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# The influence of high and low cue–action association on prospective memory performance

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**ABSTRACT**

Recent discoveries in the field of prospective memory (PM) show higher accuracy for remembering intentions in which prospective cue and action are strongly associated. In two experiments presented in this paper, participants encoded both high and low association cue–action pairs and were later tested on both prospective and retrospective PM components. Results of both studies show higher PM accuracy for the low association pairs, compared to high association ones, but only for the prospective component (across both Experiments) and only when a high association cue was presented first (Experiment 2). This finding was accompanied by longer study times for the low association pairs and study times were functionally related to later performance (across both Experiments). In the retrospective component, higher accuracy was observed for pairs with high level of association (but only in the first Experiment). Data are discussed in the context of metacognitive processes possibly related to the encoding of an intention as well as cue monitoring in case of PM tasks with high memory load and varying task difficulty.

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Prospective memory (PM) is described as the interplay of cognitive processes responsible for remembering to carry out intended actions at some appropriate moment in the future (Einstein & McDaniel, 1990). In the case of *event-based* PM, external cues signify this appropriate moment. Mirroring everyday processing demands, in typical laboratory paradigms, the prospective task is usually embedded in an *ongoing task*. When the appropriate moment (i.e. the PM cue) appears, the ongoing task has to be interrupted in order to perform the PM task. Conceptually, PM has been described as consisting of two components, the prospective and the retrospective component. The former is related to recognising *that* a prospective response is required at the right time (e.g. detecting the PM cue), and the latter is responsible for retrieving the content of the intention from long-term memory (*what* has to be done; West & Craik, 2001).

One prominent model describing key factors that modulate both the prospective and the retrospective component of PM is the *multiprocess framework* (e.g. McDaniel & Einstein, 2007; Scullin, McDaniel, & Einstein, 2010). In general, it states that PM may be either mediated by rather spontaneous or rather controlled processes. Specifically, the model proposes a number of factors that determine the processing involved in a given PM task, including the nature (e.g. *focal* vs. *nonfocal* cues) and a number of PM cues (Albiński, Kliegel, Sedek, & Kleszczewska-Albińska, 2012; Einstein & McDaniel, 2005; Scullin, McDaniel, Shelton, & Lee, 2010), ongoing task demands (Rendell, McDaniel, Forbes, & Einstein, 2007), or importance of ongoing and PM tasks (Kliegel, Martin, McDaniel, & Einstein, 2004).

While substantial research on several key components of this model has been conducted (e.g. on cue focality; see, e.g. Ihle, Hering, Mahy, Bisiacchi, & Kliegel, 2013), one of the proposed variables has received considerably less attention: the role of cue–action associations (i.e. target – intended action). According to the multiprocess framework (McDaniel & Einstein, 2000), a high level of cue–action association results in relatively spontaneous

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delivery of the intended action upon noticing the target cue. As a result, PM performance is predicted to be better when cue and action are highly related, as compared to low target-action relations (McDaniel & Einstein, 2000). This idea was subsequently tested in a number of experiments, but the results seem so far to be inconclusive. For instance, McDaniel, Einstein, Guynn, and Breneiser (2004) reported that participants' PM accuracy was higher when cue and action were highly associated (e.g. when participant had to write the word *sauce* in reaction to noticing the word *spaghetti* in the context of an ongoing word rating task). In another study, Pereira, Ellis, and Freeman (2012) also reported positive effects of high cue–action associations in young and older adults. In their study, participants (in both high and low association conditions) were asked to remember six cue–action pairs. Similar results (i.e. showing better PM performance for strongly related pairs as compared to weakly related pairs) for a task in which participants had to remember eight cue–action pairs were presented by Marsh, Hicks, Cook, Hansen, and Pallos (2003), who used lexical decisions task as the ongoing task.

Contradictory to these three studies, Loft and Yeo (2007) failed to find significant differences in PM performance between high and low association conditions (mean PM accuracy equalled .86 and .87, respectively). In their experiment, four cues were presented twice (eight possible prospective responses), and the PM task was also embedded in a lexical decision task (LDT). Comparing their results to previous research (Marsh et al., 2003; McDaniel et al., 2004) Loft and Yeo suggested that different patterns of results may be related to the number of cue–action pairs that participants are asked to remember. So far, these contradictory results have not been further addressed.

Thus, in the present paper, we are continuing the investigation into the role of cue–action relatedness in PM functioning, addressing several open questions and testing a novel metacognitive account for the disparate findings. First, it is so far not clear which of the two components of PM (or both similarly) may be mainly responsible for a possible effect of cue action association on PM performance. Second, so far, authors have not elaborated on the mechanisms driving a possible effect. For example, Pereira et al. (2012), commenting on previously published results regarding both PM accuracy and reaction times stated that "These finding indicate that not only are actions more likely to be retrieved upon the presentation of a related cue than an unrelated one, but also that retrieval may occur more readily under such conditions" (p. 1258). McDaniel and Einstein (2000) in their seminal paper on the multiprocess framework suggest that the relatedness effect may be related to automatic associative memory-based processes, as in the case of cues that are highly related to the planned action these processes effortlessly deliver the proper action upon noticing the relevant cue (which seems to imply an assumption of the retrospective component being the main pathway of this effect).

In the present paper, we describe two experiments where we systematically examined the effects of a cue–action association manipulation on both PM components. Moreover, we propose that individual difficulty judgements at encoding may be associated with those effects. Our rationale is inspired by the metacognition literature assuming that cue action associations will change encoding processes (if there is need for strategic resource allocation, e.g. when memory load is rather high). For that purpose we introduced a relatively high number of cue action pairs to encode and allowed for participant-paced cue–action encoding analysing study times as an index of subjective perception of learning difficulty (e.g. Ariel, 2013). Specifically, each participant was asked to memorise 12 cue–action pairs (six with high, and six with low association).

## Experiment 1

In the first experiment, we aimed at testing the influence of cue–action association on PM accuracy. Participants were asked to remember 12 word-action pairs (six low and six high word-actions pairs). Study times were also measured.

Relating to the currently available body of knowledge, one possible prediction was that if the possible effect regarding type of associations (low vs. high) are driven by a reflexive (automatic) memory response, then higher PM accuracy (i.e. prospective component of PM) should be observed for highly associated pairs – as reported in most above-mentioned papers. If, on the other hand, metacognitive beliefs about ease of encoding may play a role, one would expect lower accuracy for highly associated pairs, as compared to pairs with low level of association. This difference should be also reflected in study times, where one would expect longer study times for low cue–action relatedness, than for pairs with high cue–action relatedness.

## Method

### Participants

Fifty-four undergraduate students (43 females) enrolled at the University of Social Sciences and Humanities (Warsaw, Poland) took part in the experiment in return for course credit. The research was approved by the University of Social Sciences and Humanities Ethics Board.

### Materials

The stimuli were presented using E-Prime 2.0. For the purpose of the study, six high (e.g. *bowl – feed the cat*), and six low (e.g. *spider – buy shoes*) association pairs were prepared. The PM task was embedded in an LDT, participants were asked to press "M" for words, "V" for nonwords, and "Q" key whenever they noticed a PM cue. After a correct Q press, a box showed up on the screen, and participants were asked to type in the action associated with the cue. In the LDT plus PM block there were 54 words, 54 nonwords and, as mentioned, 12 PM cues. Among all 120 stimuli PM cues were placed on trials 10, 11, 20, 35, 55, 70, 72, 88, 94, 109, 111, and 115 (high associations on trials 10, 20, 55, 72, 94, 111; low associations on trials 11, 35, 70, 88, 109, 115). Prior to the LDT plus PM block participants completed also a 30 trial warm-up LDT only block, and a 100 trial LDT only block for baseline purposes (50 words/50 nonwords).

Cue–action pairs that were used in the study are presented in Table 1.

**Table 1.** Prospective cues and actions (Experiment 1) in English and Polish.

| | PM cue (Polish version in italics) | Action (Polish version in italics) |
|---|---|---|
| High association | kitchen | turn off the stove |
| | *kuchnia* (984) | *wyłączyć gaz* |
| | bowl | feed the cat |
| | *miska* (228) | *nakarmić kota* |
| | iron | iron clothes |
| | *żelazko* (129) | *wyprasować ubrania* |
| | photographer | print the photos |
| | *fotograf* (322) | *wydrukować zdjęcia* |
| | notebook | do the homework |
| | *zeszyt* (713) | *odrobić lekcje* |
| | broom | clean the apartment |
| | *miotła* (149) | *posprzątać mieszkanie* |
| Low association | curtains | repair the tv |
| | *zasłony* (2016) | *naprawić telewizor* |
| | Spider | buy shoes |
| | *pająk* (787) | *kupić buty* |
| | grandmother | cancel an order |
| | *babcia* (4212) | *anulować zamówienie* |
| | doorknob | conduct research |
| | *klamka* (347) | *zrobić badania* |
| | diet | wax the skiis |
| | *dieta* (137) | *nawoskować narty* |
| | fish | sew a dress |
| | *ryba* (1646) | *uszyć sukienkę* |

Note: In parentheses after Polish PM cue, we present data on word frequency (Polish Word Frequency Dictionary, 2011).

### Procedure

PM cue–action encoding was self-paced, participants decided when they wanted to move to the next pair, they were also informed that they cannot go back to previously studied pairs. Following a procedure introduced by Schnitzspahn, Zeintl, Jäger, and Kliegel (2011), they were told that in addition to the LDT task their task is to remember to press the Q key whenever they encounter one of the cues, and then to type in the associated action into a box on the screen (participants were also informed that they will have to do the two tasks together without further reminder after watching a short movie). Afterwards, participants completed the warm-up block – note that this phase did not contain any words that could serve as a reminder. After the LDT only block, each participant watched a 3-minute movie (water park dolphin show), and were asked to count how many times a dolphin splashes water on the audience sitting next to the pool. After the movie, participants began the LDT plus PM block – participants needed approximately 4 min to complete this block of trials.

## Results and discussion

### PM accuracy

A dependent samples $t$-test was used to assess the proportion of correct Q presses (prospective component of PM) in reaction to cue words belonging to low and high association pairs, $t(53) = 2.64$; $p = .011$, $d = .36$. Higher accuracy was observed for low associations ($M = .60$; SD = .33) than for high associations ($M = .52$; SD = .31). We also calculated the retrospective component of PM accuracy according to the methodology suggested by Schnitzspahn et al. (2011); note that this could only be done for those cases where participants correctly reacted to the cue by pressing the Q key). Whenever the replies slightly differed from the learned action, they were independently assessed by two judges, who decided if the response was still semantically accurate (e.g. *feed the cat* vs. *give food to the cat,*

**Table 2.** Accuracy presented separately for both types of PM components and both types of cue–action associations.

| | Prospective component of PM | Retrospective component of PM |
|---|---|---|
| High cue–action association | $M = .52$; SD = .31 | $M = .84$; SD = .24 |
| Low cue–action association | $M = .60$; SD = .33 | $M = .69$; SD = .36 |

which was counted as accurate). The results showed higher accuracy of the retrospective component for actions belonging to high associations pairs ($M = .84$; SD = .24) than for those belonging to low association pairs ($M = .69$; SD = .36), $t(45) = 3.65$; $p = .001$, $d = .53$[1]. The results for both components and both types of associations are presented in Table 2.

## *Ongoing task accuracy*

Dependent *t*-test analysis showed that there were no significant differences between the LDT only ($M = .84$; SD = .18) and the LDT PM block ($M = .83$; SD = 18) , $t(53) = .98$; $p = .33$, $d = .13$.

In conclusion, a cue–action effect in the PM task was indeed obtained in this experiment. However, contrary to other studies reviewed in the introduction our results indicate higher PM accuracy for low association cue–action pairs, compared to high cue–action pairs – this results refers to the prospective component of PM. For the retrospective component, our results show significantly better recall for the high association cue–action pairs. Thus, in the present experiment some kind of a double disassociation was revealed, showing that low association cue–action pairs produced better performance of the prospective component, but among the correctly noted PM cues higher retrospective component accuracy was observed for highly associated pairs.

## *Pm response time*

A dependent samples *t*-test was used to analyse reaction times to PM cues (only correct responses were taken into account). Results show that, overall, subjects reacted significantly faster to the cues belonging to high associations pairs ($M =$ 2798 ms; SD = 1803 ms) than to cues belonging to low association pairs ($M = 3904$ ms; SD = 3424 ms), $t(53) = 2.69$; $p = .009$; $d = .37$.

## *Ongoing task reaction times*

Dependent *t*-test analysis showed significant differences in reaction times between the LDT only ($M = 1423$ ms; SD = 671 ms) and the LDT PM block ($M = 1594$ ms; SD = 712 ms), $t(53) = 3.4$; $p < .01$, $d = .46$. Please note that only correct responses were taken into account here.

Taken together, the results showing faster PM reaction times for high association cues might suggest that spontaneous processes could partly be at play here. On the other hand, ongoing task data seem to suggest that monitoring processes were active to some extent as well as reaction times in the lexical decisions task were faster in the lexical decisions only block than in lexical decisions plus PM block. Thus, the speeding up for high association cues may also reflect higher activation of those cues leading to faster retrieval of the PM intention when recognising the cue.

## *Cue–action pairs study times*

An analysis using a paired samples *t*-test revealed a significant difference in study time for high and low association pairs, $t(51) = 5.4$; $p < .001$, $d = .74$. Participant spent significantly more time studying low association pairs ($M = 9866$ ms; SD = 6960) than high association pairs ($M = 6286$ ms; SD = 4170 ms).

## *Relations between study times and PM accuracy*

Correlation analyses revealed that there was a significant relation between study times and PM accuracy for low association pairs ($r = .25$; $p = .035$). For highly associated pairs a tendency in the same direction was observed ($r = .21$; $p = .069$).

Conceptually, these results may suggest an explanation for the effect described above – that PM accuracy was significantly higher for low association cue–action pairs compared to high association cue–action pairs. We argue that in a demanding task, such as the one used in this experiment (with the total of 12 pairs to remember) metacognition plays a significant role causing participants to assess the difficulty of memorising each cue–action pair. As a result participant spent significantly more time learning and encoding low association pairs. This pattern of results might have been strengthened by the fact that participants were told that they cannot go back to the pairs seen previously.

[1]Please note that omitting the first cue from data analyses did not change the obtained pattern of results. Thus, it is not simply an issue of more or less likely forgetting the first cue.

All in all, the first experiment provided evidence of a cue–action association effect – contrary to previously published research however, the direction of this effect was opposite, with higher accuracy for cues from low association cue–action pairs. Our results also highlight a possible crucial role of study times, as participant spent significantly more time reading low association pairs and study times were related to performance. Although the obtained results are very promising, the first experiment has some important limitations. First, the stimuli for the cue–action pairs were selected on the basis of association alone (low vs. high) with less regard to word frequency, emotional load and distinctiveness. Thus, inherent differences in those dimensions between high versus low association cues could not be excluded. Second, all of the participants viewed the cues in such order, that the first cue was always from the high association pair. Third, in this experiment we decided to space PM cues randomly – as a result some cues were placed next to each other which may have produced after PM response effects (Meier & Rey-Mermet, 2012; Scullin, McDaniel, & Shelton, 2013). In order to reduce the potential influence of these limitations, we conducted a second experiment.

## Experiment 2

The second experiment was conducted in order to replicate the results obtained in the first experiment, while addressing its limitations mentioned above. The following changes were made in the second study:

(a) we carefully selected a new set of stimuli: nouns only (objects, and not people or animals), controlling for word frequency, emotional load and word distinctiveness in order to remove possible confounds stemming from a-priori lexical differences between the cues;
(b) we counterbalanced the first cues encountered by the participants – as a result we added a between-subject factor to the study. We tested two separate groups of participants – for the participants in the first group the first stimulus was a word from a high association cue–action pair, whereas for the participants in the second group the first stimulus was a word from a low association cue–action pair.
(c) we also made procedural improvements in order to exclude factors related to placement of cues in the ongoing task plus PM task block*:* we increased the number of lexical decision trials (188 vs. 108 in the first study, total of 200 trials in the lexical decisions plus PM procedure), and spaced PM cues more evenly throughout the experiment (positions: 15, 31, 48, 64, 80, 97, 110, 126, 144, 160, 176, 192).

### *Method*

#### *Participants*

Fifty-nine undergraduates enrolled at the University of Social Sciences and Humanities (Warsaw, Poland) took part in the experiment in return for course credit. The research was approved by the University of Social Sciences and Humanities Ethics Board. Two groups of participants were tested, in one group ($N = 33$, 29 F) a high word-action association PM cue was presented first, whereas in the second group ($N = 26$, 23 F) a low word-action association PM cue was presented first.

#### *Materials*

In the second study, we used a new set of word-action pairs selected carefully with regard to comparable word frequency, word type (nouns describing objects), emotional load and distinctiveness.

Cue–action pairs that were used in the study are presented in Table 3.

In addition, we increased the number of lexical decisions trials in the ongoing task plus PM block from 108 to 188 (total number of trials – LDT plus PM – increased from 120 to 200). In one group, the first cue was from a high association word-action pair, whereas in the second group the first cue was from a low association word-action pair. After the first pair low and high association cues were presented in such a way that one type of PM cue was followed by the other type (i.e. low/high/low/high, etc.).

#### *Procedure*

The procedure was identical to the first study. Participants needed slightly more time (approximately 5–6 min) to complete the LTD plus PM block, as the total number of trials was increased from 120 to 200.

**Table 3.** Prospective cues and actions (Experiment 2) in English and Polish.

| | PM cue (Polish version in italics) | Action (Polish version in italics) |
|---|---|---|
| High association | desk | do the homework |
| | *biurko* (2113) | *odrobić lekcje* |
| | glass | clean the window |
| | *szyba* (587) | *umyć okno* |
| | bike | pump the tire |
| | *rower* (1161) | *napompować oponę* |
| | wood | start a fire in a chimney |
| | *drewno* (1787) | *rozpalić w kominku* |
| | Farba | pomalować pokój |
| | *paint* (462) | *paint the walls* |
| | Tea | boil the water |
| | *herbata* (648) | *zagotować wodę* |
| Low association | tie | clean the carpet |
| | *krawat* (1394) | *odkurzyć dywan* |
| | glass | freeze the meat |
| | *kieliszek* (2822) | *zamrozić mięso* |
| | ticket | take out the trash |
| | *bilet* (1519) | *wyrzucić śmieci* |
| | newspaper | mown the lawn |
| | *gazeta* (716) | *skosić trawnik* |
| | balcony | repair the tv |
| | *balkon* (791) | naprawić telewizor |
| | Shirt | fuel the car |
| | *koszula* (1082) | zatankować samochód |

Note: In parentheses after Polish PM cue, we present data on word frequency (Polish Word Frequency Dictionary, 2011).

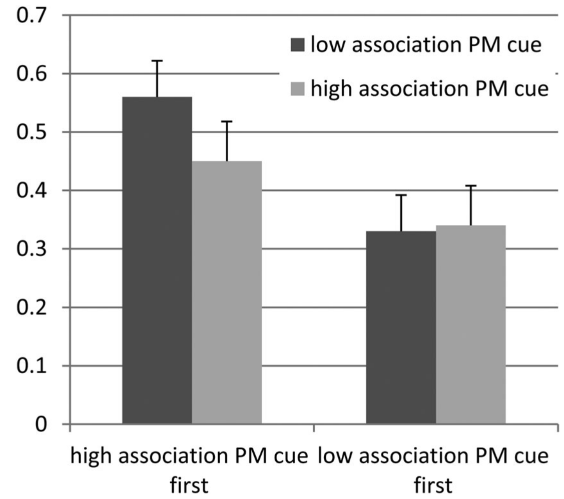


**Figure 1.** PM accuracy (prospective component) – interaction between type of PM cue (low vs. high association) and group (high association group first vs. low association group first).

### *Results and discussion*

#### *PM accuracy*

A 2 (group: high association PM cue first vs. low association PM cue first; between-subject factor) × 2 (type of PM cue: low association PM cue vs. high association PM cue; within-subject factor) mixed ANOVA was used to assess the proportion of correct Q presses (prospective component of PM) in reaction to cue words belonging to low and high association pairs. The main effect of type of PM cue showed a significant difference in PM accuracy for both types of PM cues, with higher PM accuracy observed for low association cues ($M = .444$; SD $= .37$) compared to high association PM cues ($M = .397$; SD = .34), $F(1,57) = 2.9$; $p < .05$, $\eta_p^2 = .048$. The main effect of group showed that PM accuracy was higher in the group that encountered the high association PM cue first ($M = .508$; SD = .33) compared to the group that encountered the low association PM cue first ($M = .333$; SD = .32), $F(1,57) = 4.09$; $p < .05$, $\eta_p^2 = .067$. Main effects were qualified by a significant interaction effect, showing that the difference between PM accuracy for low and high association pairs is significant in *high association PM cue first* condition ($M_{low} = .56$; $SD_{low} = .36$ vs. $M_{high} = .45$; $SD_{high} = .33$) but not significant in the *low association PM cue first* condition ($M_{low} = .33$ ; $SD_{low} = .34$ vs. $M_{high} = .34$; $SD_{high} = .33$), $F(1,57) = 4,71$; $p < .05$, $\eta_p^2 = .076$ (see Figure 1).

Interestingly, and contrary to the first experiment, a similar analysis conducted to compare the accuracy of retrospective component of PM did not reveal any significant effects.

#### *Ongoing task accuracy*

A 2 (group: high association PM cue first vs. low association PM cue first; between-subject factor) × 2 (type of block: LDT only block vs. LDT task plus PM block; within-subject factor) mixed ANOVA was used to assess the proportion of correct responses in the ongoing task (lexical decisions). Both the main effects and the interaction effect were not significant.

In the second experiment, we were able to replicate the main results on the prospective component obtained in the first study, and to identify an important factor that seems to moderate cue-association effects in our procedure. As shown by the interaction effect a significant difference between low and high cue–action pairs was observed only for participants who encountered the high association cue first. This result suggests that the first cue may be crucial to the overall PM functioning in the task. It may be that the high association cue encountered first increases the level of activation of other cues and related actions which seems to be especially beneficial for upcoming low association pairs. Interestingly, a starting cue from a low association pair did not have the same initial effect.[2] Further insights in this issue came from the following response time data.

### *PM response time*

Again, a 2 (group: high association PM cue first vs. low association PM cue first; between-subject factor) × 2 (type of PM cue: low association PM cue vs. high association PM cue; within-subject factor) mixed ANOVA was used to compare the reaction times (correct responses only) in the PM task. No significant effects were found.

### *Ongoing task reaction times*

A 2 (group: high association PM cue first vs. low association PM cue first; between-subject factor) × 2 (type of block: LDT only block vs. LDT plus PM block; within-subject factor) mixed ANOVA was used to analyse the reaction times in the ongoing task (LDT) – only reaction times for correct responses were taken into account. The results show a significant interaction effect, with longer lexical decision reaction times in the LDT only block (M = 2079 ms; SD = 1145 ms) compared to LDT plus PM block (M = 1703 ms; SD = 799 ms), but only for participants who encountered a low association cue first, $F(1, 57) = 7{,}41$; $p < .01$, $\eta_p^2 = .115$. There was no such difference in the group that encountered a high association cue first (with means of 1589 and 1664 ms, respectively). This seems to suggest some ongoing task learning but only for the low association cue first condition, or in other words more attention being allocated to the PM task by participants in the *high association cue first* condition.

Here, we also conducted an additional analysis in order to assess the degree of monitoring, depending on group and type of PM cue. As suggested by one of the Reviewers, we focused on LD reaction times occurring after the presentation of the PM cue (in order to see if one of two types of cues resulted in more monitoring). Specifically, we analysed reaction times for first five LD stimuli presented after each PM cue, and compared them to the reaction times in the LD only block. The analysis was conducted using a 2 (group: high association PM cue first vs. low association PM cue first) × 2 (type of cue: monitoring after low association cue vs. monitoring after low association PM cue) mixed ANOVA. Only the main effect of group turned out to be statistically significant, $F(1, 57) = 8.52$; $< .01$, $\eta_p^2 = .130$., showing that participants from the high association PM cue first condition were, on average, 140 ms slower in the LD plus PM block (compared to LD only block), while participants in the low association PM cue first were, on average, 385 ms faster in the LD plus PM block (compared to LD only block).

### *Cue–action pairs study times*

Again, a 2 (group: high association PM cue first vs. low association PM cue first; between-subject factor) × 2 (type of PM cue: low association PM cue vs. high association PM cue; within-subject factor) mixed ANOVA was conducted to compare cue–action pairs study times. Only the main effect of type of PM cue was statistically significant, with longer study times for low association cue–action pairs ($M = 12{,}110$ ms; SD = 9109 ms) than high association cue–action pairs ($M = 8336$ ms: SD = 8998 ms), $F(1, 56) = 30.46$; $p < .001$, $\eta_p^2 = .352$. This result directly replicates similar finding in the first experiment. It can also be analysed together with the PM accuracy result, as it shows that both groups (i.e. high association PM cue first vs. low association PM cue first) did not differ in terms of study times, $F(1,56) = 1.03$; $p = .314$, $\eta_p^2 = .018$ – but did differ in terms of PM functioning.

### *Relations between study times and PM accuracy*

The correlation analysis revealed significant relations between study times PM accuracy measures. As the pattern of results was similar in both group (i.e. high association PM cue first vs. low association PM cue first) we report correlation coefficients for the whole sample. Correlation analyses revealed that there was a significant relation between study times and PM accuracy for low association pairs ($r = .58$; $p = .001$). For highly associated pairs a similar, significant relation was found ($r = .50$; $p = .001$). As can be seen these correlations are higher than the ones in the first experiment. This might be due to the use of a new set of stimuli (cues and actions), for which word frequency, emotional load and distinctiveness were carefully controlled. Importantly, in the first experiment correlation for the high association cues was not significant, although there was a tendency – in the

[2]Note that – similar to Experiment 1. – omitting the first cue from data analyses did not change the obtained pattern of results. Thus, it is not simply an issue of more or less likely forgetting the first cue.

second study we have obtained much stronger, and highly significant relation.

## General discussion

The present studies followed up on the limited available research on the effects of cue–action association on PM performance, one of the factors proposed by the multiprocess framework to modulate PM performance. Several novel and potentially conceptually important results emerged. First, an effect of cue–action association was revealed in both experiments. Second, this effect was, however, (again in both studies) in the opposite direction as predicted by previous studies. Third, this effect was moderated by an additional variable in the second study namely which cue type was presented first. Fourth, study times, and thereby metacognitive processes were related to the associativity effect. Fifth, both the prospective and the retrospective component were differentially involved in producing the effect – this, however, was limited to the first of the two experiments.

Overall, both studies corroborate the significance of the factor cue action association proposed by the multiprocess framework for modulating PM performance. In addition, they offer also some qualification and differentiation. The present results dovetail with the (so far somewhat implicit) assumption that high cue action association *positively* affects the retrieval of the intention content (the retrospective component). This is in line with the great majority of previous conceptual arguments (e.g. McDaniel & Einstein, 2000). We acknowledge that this results is not PM specific, as episodic memory studies consistently show that immediate and delayed recall is significantly better when association of both elements of remembered pair is high (e.g. Naveh-Benjamin, Craik, Guez, & Kreuger, 2005). Also, the result regarding increased recall of action in the high association cue–action pairs was limited to the first experiment.

In addition, our method of choice for separating prospective and retrospective component of PM used in our study is only one of several possible approaches (suggested by Schnitzspahn et al., 2011), but other methods such as free recall of cue and actions at the end of the study or using multinomial modelling are also presented in the literature (Cohen, Dixon, Lindsay, & Masson, 2003; Smith & Bayen, 2004). Thus, we acknowledge that our method has some limitations, the major one being that if participants fail to notice the cue (and therefore do not react by pressing the "Q" key) they will not be asked to recall the paired action. In future studies we plan to combine our method with a more classic approach, that is, asking participants at the end of the procedure to recall all cues and action they were supposed to remember.

Considering those effects, it seems, however, even more remarkable that the present findings on the prospective component are relatively clear and consistent, but go into the opposite direction to the traditional paired associate literature. Here, data strongly suggest that – at least under the present task constraints of high memory load and free study time – the prospective component may actually be positively affected by *low* cue action association – this result, obtained in the first study was replicated in the second experiment. Conceptually, present results suggest two possible (and not mutually exclusive) mechanisms for this, on first view, somewhat counter-intuitive effect. One insight comes from the study times. Here, longer study times emerged for low associations and study times were functionally related to PM accuracy. This was shown consistently across both experiments and suggests that metacognitive processes at encoding may play an important role in modulating this effect. So far, the role of metacognition in PM performance has rarely been studied. In line with the few available studies, metacognitive indicators were predictive for later performance; specifically, it seemed that participants perceived the low association pairs as more difficult, and therefore they devoted more time to study. This is in line with Rummel and Meiser's (2013) suggestion that metacognitive expectations regarding the difficulty of the PM task influence attention-allocation strategies (for a first study using judgments of learning, JOL, in PM see Schnitzspahn et al. (2011), who have shown that that individuals' predictions were (moderately) accurate for delayed judgements of learning (JOL) but not for JOLs that had to be given immediately after task encoding.). Present results corroborate the importance of metacognitive processes for PM in general and for PM encoding particularly in the context of effects of cue–action association on PM.

A second possible mechanism was revealed in Experiment 2. Here, one additional variable played a significant moderating role for our effect – the type of the first cue presented to participants. The effect showing higher PM performance for cues from low association pairs was observed only in one of the two conditions – the one in which a high association cue was presented first. Thus, it can be argued that some of the qualities of the of the first presented PM cue (i.e. a cue from a high association pair) have an influence over subsequent PM functioning. Importantly, study time allocation did not differ between both compared groups, and so we can assume that difference in PM functioning between groups did not stem from different learning patters – participant in both groups spent more time learning low associations pairs.

While empirically disentangling those possibilities remains a task for future studies, response time data on the ongoing task seem to favour the latter. Specifically, lexical decision reaction times showed different pattern in both compared groups, namely, the group that encountered the high association cue first seemed to activate monitoring processes to some extent, as we did not observe learning advantages for the LDT task as observed in the low association cue first condition. This suggestion is also supported by monitoring analysis presented in the Results section (this analysis was conducted for the first five LD stimuli presented after each cue) – our results show that, compared to reaction times in the LD only block, participants in the high association PM cue first condition were, on average, 140 ms slower in the LDT plus PM block, compared to LDT only block, while participants in the low association PM cue first condition ere, on average, 385 ms faster in the LDT plus PM block, compared to LDT only block. Thus, participant in the former group seemed to engage more monitoring processes compared to participants in the latter condition. At the present moment it remains unclear, however, why such pattern of results was observed in our study, that is, why encountering a high association PM cue first leads to more monitoring, while encountering low association PM cue first does not.

Across both experiments it is worth mentioning, that the above-mentioned results, i.e. the increased accuracy for low association PM cues, were obtained even though both experiments differed in terms of cue placement. In the first study we decided to place the 12 cues randomly across the trials in the ongoing task. We chose to do this, as we expected that a less random placement in PM task with so many cues may cause participants to expect when the next cue will be presented. An important limitation of this approach is that in some cases such randomly placed cues were presented close to each other (e.g. trials 10 and 11, or 70 and 72). In the second study however, cues were placed more evenly, and were never placed next to each other. Overall, it may be interesting to manipulate this variable in the future studies, as the type of cue placements may moderate the observed high–low association effects.

One of the limitations of the present procedure is the fact that both cue action association conditions were included in the same block; which unfortunately rendered precise reaction time costs comparisons of both within-subject conditions impossible. Future studies will have to follow up on this route. Note that, as described in the literature, number of cues used in a PM task may also significantly impact PM accuracy (e.g. Cohen, Jaudas, & Gollwitzer, 2008; Wesslein, Rummel, & Boywitt, 2014). Thus, in further studies it will be interesting to test if our effects can be replicated using procedures with a different number of cues (e.g. 6 instead of 12). Also interesting in future research would be to manipulate the features and cues and actions, by pairing same cues with high and low association actions (here however, an additional between-subject variable would have to be introduced).

The presented results seem also to be relevant to an argument proposed by Gonneaud et al. (2011) who noted that any event-based PM impairment may stem from a deficit in binding cues and actions. These authors suggest that such impairment may be more pronounced in older adults (in their study binding deficits were largely responsible for event-based PM decline in an older sample). Our results show a potentially promising method of increasing event-based PM by prolonged processing of cue–action pairs. Older adults could be trained to create more unusual or bizarre associations even when cue–action pairs seem related (in our study low associations pairs were able to evoke such increased processing).

An important feature of our study was high memory load in the PM task. Compared to other studies cited in our paper we used more word-action pairs (12, compared to 4, 6 or 8 in Loft & Yeo, Pereira et al. or Marsh et al., respectively). This was intended as we wanted to increase the memory demands of the task to maximise the potential effect of associativity. This follows up on Loft and Yeo’s notion who suggested that different patterns of results (them not finding an effect) may be related to the (lower) number of cue–action pairs that participants were asked to remember.

Taken together, the data from both experiments – together with the introduction of study times – allow a better understanding of the nature of cue–action association effects in PM. Present studies open up new avenues of research, with special emphasis on manipulating the experiment's design (between- or within-subjects) and number and nature of cues, actions and their associations.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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