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# The Multinomial Model of Prospective Memory: Validity of Ongoing-Task Parameters

**Sebastian S. Horn**,
Institut für Experimentelle Psychologie, Heinrich-Heine-Universität Düsseldorf

**Ute J. Bayen**,
Institut für Experimentelle Psychologie, Heinrich-Heine-Universität Düsseldorf

**Rebekah E. Smith**, and
Department of Psychology, The University of Texas at San Antonio

**C. Dennis Boywitt**
University of Mannheim

## Abstract

The objective of this research was to provide additional experimental validation of the multinomial processing tree (MPT) model of event-based prospective memory (Smith & Bayen, 2004). In particular, the parameters that measure trial type detection in the ongoing task were examined. In three experiments with different response instructions, event-based prospective memory tasks were embedded in ongoing color-matching tasks. The results support the validity of the MPT model, that is, manipulations of ongoing-task difficulty affected the ongoing-task parameters of the MPT model, while leaving the estimates for the prospective and the retrospective components of prospective memory unaffected.

### Keywords

prospective memory; multinomial model; formal model

Prospective memory (PM) refers to remembering to carry out intentions. Time-based PM tasks must be performed at a certain point in time or after a certain period of time has passed (e.g., switching off the oven after 25 minutes), whereas event-based PM tasks require us to carry out an intention in response to a specific target event in the future. For example, one may be riding a bike on the way home and be watching the traffic, but then must remember to interrupt the ride in order to stop at the bakery to buy bread. PM tasks often occur in the midst of other activities that must be interrupted in order to carry out the intended action. To capture this aspect of real world PM, the PM tasks in the laboratory are embedded in other ongoing activities (Einstein & McDaniel, 1990). For instance, participants are instructed to engage in an ongoing activity (e.g., a lexical decision task, a working memory task, etc.), and at the same time must remember to carry out another action (e.g., to press a certain key on a computer keyboard) when a particular target occurs (e.g., a particular word appears on the screen). In this paradigm, participants' responses depend on different processes, some of which are related to the ongoing activity and others to the PM task. The *interplay* of ongoing

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Correspondence concerning this article should be addressed to Sebastian S. Horn or Ute J. Bayen, Institut für Experimentelle Psychologie, Abteilung Mathematische und Kognitive Psychologie, Heinrich-Heine-Universität Düsseldorf, Universitätsstr. 1, Geb. 23.02, 40215 Düsseldorf, Germany. s.horn@uni-duesseldorf.de, ubayen@uni-duesseldorf.de.

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activities and PM has been of great interest in PM research, and valid measurement of the processes involved in the ongoing task, as well as processes that contribute to various components of PM are therefore very important.

## The Multinomial Model

Smith and Bayen (2004) introduced a multinomial processing tree (MPT) model for the measurement of processes involved in embedded event-based PM tasks (see Batchelder & Riefer, 1999, and Erdfelder et al., 2009, for reviews of MPT models). The model provides independent estimates for two core components of PM (Einstein & McDaniel, 1990, 1996), namely the *prospective component* (remembering *that* something must be done), and a *retrospective component* (recognition memory for targets). Importantly, the model also includes estimates of detection of different ongoing-task trial types and corrections for guessing.

Smith and Bayen (2004) experimentally validated the model parameters related to the PM task; however, the ongoing-task parameters have not yet been validated. In this article, we describe the MPT model, briefly review prior validation studies and discuss the importance of validating the parameters measuring ongoing-task trial type detection. We then present three experiments that served to validate the ongoing-task parameters of the model.

The MPT model is designed for experiments in which PM target events are embedded in an ongoing task with two response alternatives. We used an ongoing color-matching task in which a series of colored squares is presented, followed by a colored probe word. Participants decide whether the color of the probe word matches one of the preceding colored squares. For the PM task, participants must remember to press another key whenever a particular target occurs (e.g., the word *tiger*). The MPT model has been used extensively to analyze data from the color-matching task (Smith & Bayen, 2004, 2006; Smith, Bayen, & Martin, 2010), but has also been used with a sentence-verification task (Smith & Bayen, 2005) and can in fact be used with any ongoing task involving two response alternatives.

