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Time-of-day affects prospective memory differently in younger and older adults

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ABSTRACT

The goal of this study was to investigate the impact of circadian arousal on prospective memory performance as a function of age. We tested a younger (18–34 years) and an older group (56–95 years) of participants on- and off-peak with regard to their circadian arousal patterns in a computer-based laboratory experiment. For the prospective memory task, participants had to press a particular key whenever specific target words appeared in an ongoing concreteness-judgment task. The results showed that prospective memory performance was better on- than off-peak in younger but not older participants. Younger participants consistently outperformed older participants in all conditions. We conclude that prospective remembering underlies time-of-day effects which most likely reflect controlled processes.

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1. Introduction

A normal day requires multiple times that we realize previously planned intentions at a specific time or in response to an event. The ability to do so at the appropriate occasion is termed "prospective memory." In event-based prospective memory, which is the topic of this article, the prospective memory task (e.g., a particular target word) is embedded in an ongoing task which needs to be interrupted to accomplish the intention. The realization that the appropriate moment has been encountered can be the result of spontaneous retrieval or strategic monitoring processes (e.g., Ball, Brewer, Loft, & Bowden, 2014; Einstein et al., 2005; Meier, Zimmermann, & Perrig, 2006; Scullin, McDaniel, & Shelton, 2013). From research on retrospective memory, we know that the efficacy of automatic and controlled processes is differentially affected by circadian arousal over the course of a day (Intons-Peterson, Rocchi, West, McLellan, & Hackney, 1998; May, Hasher, & Foong, 2005; West, Murphy, Armilio, Craik, & Stuss, 2002). Effects of circadian arousal on prospective memory performance have previously been predicted to vary according to the specific retrieval situation (i.e., spontaneous vs. strategic; McDaniel & Einstein, 2007, p. 78). However, initial evidence for circadian arousal to affect prospective memory performance is only available from a naturalistic setting (Leirer, Tanke, & Morrow, 1994). Hence, the primary goal of this study was to investigate time-of-day effects in a laboratory-based prospective memory setting.

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Time-of-day effects refer to the efficacy of cognitive processes which are differentially affected over the course of a day as a function of systematic variation in circadian arousal (e.g., Blatter & Cajochen, 2007; Murray et al., 2009; Paradee, Rapport, Hanks, & Levy, 2005; Schmidt, Collette, Cajochen, & Peigneux, 2007). Specifically, the effectiveness of controlled processes is enhanced at the optimal time of day (i.e., on-peak) over the nonoptimal time of day (i.e., off-peak). In contrast, the effectiveness of automatic processes is enhanced at the nonoptimal time of day over the optimal time of day (e.g., Goldstein, Hahn, Hasher, Wiprzycka, & Zelazo, 2007; Hahn et al., 2012; Intons-Peterson, Rocchi, West, McLellan, & Hackney, 1999; Lehmann, Marks, & Hanstock, 2013; May, 1999; May & Hasher, 1998; May, Hasher, & Stoltzfus, 1993; Ramírez, García, & Valdez, 2012; Ramírez et al., 2006; Rowe, Hasher, & Turcotte, 2009; Yang, Hasher, & Wilson, 2007). There is a tendency for age effects with the peak time of circadian arousal in older adults shifting toward the morning (i.e., morning-types) and the peak for young adults more likely being in the middle toward the evening of a day (i.e., neutral-/evening-types). The peak in circadian arousal (i.e., morningness-eveningness) can be measured with questionnaires which substantially correlate with physiological measures of circadian arousal (e.g., Griefahn, Künemund, Bröde, & Mehnert, 2001; Horne & Ostberg, 1976). The prevalent explanation for time-of-day effects is that inhibitory processes are weakened during nonoptimal times allowing material which is not at the focus of attention to be processed more easily than during optimal times. In contrast, stronger inhibitory processes at optimal times increase the focus of attention and are more likely to block material which is not relevant for the predominant task at hand (e.g., Anderson, Campbell, Amer, Grady, & Hasher, 2014; Schmidt et al., 2007).

Crucially, prospective memory target events are embedded in an ongoing task and are not necessarily at the focus of attention when they occur. Hence, they can be missed without noticing. One strategy to prevent prospective memory lapses is to engage in strategic monitoring. However, strategic monitoring comes at a cost in ongoing task performance due to the allocation of resources to the prospective memory task (McDaniel & Einstein, 2000; Meier & Zimmermann, 2015; Smith, 2003). In contrast, spontaneous retrieval does not direct cognitive resources away from the ongoing task. Whether prospective remembering relies on strategic monitoring or spontaneous retrieval depends on the specific context of the prospective memory task, the ongoing task, and the remembering individual (e.g., McDaniel & Einstein, 2000; Walter & Meier, 2014, 2016). McDaniel and Einstein (2007, p. 72) have previously hypothesized that strategic monitoring leads to better prospective memory performance because we are better able to maintain our cognitive goals and to inhibit distractions at the optimal time-of-day. In contrast, they predicted better prospective memory performance at the nonoptimal time-of-day for spontaneous retrieval because we are less able to inhibit the target event when focussing on the ongoing task. Although several studies have manipulated the time of prospective memory encoding, the predictions remain to be tested (e.g., Diekelmann, