might be underlying the RT behavior, and how this behavior is related to eventual intention fulfillment.

Consistent with previous research (e.g., Knight et al., 2011; Marsh, Hicks, & Cook, 2006), standard RT analyses revealed that participants in the linked condition demonstrated a substantial increase in cost when the context was appropriate for executing the intended action. However, ex-Gaussian analyses found that the change in RTs was due to an increase in the number of longer RTs (i.e., τ), rather than an overall shift in the distribution (i.e., μ). The finding of increased τ, but not μ, is informative inasmuch as it has generally been assumed that cost within a specified PM context primarily reflects cue detection processes that operate continuously on a trial-by-trial basis (e.g., Guynn, 2003; Marsh et al., 2006; Smith, 2003). However, the results from the present study suggest that, instead, cognitive processes underlying cost in the linked condition occurred more transiently (Einstein et al., 2003). In contrast to the findings of the linked condition, standard RT analyses revealed that for participants in the control and not-linked conditions, RTs actually decreased across phases. Interestingly, despite no discernable differences between the two groups in the standard RT analyses, ex-Gaussian analyses

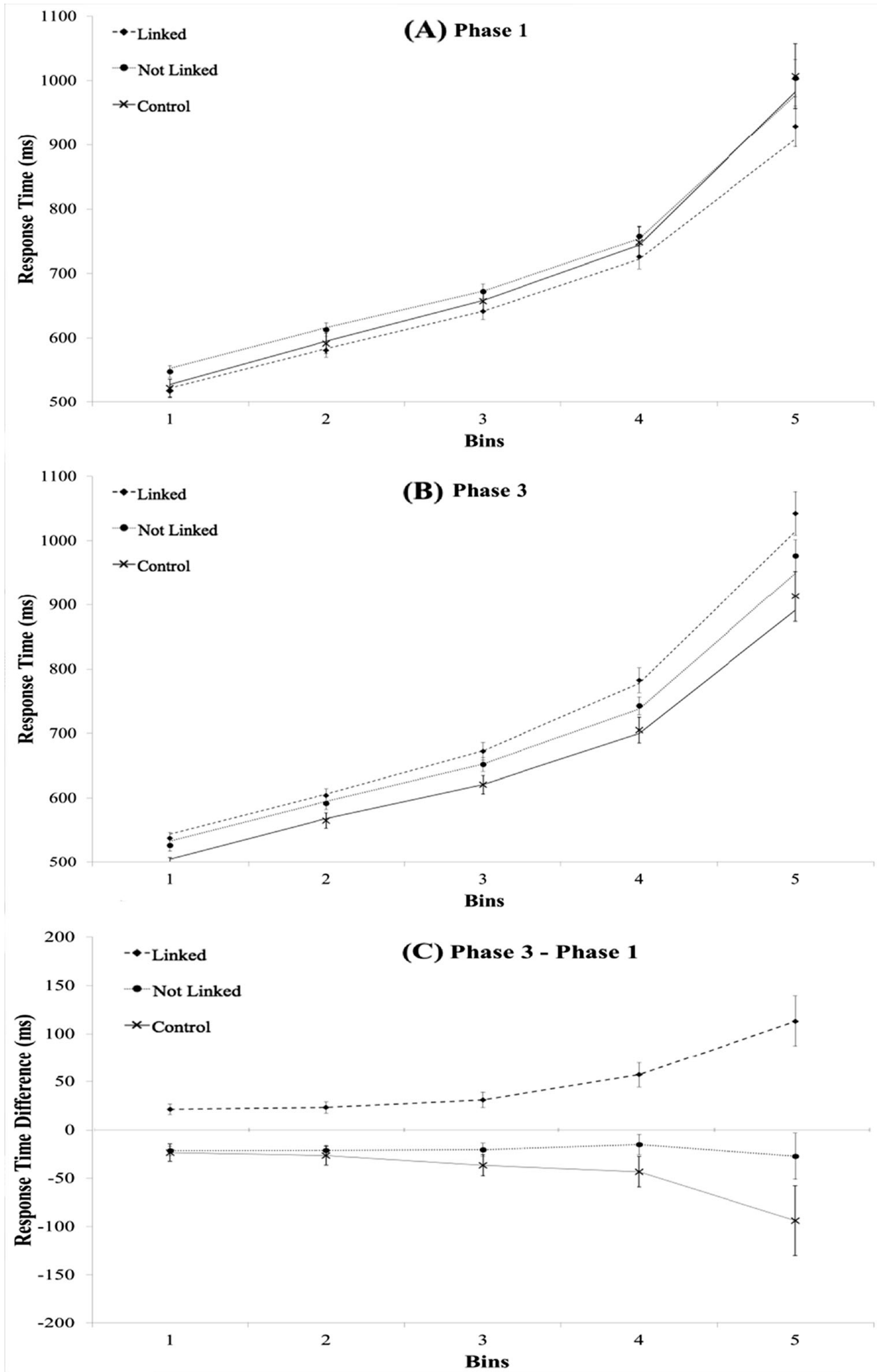

Fig. 1 Response times as a function of condition and quantiles during phase 1 (**a**) and phase 3 (**b**), along with the response time difference across phases (**c**). In the top and middle panels, participants' mean quantiles are represented by data points and standard error bars, whereas the best-fitting ex-Gaussian quantiles are represented by lines. The bottom panel displays only the empirical quantiles that represent the difference score from the top two panels (phase 3 − phase 1) for each condition

showed that the shorter RTs were associated with a decrease in τ in the control condition but a decrease in μ in the not-linked condition. The decrease in μ in the not-linked condition may reflect that participants disengaged continuous monitoring processes after cues failed to appear during the first phase (Meier et al., 2006) or that they simply forgot about the intention until it was reactivated upon encountering the first cue. If indeed this was the case, this could account for differences in PM performance between the two PM conditions. However, the lack of decrease in τ across phases in the not-linked condition could suggest that participants still engaged some transient monitoring processes to support cue detection that partially offset the disengagement of continuous monitoring process.

Our theory suggests that variations in continuous and transient attention processes are being exposed by μ and τ, respectively, in the ex-Gaussian analysis. Importantly, these transient fluctuations could reflect sporadically thinking about the intention in contexts where continuous monitoring is a better strategy for successful PM performance, or momentary lapses of intention (West, Krompinger, & Bowry, 2005) where continuous monitoring processes are interrupted by task-unrelated thoughts. In both instances, an increase in τ would be predicted to result in worse PM performance, but in the latter case, the increase in τ should be accompanied by an increase in μ. In the present study, we found a moderate negative correlation with τ and cue detection in the linked condition, without a significant increase in μ. However, only μ was positively correlated with PM performance. These findings suggest that the increase in τ across phases may not reflect lapses of intention but may, instead, reflect transient periods in which more attention was devoted to cue detection. However, because the prospective cues were not focal to ongoing task processing (McDaniel & Einstein, 2000), participants who relied on more continuous monitoring processes were more successful at detecting cues, as evidenced by the positive correlation between μ and PM performance. Similarly, the decrease in μ across phases for the not-linked condition suggests that participants may have disengaged more efficacious continuous search processes but that those who at least periodically engaged transient monitoring processes successfully detected more cues than did those who did not, as evidenced by the positive correlation between τ and PM performance. Together, these results suggest not only that contextual associations aid successful prospective remembering, but also that inaccurate contextual associations may hinder prospective remembering (Cook et al., 2005). Future research should better classify monitoring strategies using RT distribution estimates at the participant level and relate these profiles to individual-difference variables and ultimate PM performance.

Theoretically, monitoring for event-based PM cues has been described as *either* continuously active from trial to trial (Guynn, 2003) or transiently occurring whenever the intention rarely comes to mind (Einstein et al., 2003). The results from the present study indicate that participants may be capable of using *both* continuous and transient strategies when monitoring for event-based cues. Although traditional approaches using mean RTs have provided a greater understanding of the underlying memory and attentional processes involved in monitoring and intention fulfillment, these techniques may have reached their theoretical limit in explanatory utility. We suggest that ex-Gaussian analyses may provide a more detailed understanding of the RTs that make up the distribution in the standard analyses and suggest that both μ and τ track continuous and transient monitoring strategies, respectively. Future research should further examine the relation between PM monitoring profiles emerging from RT distributional analyses and successful fulfillment of intentions for future action.

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