For the color-matching task, there is good evidence that the prospective component relies on resource demanding preparatory attentional processes, as indicated by significant costs in ongoing-task reaction time (RT) when a PM task is added (Smith & Bayen, 2004). Current theories of event-based PM (McDaniel & Einstein, 2007; Smith, 2003, 2010) agree that in this paradigm, the prospective component of the PM task requires resources.[1] Therefore, we will refer to the prospective component in our PM task as preparatory attentional processes. When embedding a PM task in an ongoing color-matching task, there are four different trial types (Figure 1). For each trial type, latent cognitive processes lead to observable responses that can either be *Match* (i.e., the color of the probe matches one of the previously presented colors), *Nonmatch* (i.e., the color of the probe does not match one of the previously presented colors), or *PM* (i.e., the probe word is a PM target). The top tree in Figure 1 represents a PM target trial with color-match. In the upper half of this tree, $C_1$ represents the probability that participants detect the color of the item as a match. With probability $P$, participants engage in preparatory attentional processes (the prospective component). With probability $M_1$, the target item is recognized, resulting in a “PM” response. When a target is not recognized (with probability $1 - M_1$), participants either guess (with probability $g$) or do not guess (with probability $1 - g$) that the item is a target. When participants do not engage

[1]An ongoing task that is nonfocal to the PM task does not direct the attention to the PM target and its relevant characteristics as defined at encoding (McDaniel & Einstein, 2007). For instance, in our paradigm, the ongoing task requires processing colors in which words are presented (i.e., visuo-perceptual features), but the PM task requires detection of particular target words (i.e., semantic features).

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preparatory attentional processes, with probability $1 - P$, the “PM” response will not be given. Still, the word is detected as a color match, resulting in a “Match” response. The lower half of the tree represents the case in which the match is not detected (with probability $1 - C_1$). Participants may engage in preparatory attentional processes with probability $P$ and recognize the item as a target (with probability $M_1$), resulting in a “PM” response. If the item is not recognized as a target, participants may guess (with probability $g$) that the word is a target and make the “PM” response. If they do not guess that the item is a target (with probability $1 - g$), they may guess with probability $c$ that the color of the item matches, resulting in a “Match” response, or may guess with probability $1 - c$ that the item does not match, resulting in a “Nonmatch” response. If preparatory attentional processes are not engaged, participants guess ($c$) or do not guess ($1 - c$) that the color of the word is a match, resulting in a “Match” or “Nonmatch” response, respectively. The second tree represents trials in which a PM target item is presented but its color does not match. It is identical to the first tree, except for parameter $C_2$, the probability to detect that the color of a word does not match one of the colors in the preceding set of rectangles. The third and fourth trees represent nontarget match trials and nontarget nonmatch trials, respectively. The parameter $M_2$ in these last two trees represents the probability of recognizing that a word is not a PM target.

The model with seven free parameters, $C_1$, $C_2$, $P$, $M_1$, $M_2$, $g$, and $c$, is not identifiable; therefore, theoretically motivated restrictions on ancillary parameters are necessary (Smith & Bayen, 2004). Assuming that individuals calibrate their responses to the perceived ratio of targets to distracters during an experiment, known as probability matching (cf. Spaniol & Bayen, 2002), $c$ is set to the proportion of match trials in the experiment and $g$ is set to the proportion of targets (i.e., $c = .50$; and $g = .10$ in the present experiments). A further constraint is imposed on the $M$ parameters by assuming that PM target items and nontarget items are equally well recognized (i.e., $M_1 = M_2$; for further explanation of this restriction, see Smith & Bayen, 2004). The resulting model with four free parameters $P$, $M$, $C_1$, and $C_2$ is globally identifiable (as shown analytically in Smith & Bayen, 2004).

A model must be empirically validated before it can be used. The objective of such validation is to test whether parameters measure the cognitive processes as postulated. For each parameter, at least one experimental manipulation must be found that has expected effects on the parameter on the basis of established theory or research. A strict validity test is passed if the parameter in question is affected *selectively*, that is, other parameters remain unaffected by the manipulation (i.e., discriminant validity; cf. Campbell & Fiske, 1959). Smith and Bayen (2004) validated the $P$ and $M$ parameters, which pertain to PM performance (see Horn, Bayen, & Smith, 2008, for a review). First, instructions emphasizing the importance of the PM task selectively influenced the $P$ parameter: when instructions stated that the PM task was more important than the ongoing task, the probability of engaging in preparatory attentional processes ($P$) increased, leading to higher PM performance. Second, available encoding time for PM targets selectively influenced the recognition-memory parameter $M$, with longer encoding times leading to higher estimates for discrimination between targets and nontargets ($M$).

However, there remains an important gap to be filled in model validation. Specifically, the validity of the two $C$ parameters, which are supposed to measure the processes underlying ongoing-task performance (i.e., trial-type detection), has not yet been put to empirical test. For several reasons, it is critical that a validation of the ongoing-task parameters of the MPT model be performed. If the model provides valid measurement of ongoing-task trial type detection, the effects of ongoing-task load and other task characteristics can be examined more specifically. Importantly, if all model parameters pass strict validity tests, analyses at the level of latent parameters will help to reveal the interplay of ongoing-task processes and

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PM processes without concern that these measures be confounded, and will fruitfully add to earlier research (e.g., Marsh & Hicks, 1998).

The aim of the present experiments was to test the validity of the ongoing-task parameters with a manipulation that should selectively affect the ease of performing the ongoing task, while leaving the parameters related to the PM task unaffected. Several studies have systematically manipulated the cognitive load of ongoing activities and have examined corresponding changes in PM (e.g., Marsh, Hancock, & Hicks, 2002; Otani, Landau, Libkuman, St. Louis, & Kazen, 1997). On the basis of established theories of attentional control (Baddeley, 1996; Norman & Shallice, 1986), Marsh and Hicks (1998) argued that PM suffers if additional ongoing demands tap executive resources, whereas this is not the case if the phonological loop or the visuo-spatial sketchpad are engaged, because the latter are thought to require few, if any, central resources. These authors showed empirically that increasing cognitive load reduced PM performance if the manipulation engaged the central executive (generating random digits), but not if load was increased with a task requiring articulatory suppression (verbal rehearsal) or visual processing (watching color squares).

With an ongoing task that is nonfocal[1] to the PM task, theorists agree that resource demanding processes are involved in the prospective component of the PM task (McDaniel & Einstein, 2007). These processes likely involve executive functions (Kliegel, Ramuschkat, & Martin, 2003). To apply an ongoing-task manipulation that would *not* simultaneously affect the PM parameters by tapping the central executive, we varied ongoing-task difficulty in a fashion that should selectively affect visual short-term memory load rather than the central executive of working memory (Baddeley, 1986, 1996). That is, even if our ongoing-task tapped some executive resources for baseline performance, the *increase* in difficulty should absorb negligible *additional* resources, because difficulty is manipulated in a specific way. To this end, we used the color-matching task and manipulated task difficulty by varying the number of color rectangles shown on each trial. Comparable manipulations have been used to selectively interfere with visual short-term memory (Klauer & Zhao, 2004; Marsh & Hicks, 1998, Experiment 5; Tresch, Sinnamon, & Seamon, 1993). Our experiments did not require additional articulatory suppression (e.g., repeating the word *the*) during stimulus presentation. Thus, it is possible that participants encoded the colors phonologically. However, this would not alter the general purpose of our difficulty manipulation to affect slave systems of working memory, either visual or phonological, rather than the central executive.[2] Our difficulty manipulation should thus decrease the *C* parameter estimates, while leaving the other model parameters unaffected.

## Overview of the Experiments

We performed three experiments to test the validity of the ongoing-task parameters. The experiments were similar in procedures and all employed an ongoing color-matching task, but used different response formats. Instructions to respond in a particular order on PM target trials can influence participants' strategies and attentional allocation policies (Bisiacchi, Schiff, Ciccola, & Kliegel, 2009; Marsh, Hicks, & Watson, 2002) and can therefore interact with effects of ongoing-task difficulty. To assure that parameter validation would not depend on response coordination, three possible response formats were included in this study.

[2]We derived the manipulation of ongoing-task load from Baddeley's (1986) model of working memory, as it has fared well in accounting for a variety of data. Other models might also predict negligible load effects on PM if the relevant elements for the PM task and the ongoing task could be simultaneously held in the *focus of attention* (Cowan, 1988) or in the *region of direct access* (Oberauer, 2002) with little interference or competition for shared resources.

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In Experiment 1, like in many published studies, participants made “PM” responses *instead of* ongoing-task responses on PM target trials (e.g., Burgess, Quayle, & Frith, 2001). No explicit request to give an additional ongoing-task response was included. Everyday PM typically depends on the interruption of ongoing activities (Shallice & Burgess, 1991). Thus, to skip the coordination of several responses may be the most natural requirement in this context.

Some researchers, however, have explicitly instructed participants to always respond to the ongoing task first, and then make the “PM” response, if appropriate (e.g., Cohen, Jaudas, & Gollwitzer, 2008; Marsh, Hicks, et al., 2002). Cohen et al. argue that with this response format, participants need not inhibit their ongoing-task responses until a PM decision is made, whereas inhibition (requiring additional resources) would be necessary if a “PM” response replaces an ongoing-task response. To examine difficulty effects without such possible inhibition costs, the instructions in Experiments 2A and 2B required to make both responses on PM target trials.

## Experiment 1

### Method

**Participants—**Sixty-four students (49 female) from the University of Mannheim volunteered for this experiment or received course credit. All participants were native speakers of German with normal color vision. Seven participants who failed to recall the target action after the experiment and never performed the action during the experiment were replaced. Two additional students were excluded because their ongoing-task accuracy was more than 2 *SD*s below the mean in a condition.

**Design—**Ongoing-task difficulty (easy vs. difficult) was manipulated between participants, with 32 participants randomly assigned to each condition.

**Materials—**We used a set of 156 medium frequency ($M$ = 130.19, $SD$ = 14.6) German words from the CELEX database (Baayen, Piepenbrock, & Gulikers, 1995) to create two lists with six PM target words and two 56-word filler lists, all matched on word frequency and length. The four possible target list-filler list combinations were counterbalanced. The colors blue, cyan, green, pink, red, white, and yellow were chosen for the ongoing task.

**Procedure—**Sessions lasted approximately 35 min and included between one and four participants. Participants read instructions on a computer screen.

On each color-matching trial, rectangles (3.81 × 3.30 cm) appeared sequentially in the center of the screen, each in a different color. Following the last rectangle, a colored word (18-point font) was presented in the center of the screen. For half the trials, the color of the word was identical to one of the colors shown in the preceding sequence of rectangles. The color of the word did not match for the other half of the trials. After participants pressed the J key (match) or N key (nonmatch), the word was replaced by a prompt to press the space bar to continue. The occurrence of particular colors, match and nonmatch trials, and the order of word presentation was randomly determined. In the easy condition, participants saw four color rectangles per trial, each shown for 500 ms and followed by a 250 ms interstimulus interval (ISI). In the difficult condition, participants saw six color rectangles per trial, each for 300 ms, with ISIs of 200 ms. After four practice trials, participants received PM task instructions. They were told that they would study six words and if these words occurred during the color-matching task, they should press the 1 key. Six PM target words were then displayed sequentially in a random order, each for 5 s, with ISIs of 500 ms. Participants then performed a two-minute distracter task, in which a letter was shown on the screen and

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participants pressed the key of the subsequent letter in the alphabet. There was no further mention of the PM task.

Participants then completed 78 color-matching trials with PM target words occurring in random sequence on trials 10, 23, 36, 49, 62, and 75. Half of the target trials were match trials and the other half were nonmatch trials. If a participant pressed the 1 key at any time between the presentation of a target word and the next probe word, this was counted as a correct PM response.

After completion of the task, participants were asked to recall the PM action (press the 1 key) and took an old-new recognition memory test in which the six target words and six distracter words, randomly chosen from the filler list, were presented sequentially in random order. Participants responded with the J key (*old*) or N key (*new*). Post-task measures of target recognition or recall have been frequently used in PM research to assess the retrospective component of PM.

## Results and Discussion

We set the alpha level to .05 for all statistical tests.

**PM performance and target recognition—**The proportion of PM target words to which participants gave "PM" responses (i.e., pressed the 1 key) served as a measure of PM performance (see Table 1). The two ongoing-task difficulty conditions did not differ in PM performance, $t(62) = 1.03$, $d = 0.26$. Furthermore, there was no difference in post-task recognition memory for PM target words as measured by hit rate minus false alarm rate ($HR - FAR$), $t < 1$ (Table 1).

**Ongoing-task performance—**The target trials and the four trials immediately following each target trial were excluded from analyses of ongoing-task performance in all experiments, which is a standard approach to avoid artifactual costs produced by response processes to targets or by task switching (e.g., Marsh, Hicks, et al., 2002). Additionally, the first four trials of the block were excluded as a practice buffer. The sensitivity index $HR - FAR$ was used to measure accuracy in the ongoing task (Table 2). As expected, mean accuracy was significantly lower in the difficult than the easy ongoing-task condition $t(48.97) = 10.56$ (unequal variances test), $d = 2.64$.

We examined RTs for correct ongoing-task responses after trimming RTs deviating more than ± 2 *SD*s from an individual's mean in a condition (Table 2). Participants in the difficult condition responded more slowly than participants in the easy condition, $t(57.06) = 2.11$ (unequal variances test), $d = 0.53$. Note that with this pattern of RTs, potential speed-accuracy trade-offs cannot account for the effect on accuracy.

**Multinomial modeling—**We fit the MPT model (Figure 1) to the observed response category frequencies listed in the Appendix. Participants responded *Match*, *Nonmatch*, or *PM* to one of four possible item types in this experiment. We estimated parameter values that best predict the response frequencies with available software (Moshagen, 2010;Stahl & Klauer, 2007) using the maximum likelihood method. We determined goodness-of-fit with the log-likelihood statistic $G^2$, which is asymptotically $\chi^2$-distributed (Hu & Batchelder, 1994).

The model fit the data well both in the easy condition, $G^2(4) = 3.39$, $w = 0.03$, and the difficult condition, $G^2(4) = 3.38$, $w = 0.04$, with a power of .99 to detect even small deviations ($w = 0.10$; Cohen, 1988) of predicted from observed data.[3] We performed significance tests of effects of ongoing-task difficulty on all four model parameters (see

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Table 3 for parameter estimates and results of significance tests for all three experiments). The parameters related to ongoing task trial type detection (match or nonmatch), $C_1$ and $C_2$, were both affected by difficulty in the predicted direction, with significantly lower estimates in the difficult condition. By contrast, estimates for the prospective component (*P* parameter) and the retrospective component (*M* parameter) did not differ as a function of ongoing-task difficulty.

This finding is consistent with various experiments that manipulated difficulty in ways that likely tapped phonological or visuo-spatial components rather than the central executive of working memory and reported null effects on PM (Marsh & Hicks, 1998; Otani et al., 1997). Importantly, the data support the validity of the *C* parameters of the MPT model. As hypothesized, the results clearly show that increased ongoing-task difficulty reduced the likelihood of detecting color matches and nonmatches, whereas the other model parameters remained unaffected. This *selective* effect corroborates the validity of the model to adequately measure the processes underlying ongoing-task performance and to disentangle these processes from unrelated cognitive operations in PM tasks. Moreover, the modeling results converge with behavioral measures commonly used in PM research. That is, the decrease of the model's *C* parameters is mirrored in a substantial loss of ongoing-task accuracy ($HR - FAR$). On the other hand, changes in ongoing-task difficulty did not affect the estimates of the prospective (*P*) or retrospective (*M*) component, nor PM performance or post-task recognition memory.

## Experiments 2A and 2B

In Experiments 2A and 2B, we tested effects of ongoing-task difficulty under altered response formats. Participants received explicit instructions for PM target trials to always give their ongoing-task response first, and a "PM" response afterwards (Experiment 2A; cf. Cohen et al., 2008), or vice versa (Experiment 2B). The two experiments did not differ otherwise.

### Method

**Participants—**Twenty-seven (19 female) and twenty-nine students (22 female) from the University of North Carolina at Chapel Hill participated for course credit in Experiment 2A and 2B, respectively. They were native speakers of English with normal color vision. Participants who failed to recall the target action and never pressed the respective key during the experiment were replaced (three participants in Experiment 2A), and participants with ongoing-task accuracy more than 2 *SD*s below the mean of a condition were excluded from further analyses (two and three participants in Experiment 2A and 2B, respectively).

**Design and procedure—**We manipulated ongoing-task difficulty within participants. Each participant worked on two blocks of the embedded PM task, one block with an easy ongoing color-matching task and one block with a difficult one. Block order was counterbalanced.

Procedures were the same as in Experiment 1 with the following exceptions. Participants repeated the instructions to the experimenter to assure that participants understood the task to give *both* the ongoing and PM response on target trials. Participants then received six practice trials, four ongoing-task trials and two additional trials with an embedded PM task. For these practice trials, they were presented a single practice target word that then occurred on the last practice trial, and that they did not have to remember afterwards.

[3]Power analyses were performed with G*Power3 (Faul, Erdfelder, Lang, & Buchner, 2007).

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The first embedded PM task block included 62 trials. The target words occurred on Trials 10, 20, 30, 40, 50, and 60. Between the first and second block, participants took a vocabulary test for about seven minutes. The instructions and procedures for the second block were identical to those for the first block with the only exception that difficulty of the ongoing task changed. In the easy condition, four color rectangles were shown within each trial, each for 500 ms, with ISIs of 250 ms. In the difficult condition, six color rectangles were shown within each trial, each for 300 ms, with ISIs of 250 ms.

**Materials—**We used a set of 124 English medium frequency words ($M$ = 136.10, $SD$ = 10.24) from the Kučera and Francis (1967) norms to create the two target word lists with 6 items each, and two filler lists with 56 items each. The two PM target lists were matched on word frequency and word length, respectively. The four possible combinations of target and filler lists were counterbalanced across participants and blocks.

### Results Experiment 2A

**PM performance and target recognition—**Ongoing-task difficulty did not affect PM performance, $t < 1$, nor post-task recognition memory for the target words, $t(26) = 1.07$, $d$ = 0.21.

**Ongoing-task performance—**The expected effect of ongoing-task difficulty recurred, with higher accuracy in the easy than the difficult condition, $t(26) = 10.81$, $d = 2.08$. The corresponding difference in trimmed RT for correct responses was not significant, $t$s < 1.

**Multinomial modeling—**Goodness-of-fit tests in the easy condition, $G^2(4) = 8.78$, $w$ = 0.08, and the difficult condition, $G^2(4) = 6.74$, $w = 0.10$ were acceptable in light of the high power of .92 to detect even small deviations ($w = 0.10$). Effects of ongoing-task difficulty on all four model parameters fully replicated the pattern from Experiment 1. We obtained significantly lower estimates for color-match detection ($C_1$ parameter) and nonmatch detection ($C_2$ parameter) when the number of color rectangles in a trial was increased (Table 3). The parameters measuring the prospective ($P$) and retrospective component ($M$) of PM were not affected by the difficulty manipulation.

### Results Experiment 2B

**PM performance and target recognition—**PM performance and post-task recognition memory for the target words did not differ between the easy and the difficult condition, $t$s < 1.

**Ongoing-task performance—**The effect of difficulty on accuracy in the ongoing color-matching task was replicated, $t(28) = 7.82$, $d = 1.45$. The corresponding difference in trimmed RT of correct responses was not significant, $t < 1$.

**Multinomial modeling—**The model fit the data well in the easy condition, $G^2(4) = 6.81$, $w = 0.06$, and the difficult condition, $G^2(4) = 2.21$, $w = 0.03$, given a power of .94 to detect small effects ($w = .10$). Tests of the four model parameters across ongoing-task conditions yielded a significant decrease of both $C_1$ and $C_2$ in the difficult ongoing-task condition, while there were no effects on $P$ and $M$.

### Discussion

The extent of the visual short-term memory load imposed by the ongoing task affected the model's ongoing-task parameters in the predicted direction, whereas the other parameters and PM performance remained unaffected. Thus, we obtained the same consistent pattern

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across all experiments, and modified response formats did not further qualify the validation. Although cross-experimental comparisons must be interpreted with caution, PM performance, RTs, and estimates of the prospective component (parameter *P*) were higher in Experiment 2B than 2A. Possibly, with instructions to make “PM” responses first (Experiment 2B) participants may have perceived the PM task as more important than those who received the reverse instructions. Perceived importance can induce a strategy to allocate more resources to the PM task, as found in experiments manipulating importance instructions (Smith & Bayen, 2004).

## General Discussion

The MPT model of event-based PM has been suggested as a useful tool for disentangling cognitive processes in the event-based PM paradigm. Thus far, only two of the model parameters have been validated (Smith & Bayen, 2004). To complement the previous validation studies, the primary aim of the present experiments was to assess the validity of the *C* parameters for measuring trial type detection in the ongoing task. Using a theoretically motivated manipulation of ongoing-task difficulty, we varied the extent of visual short-term memory load in an ongoing color-matching task and produced selective decreases of both *C* parameters in the conditions with higher load. We obtained this pattern across different response instructions, languages (German, English), and designs (between- vs. within-subjects), thus providing strong support for the validity of the MPT model.

In all three experiments, the differences between the easy and difficult conditions in the probability to detect color matches ($C_1$) were larger than the differences for nonmatches ($C_2$). The probabilities to detect a nonmatch in the easy ongoing-task conditions were around .95 and thus approached ceiling. This near-ceiling level of performance may have reduced the difference between the easy and difficult conditions for nonmatch trials. In previous studies, nonmatch detection was also generally higher than match detection (Smith & Bayen, 2004, 2006), and is thus more likely to approach ceiling.

We supplemented MPT-model based analyses with RT analyses to evaluate potential speed-accuracy trade-offs (Schouten & Bekker, 1967). Such trade-offs would qualify the interpretation of the parameters of the MPT model, which does not take RTs into account. None of the present findings suggests that trade-offs are an explanation for reduced accuracy in the more difficult ongoing-task conditions. RT remained stable (Experiments 2A and 2B) or even increased (Experiment 1) when the task was more difficult, whereas accuracy decreased substantially.

Standard performance measures of PM were also in accordance with our modeling results. In all three experiments, there were null effects of ongoing-task difficulty on the proportion of correct PM responses and on post-task recognition memory. This is consistent with the model-based estimates of the prospective component (*P* parameter) and the retrospective component (*M* parameter), neither of which differed as a function of ongoing-task difficulty. Our modeling results add to research that examined the effects of ongoing-task load on PM, in which PM was not affected by increased short-term memory load (e.g., Marsh & Hicks, 1998; Otani et al., 1997). In our study, this was reflected in the null effect of increased visual load in the ongoing task on the PM parameters, *P* and *M*, accompanied by effects on the ongoing-task parameters.

The MPT model is now fully validated and researchers who wish to go beyond standard measures of PM can apply the model to study theoretical questions and to assess the impact of variables on several components of a PM task independently.

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# Appendix

## Appendix

Response Category Frequencies for Each Trial Type Aggregated Over Participants in Each Condition

| Experimental condition<br>Trial type | Response | | |
|---|---|---|---|
| | "PM" | "Match" | "Nonmatch" |
| Experiment 1 | | | |
| Easy | | | |
| Target, match | 61 | 29 | 6 |
| Target, nonmatch | 65 | 1 | 30 |
| Nontarget, match | 3 | 1041 | 108 |
| Nontarget, nonmatch | 6 | 30 | 1116 |
| Difficult | | | |
| Target, match | 56 | 19 | 21 |
| Target, nonmatch | 55 | 4 | 37 |
| Nontarget, match | 8 | 668 | 475 |
| Nontarget, nonmatch | 5 | 70 | 1077 |
| Experiment 2A | | | |
| Easy | | | |
| Target, match | 48 | 32 | 1 |
| Target, nonmatch | 36 | 3 | 42 |
| Nontarget, match | 12 | 680 | 62 |
| Nontarget, nonmatch | 8 | 15 | 733 |
| Difficult | | | |
| Target, match | 44 | 22 | 15 |
| Target, nonmatch | 39 | 1 | 41 |
| Nontarget, match | 13 | 474 | 270 |
| Nontarget, nonmatch | 9 | 90 | 656 |
| Experiment 2B | | | |
| Easy | | | |
| Target, match | 60 | 26 | 1 |
| Target, nonmatch | 72 | 1 | 14 |
| Nontarget, match | 16 | 725 | 71 |
| Nontarget, nonmatch | 12 | 23 | 777 |
| Difficult | | | |
| Target, match | 68 | 15 | 4 |
| Target, nonmatch | 63 | 3 | 21 |
| Nontarget, match | 13 | 597 | 204 |
| Nontarget, nonmatch | 9 | 65 | 736 |

