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Context-specific prospective-memory processing: Evidence for flexible attention allocation adjustments after intention encoding

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Abstract Prospective memory (PM) is remembering to fulfill intentions in the future. Interference of unfulfilled intentions with ongoing activities reflects the allocation of attention to the PM task. Prior research has shown that, when people know in which specific context PM cues will occur, attention allocation is adaptive, with slower responses in the PM-relevant context. We examined whether people flexibly adjust their attention allocation when the PM–context association is unknown at intention encoding and must be learned on-task. Different stimulus shapes represented contexts in an ongoing task, with PM cues only occurring in trials with one specific shape. Participants informed about the PM-relevant shape responded more slowly on trials with this shape. Participants instructed that only one, unspecified shape was PM-relevant learned the PM–context association and also allocated attention flexibly, depending on context relevance. However, participants with no context-related information at intention encoding failed to learn the PM–context association, resulting in inflexible attention allocation and poorer PM performance. The present study provides evidence that people can flexibly update their attention-allocation policy, and thereby optimize their PM performance after initial intention encoding, but self-guided learning of intention–context associations appears to be limited.

Keywords Prospective memory · Attention allocation · Intention fulfillment · Context · Multitasking

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The cognitive processes involved in remembering to fulfill an intention at the appropriate future moment are subsumed under the term *prospective memory* (PM). Often, this moment is indicated by a target event; for example, the event of encountering a colleague may cue the intention to deliver a message. Therefore, when holding a PM intention, we must ensure that we do not miss the appropriate moment for its fulfillment, but we also have to complete various other tasks in the meantime. Thus, we are required to keep an intention in mind while performing other daily activities. In the present study, we examined how flexibly people can adjust how much attention they pay to their future intentions on the basis of a context's relevance for the intention.

Holding a PM intention often interferes with performance in ongoing tasks, resulting in slower and sometimes more erroneous responses, as compared to when that same task is performed without holding an intention (Smith, 2003). On the basis of such task interference, leading theories propose that participants usually engage attentional processes on PM tasks to ensure that they detect the appropriate moment for intention fulfillment. The "preparatory and attentional memory processes" (PAM) theory emphasizes the role of attentional processes as being a necessary condition for successful PM (e.g., Smith & Bayen, 2004), and the multiprocess (MP) theory also suggests that attentional processing is crucial for PM unless certain conditions for more automatic, spontaneous retrieval processes are met (Einstein et al., 2005). However, there is also evidence that the level of task interference varies greatly with the PM-processing demands (e.g., the PM-cue focality: Einstein et al., 2005; Rummel, Boywitt, & Meiser, 2011), as well as with instructions that affect participants' expectations regarding the importance of the PM task (Smith & Bayen, 2004) or the likelihood of PM-cue occurrence (Boywitt & Rummel, 2012). The leading theories of PM (PAM and MP theory) currently do not specify how people determine how much attention to pay for a given PM task. An important related question is how flexibly people can adjust their attention allocation to situational changes in PM demands. For example, if PM intentions will only be fulfilled in certain contexts (e.g., having to remember to call your client while in your office during business hours), flexible attention allocation would allow one to pay more attention to the PM task in relevant than in irrelevant contexts.

Despite the clear advantage of context-specific PM processing, to date only few studies have examined people's adaptation of PM processing to contexts. There is evidence that instructed context expectations benefit PM performance when they are accurate but harm it when inaccurate, suggesting that people make use of (instructed) context information in PM (Cook, Marsh, & Hicks, 2005; see also Nowinski & Dismukes, 2005). Furthermore, Marsh, Cook, and Hicks (2006) found that participants make ongoing-task responses particularly slowly in PM-relevant contexts (e.g., pictures as ongoing-task stimuli when the PM cues were pictures) relative to PM-irrelevant contexts (e.g., words as ongoing-task stimuli in the same context), even when the context changed randomly on a trial-by-trial basis (when trial type was precued, as in Exp. 2; see also Cohen, Jaudas, Hirschhorn, Sobin, & Gollwitzer, 2012; Guynn, 2003; Lourenço, White, & Maylor, 2013). According to Marsh and colleagues, this result can be interpreted as evidence for a two-component attention-allocation policy: One component is a global or "sticky" distribution policy, reflecting people's general decision of how much attention is devoted to the intention, which is assumed to be made during the initial intention encoding. The other component is a more flexible, on-task adjustment of this global policy to situational changes in PM demands, presumably allowing changes in attention allocation on the fly. Notably, though, in prior studies on PM and context, participants were always informed about the PM-relevant and PM-irrelevant contexts during initial intention encoding, such that participants could already have established context-sensitive resource allocation policies (i.e., deciding to especially prioritize PM processing in the PM-relevant context) as part of the global policy before the PM task began (see also Marsh et al., 2006, p. 1642, for a discussion of this argument). Therefore, it remains open to what extent people can flexibly adjust their attention allocation to different contexts *after* initial intention encoding, as is suggested by the attention-allocation policy account.