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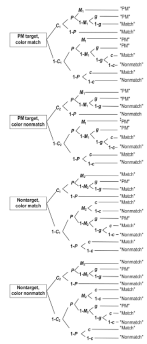

**Figure 1.**
The multinomial processing tree model of event-based prospective memory for three responses. PM = prospective memory; $C_1$ = probability of detecting a color match; $C_2$ = probability of detecting that a color does not match; $P$ = prospective component; $M_1$ = probability of detecting a PM target; $M_2$ = probability of detecting that a word is not a PM target; $g$ = probability of guessing that a word is a target; $c$ = probability of guessing that the color matches. Adapted from “A multinomial model of event-based prospective memory” by R. E. Smith and U. J. Bayen, 2004, *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *30*, p. 758. Copyright 2004 by the American Psychological Association. Adapted with permission.

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## Table 1

Proportion of Correct Prospective Memory Responses, and Post-Task Recognition Memory

| Experiment and condition | Prospective memory | | Post-task recognition | |
|---|---|---|---|---|
| | *M* | *SE* | *M* | *SE* |
| Experiment 1 | | | | |
| Easy | .66 | .06 | .86 | .03 |
| Difficult | .57 | .06 | .84 | .03 |
| Experiment 2A | | | | |
| Easy | .52 | .06 | .85 | .03 |
| Difficult | .51 | .07 | .80 | .04 |
| Experiment 2B | | | | |
| Easy | .76 | .04 | .85 | .03 |
| Difficult | .75 | .04 | .86 | .02 |

*Note.* Recognition memory is measured as hit rate − false alarm rate.

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**Table 2**

Performance in the Ongoing Color-Matching Task

| Experiment and condition | Discrimination | | Reaction time | |
|---|---|---|---|---|
| | ***M*** | ***SE*** | ***M*** | ***SE*** |
| Experiment 1 | | | | |
| Easy | .88 | .02 | 1594 | 77 |
| Difficult | .53 | .03 | 1869 | 105 |
| Experiment 2A | | | | |
| Easy | .90 | .01 | 1882 | 114 |
| Difficult | .53 | .03 | 1822 | 78 |
| Experiment 2B | | | | |
| Easy | .92 | .01 | 2123 | 118 |
| Difficult | .67 | .03 | 2171 | 119 |

*Note.* Discrimination of match vs. nonmatch items is measured as hit rate − false alarm rate. Reaction times are in milliseconds.

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## Table 3

Parameter Estimates and Tests of Parameter Differences Between the Easy and Difficulty Ongoing-Task Conditions.

| Experiment and model parameter | Parameter estimates | | $G^2(1)$ | |
|---|---|---|---|---|
| | Easy condition | Difficult condition | | |
| Experiment 1 | | | | |
| *P* | .69 (.04) | .63 (.04) | 1.40 | |
| *M* | .94 (.02) | .91 (.02) | 1.30 | |
| $C_1$ | .81 (.02) | .16 (.03) | 348.93 | ** |
| $C_2$ | .95 (.01) | .88 (.01) | 18.54 | ** |
| Experiment 2A | | | | |
| *P* | .64 (.05) | .64 (.05) | 0.01 | |
| *M* | .79 (.04) | .77 (.04) | 0.11 | |
| $C_1$ | .84 (.02) | .27 (.03) | 192.06 | ** |
| $C_2$ | .95 (.01) | .77 (.02) | 57.54 | ** |
| Experiment 2B | | | | |
| *P* | .91 (.04) | .87 (.04) | 0.42 | |
| *M* | .81 (.03) | .85 (.03) | 0.66 | |
| $C_1$ | .83 (.02) | .49 (.03) | 83.13 | ** |
| $C_2$ | .94 (.01) | .84 (.02) | 22.62 | ** |

*Note*. Standard errors are in parentheses. $G^2(1)$ is the logarithmic-likelihood test statistic with one degree of freedom. *P* prospective component; *M* retrospective component; $C_1$ color match detection; $C_2$ color nonmatch detection.

** $p < .01$.