In the present study, we aimed at testing whether adaptive adjustment of attention-allocation policies to contextual variations in PM demands is possible, even when information about the PM-relevant context is not yet available during intention encoding. Such on-task attention allocation adjustment would be direct evidence for an adaptive, flexible attention-allocation component, as was proposed by Marsh et al. (2006). In our study, participants performed an ongoing color-matching task (Smith & Bayen, 2004), requiring them to continuously decide whether a word's color matched one of four preceding colored polygons. As a PM intention, we asked participants to respond to animal names with a designated key. To manipulate contextual PM demands, the shape of the polygons randomly varied between color-matching trials (triangles, squares, or pentagrams), and PM cues only occurred in one of the shape contexts. Because the first polygon of a trial revealed the trial context well before the word probe appeared, we expected participants instructed as to which shape context the PM cues would occur in to be able to flexibly adjust attention allocation to context, replicating Marsh et al. (2006, Exp. 2).[1] That is, we expected these participants to respond more slowly on trials in the PM-relevant shape context than in PM-irrelevant contexts.

Importantly, we included two other conditions that did not receive complete information about the contexts at intention encoding. Finding context-sensitive attention allocation in these conditions would be direct evidence for flexible on-task adjustment of attention-allocation policies. In one condition, participants did not receive any information regarding context. Because we anticipated learning that PM cues only occur in one particular (shape) context to be quite difficult for participants who did not know that shape might matter, we further included a third condition in which participants were informed that PM cues would occur in one of the shape contexts only, but without further specification which context this was going to be. We intended these instructions to aid PM-context learning, but without specific information ahead of time, participants would still have to adjust their attention-allocation on-task, once they knew which context was PM-relevant. Therefore, the present experiment allowed us to examine whether people can learn (without or with a hint) which context is PM-relevant after forming an intention and can use such knowledge to better guide their further attention allocation.

Method

Participants and design

A group of 90 students (18–30 years old, mean age = 20.6), who were all native speakers of German, participated for course credit or payment. One participant who did not recall the PM task at the end of the experiment was excluded from the analyses. The study was based on a 2 × 3 mixed factorial design. Context relevance (PM-relevant vs. PM-irrelevant)

[1] After completion of this study, we learned that Lourenço et al. (2013) observed context-specific attention allocation when the context varied randomly trial by trial, without any advanced cueing or prior presentation of context-defining stimuli. Thus, participants' ability to determine the context before being required to give a response does not appear to always be necessary for this phenomenon.

was manipulated within participants, through PM cues only occurring on trials of one specific shape of the ongoing-task stimuli (where three shapes varied randomly trial by trial). Context information at intention encoding was manipulated between participants, with random assignments to conditions. In the *explicit* context-information condition ($n = 27$) participants were told during the initial instructions which specific shape was PM-relevant. In the *oblique* context-information condition ($n = 32$), participants were told that PM cues would only occur on trials of one specific shape, but did not yet know which particular shape. In the *no*-context-information condition ($n = 30$), participants did not receive any information regarding context. Power (assessed via GPower 3.1; Faul, Erdfelder, Lang, & Buchner, 2007) to detect medium-sized effects ($\eta_p^2 = .06$) of context relevance as well as its interaction with context information was high (both > .99, conservatively assuming a moderate .5 correlation between response times in the different contexts).

Materials and procedure

First, participants received instructions for the ongoing color-matching task. In particular, they were informed that in each trial they would see four polygons of the same shape (triangles, squares, or pentagrams), followed by a probe word in colored font. Their task was to press the *J* key if the probe word's font color matched the color of one of the four preceding polygons, and the *N* key if it did not match. Then, participants completed six practice trials (two of each shape). Polygons and probe words were presented centered on a black background in one of five colors (blue, green, cyan, yellow, and red). Each polygon was presented for 500 ms, followed by a 250-ms blank screen, and polygons within one trial were always of different colors. The probe words were presented until participants responded. After a response, participants were prompted to press the space bar to start the next trial. Participants then had the opportunity to ask any questions and were further informed about the additional (PM) task, which required pressing the *T* key whenever a probe word was an animal word. These instructions were enriched with context information in the explicit and oblique conditions, as described above. To delay the PM intention, all participants then performed a visual-search task requiring identification of a specific character in busy scene pictures for 3 min.

The main task consisted of 144 color-matching trials (set up like the practice trials described above), divided into two blocks of 72 trials each with a 1-min break (during which participants were instructed to rest and relax) in between. Within each block, one third of the trials (half match, half nonmatch) featured each polygon shape. The order of trials was randomized for each participant. For the probe words, 138 German nonanimal nouns were randomly selected from a word database. Additionally, 12 animal words (i.e., *penguin*, *lion*, *swan*, *frog*, *lizard*, *otter*, *zebra*, *alligator*, *buffalo*, *blackbird*, *marten*, and *peacock*) were selected as PM cues. In both blocks, the PM cues occurred on Trials 12, 24, 36, 48, 60, and 72; half of these were match, and the other half nonmatch trials. Crucially, in all conditions the PM cues always occurred in trials of the same shape; which particular shape was randomly determined for each participant, resulting in approximate counterbalancing. Upon completion of both blocks, participants answered questions about the PM task and were then debriefed and dismissed.

Results

We set an alpha level of .05 for all analyses.

Color-matching performance

The mean error rates and response times (RTs) in the ongoing color-matching task are displayed in Table 1. The first trial of each block and the first trial following each PM trial were excluded, in order to avoid finding artifactual costs associated with these trials (cf. Boywitt & Rummel, 2012). Both measures were analyzed with 2 (context relevance; within subjects) × 3 (context information; between subjects) mixed analyses of variance (ANOVAs).

For error rates, we found no main effect of context information, $F < 1$, but a main effect of context relevance, $F(1, 86) = 5.95$, $p = .024$, $\eta_p^2 = .06$, with participants making slightly more errors in the PM-relevant ($M = .10$, $SE = .007$) than in the PM-irrelevant ($M = .09$, $SE = .009$) context. Table 1 also displays mean error difference scores (PM-relevant context – PM-irrelevant context) for each condition. Although, numerically, the error difference by PM relevance was most pronounced in the explicit context information condition, the interaction between context information and context relevance was not significant, $F < 1$.

RT analyses were confined to correct responses. To control for outliers, RTs faster than 300 ms or slower than two standard deviations of a participant's mean RT (assessed separately for PM-relevant vs. PM-irrelevant contexts and match vs. nonmatch trials) were discarded (cf. Boywitt & Rummel, 2012). The 2 × 3 ANOVA on trimmed RTs revealed no main effect of context information, $F < 1$, a main effect of context relevance, $F(1, 86) = 81.84$, $p < .001$, $\eta_p^2 = .49$, and, importantly, a significant interaction, $F(1, 86) = 28.68$, $p < .001$, $\eta_p^2 = .40$, indicating that the degrees to which RTs varied with context relevance differed between context-information conditions. We followed up on this significant interaction by computing simple-effects analysis examining the context-relevance effect in each context-information condition separately. Context relevance had a significant effect in the explicit, $F(1, 86) = 105.00$, $p < .001$, $\eta_p^2 = .55$, and in the

Table 1 Mean prospective-memory (PM) and ongoing-task performance as a function of experimental condition

		Error Rates			Response Times (milliseconds)		
Context Information	PM Accuracy	PM-Irrelevant Context	PM-Relevant Context	Context Difference	PM-Irrelevant Context	PM-Relevant Context	Context Difference
Explicit	.64 (.04)	.084 (.010)	.108 (.016)	.024 (.011)*	1,103 (36)	1,280 (41)	176 (17)***
Oblique	.70 (.04)	.081 (.009)	.089 (.014)	.008 (.010)	1,142 (35)	1,227 (39)	85 (16)***
No	.53 (.04)	.105 (.016)	.114 (.015)	.009 (.010)	1,161 (42)	1,158 (42)	–3 (16)

Difference scores were computed by subtracting mean scores on PM-irrelevant context trials from mean scores on the PM-relevant context trials. Standard errors are displayed in parentheses. Statistical significance refers to simple-effects analysis. * $p < .05$, *** $p < .001$.

oblique, $F(1, 86) = 28.79$, $p < .001$, $\eta_p^2 = .25$, context-information conditions, but not in the no-context-information condition, $F < 1$. Table 1 also displays mean context difference scores, computed by subtracting each participant's mean RT on PM-irrelevant trials from the mean RT on PM-relevant trials. These positive difference scores revealed that the significant context difference in both the explicit and oblique context-information conditions stemmed from slower RTs on the PM-relevant than on the PM-irrelevant trials. This same-direction context difference in RTs was more pronounced in the explicit than in the oblique condition, $F(1, 86) = 15.34$, $p < .001$, $\eta_p^2 = .15$. As compared to the no-context-information condition, RTs in the explicit and oblique conditions were numerically slower on PM-relevant trials and numerically faster on PM-irrelevant trials, resulting in the significant interaction. When tested separately, only the slowing on PM-relevant trials in the explicit versus the no-information condition reached statistical significance, $t(55) = 2.09$, $p = .041$, $d = 0.55$, all other ts ≤ 1.21.[2]

To examine how fast context-relevance learning occurred in the oblique context-information condition, we compared their RT difference scores (i.e., relevant context – irrelevant context) for the first and second blocks. No difference in RT differentiation was apparent early (first block; $M_{\text{Diff}} = 86$ ms, $SE = 21$) versus late (second block; $M_{\text{Diff}} = 88$ ms, $SE = 24$) in the task, $t < 1$, suggesting fast learning of context relevance. Interestingly, in the explicit context-information condition, in which participants had full context-relevance knowledge from the beginning, a tendency emerged for RT differentiation to decrease from the first ($M_{\text{Diff}} = 203$ ms, $SE = 26$) to the second ($M_{\text{Diff}} = 156$ ms, $SE = 23$) block, $t(26) = 2.00$, $p = .056$, $d = 0.38$. The effect of greater differentiation in the explicit than in the oblique condition did not interact with block, $F(1, 51) = 1.19$, $p = .280$. Of course, when examining just the trials preceding the very first cue (at Trial 12), we found significant RT differentiation only in the explicit ($M_{\text{Diff}} = 266$ ms, $SE = 62$),[3] $t(25) = 4.33$, $p < .001$, $d = 0.85$, but not in the oblique ($M_{\text{Diff}} = 50$ ms, $SE = 42$), $t(31) = 1.18$, $p = .246$, context-information condition, in which participants could not know which context was PM-relevant yet. The no-context-information condition consistently showed no difference between RTs on PM-relevant and PM-irrelevant trials, with no difference between the first ($M_{\text{Diff}} = –5$ ms, $SE = 26$) and second ($M_{\text{Diff}} = 11$ ms, $SE = 17$) blocks, ts < 1.

PM performance

All but the one excluded participant were able to recall the PM task in a final recall test. Proportions of accurate PM responses to cues in the color-matching task (i.e., pressing the *T* key for animal words) are displayed in Table 1 and were submitted to a one-way ANOVA with the factor Context Information (explicit vs. oblique vs. no context information). We observed a significant main effect, $F(2, 86) = 4.71$, $p = .011$, $\eta_p^2 = .10$. LSD comparisons revealed that PM performance was significantly higher in the oblique context-information condition than in the no-context-information condition, $p = .005$. PM performance was also marginally higher in the explicit context-information condition than in the no-context-information condition, $p = .053$. The explicit and oblique context-information conditions did not differ in their PM performance, $p = .344$.

Context knowledge

To investigate whether participants explicitly knew the PM-relevant context after task completion, we asked those in the explicit and oblique context-information conditions in which context the PM cues occurred. In the explicit condition, all participants accurately remembered the (instructed) PM-relevant context. More interestingly, in the oblique condition, all but four participants accurately learned which context was

[2] As we stated earlier, our design was powerful for detecting the within-subjects effect of context relevance as well as the within–between interaction of context relevance and context information, which was our primary research question. However, for between-subjects comparisons of RTs from one context only, power was only satisfactory (>.80) for large ($d = 0.80$) effects.

[3] No PM-relevant trials occurred for one participant before the first cue in the explicit context-information condition, reducing the sample size for this analysis to 26.

PM-relevant; these four participants showed only very little RT variation with context (M_{Diff} = 22 ms, SE = 63). In the no-context-information condition, we asked participants whether they had realized that the animal names always occurred in the same context, and if so, which context it was. Only two participants indicated noticing a cue–context association, and only one of them identified the PM-relevant context correctly.

Discussion

In the present study, a PM intention only had to be fulfilled in a specific context, with contexts varying on a trial-by-trial basis. Replicating Marsh et al. (2006, Exp. 2), we found that participants instructed about the PM-relevant context during intention encoding allocated their attention in a context-specific manner, with slower ongoing-task responses in trials of the context in which the cue for intention fulfillment might occur. Going beyond Marsh et al., we also examined participants who did not have full knowledge about the context relevance for PM when initially forming the intention. Those who had not been explicitly told that PM cues would only occur in one specific context did not acquire this context knowledge across the study and performed ongoing trials equally, independent of context. Participants who knew that PM cues would only occur in one context without knowing which specific one, however, were able to learn which context was PM-relevant and showed context differentiation in their response times. Importantly, because the latter participants did not initially know which specific context PM cues would occur in, they could not have already decided at intention encoding on which trials to focus more on the PM task. Consequently, they must have flexibly adjusted their attention-allocation policy once they learned which context was PM-relevant, providing the first empirical evidence for the flexible component of attention-allocation policies proposed by Marsh et al.

General theories of PM processes such as the PAM and MP accounts do not specify how and when people decide on attention allocation and how flexible this allocation is. Recently, the MP theory has been extended to include a dynamic component through which certain events or contexts may situationally trigger monitoring, which is in line with our finding of context-varied attention allocation (Scullin, McDaniel, & Shelton, 2013). Guynn (2003) proposed a two-component theory of attentional monitoring in PM, with a global RT increase under a PM intention due to maintaining that intention, and a more flexible increase due to checking for the cue on relevant trials. All of these accounts are in line with our finding of context-differentiated attention allocation. However, these accounts currently do not make predictions regarding the timing of learning context information. A novel and important finding in our study is that although both the explicit and oblique context-information conditions showed context effects, these effects were more strongly pronounced in the explicit condition, in which full context information was provided at intention encoding. This stronger adjustment is in line with Marsh et al.'s (2006) suggestion that people form a first attention-allocation decision during intention encoding that is global and "sticky." That is, even though later adjustments are possible, as is evident in the oblique context-information condition, the earliest attention-allocation decision (which had already differentiated contexts in the explicit condition only) seems to have a profound effect. Notably, though, the flexibly adjusted attention allocation in the oblique condition was sufficient for comparably successful PM performance. Of course, the attention-allocation policy account is not mutually exclusive with the other PM accounts, but rather can be regarded as an important addition to any account that posits attentional monitoring as a PM process.

Participants (except for one) in the no-context-information condition did not learn the association between the PM task and shape context. Given that only one participant realized which context was PM-relevant after 12 PM-cue presentations, it seems unlikely that many participants would have learned the cue–context association with more trials of the task. This lack of PM–context association learning manifests a limitation in people's optimal adaptation to PM demands. However, in the present task the context feature (i.e., shape) was irrelevant to the ongoing color-matching task, which is why participants in the no-context-information condition may have ignored it. Upon revision of this article, we learned of research by Lourenço et al. (2013) employing a condition like our no-context-information group (labeled the *nonspecific group* in their article). In their study, the PM cues (i.e., a specific syllable) occurred on word trials only. Here, the context feature (word vs. nonword) was the main focus of the ongoing task (deciding whether a stimulus was or was not a word), yet their participants in the nonspecific group did not show context differentiation in RTs as an explicitly instructed condition did, suggesting that the former group also did not learn context relevance (no self-reports were obtained). An important difference, though, is that during the PM instructions, Lourenço et al. told this nonspecific group that PM cues might occur in *either* words *or* nonwords; hence, context learning in their study may have been impeded by this false information. In our study, the instructions for the no-context-information condition did not include anything related to context, and the participants' reports after task completion rule out that they explicitly learned the PM–context relation but did not act upon it. Although it is plausible that context learning could happen implicitly, the present findings suggest that explicit context knowledge may be necessary for the flexible adjustment of attention allocation.

An interesting aspect of context-specific attention allocation is whether people increase attentional monitoring in relevant contexts and/or decrease it in irrelevant contexts. Relative to a typical no-context PM condition, we found evidence for a significant increase in attentional monitoring in the PM-relevant context in the explicit condition (and, numerically, in the oblique condition), and no evidence for a change in monitoring in the PM-irrelevant context. This finding contradicts results from Cohen et al. (2012), who found no evidence for monitoring on PM-irrelevant trials as compared to a no-PM control group. Our findings fit better with Marsh et al. (2006) and Lourenço et al. (2013), who found that despite significant savings in costs on irrelevant trials, the costs on these trials were still significant. These findings and ours suggest that people cannot be completely freed from the attentional burden of a PM intention in irrelevant contexts. Lourenço et al. interpreted this residual cost in terms of Guynn's (2003) global cost component, reflecting maintenance of the PM intention, an explanation that also fits our present data. Aside from general intention maintenance, determining the current context, especially in random alternation, may also be attention-consuming. In a way, this may act like a second PM intention, in which one must remember to remember the primary PM intention when in the appropriate context.[4] Of course, the difficulty of context determination may vary with the nature of the contexts within an ongoing task. Longer durations of a context (as in the blocked trials of Marsh et al., 2006, Exp. 1B) might allow for greater savings in attention allocation on the irrelevant trials. Nonetheless, people are flexible enough to put forth less effort in the irrelevant than in the relevant context, even given random trial-by-trial variations. Future research will be needed to determine under what conditions (if any) people can completely spare the attentional costs of PM in irrelevant contexts.

Our finding that only participants who knew or learned which context was PM-relevant outperformed those who did not learn the PM–context association supports Marsh et al.'s suggestion that flexible attention allocation between PM-relevant and PM-irrelevant contexts is adaptive for PM performance. Notably, whereas prior studies have shown that a cue–context association can benefit PM performance when the association is developed during encoding (Cook et al., 2005; Nowinski & Dismukes, 2005), this is the first demonstration of such benefits under conditions in which the cue–context association is not known at the outset of the PM task. Nowinski and Dismukes suggested that forming a cue–context association boosts PM performance through the relevant context automatically cueing the PM intention. In our study, the context benefit was accompanied by differences in attention allocation, which Nowsinki and Dismukes did not assess. Future research will be needed to determine the contributions of automatic context cueing and context-dependent attention allocation to PM performance.

Our findings suggest that people need to have at least vague context information available when forming novel PM intentions in order to benefit from PM–context associations in their attention allocation. Importantly, these initial (at encoding) context beliefs have quite a profound influence; thus, wrong expectations at encoding may also harm us (cf. Cook et al., 2005) and may not be overcome if the new context associations are not learned (see also Lourenço et al., 2013). Future research will be needed, though, to test whether self-guided context learning might be possible under optimal conditions—that is, when contexts are very easy to distinguish and/or when the appropriate context is naturally associated with the intention. In many everyday tasks, for instance, there is a logical connection between contexts and PM cues, such as knowing that we will most likely see the colleague we have to give a message to during regular working hours. Similarly, the trial-by-trial context change that we employed was the strictest theoretical test of flexibility in attention-allocation policies, but it is not representative of most context changes in everyday life, where contexts last for longer periods and changes are more gradual.

In sum, the present study advances our understanding of how attentional resources are distributed between ongoing activities and unfulfilled intentions by providing direct evidence for a two-component attention-allocation policy (Marsh et al., 2006), consisting of a global attention-distribution decision established during intention encoding and a flexible on-task adjustment of this policy through information learned after intention encoding. However, there are limits to these flexible cognitive adjustments, because people's ability to learn intention–context associations appears poor unless a prior hint that context matters is provided. Therefore, people may depend on information about a context's relevance or help with intention–context association learning in order to optimize their PM performance.

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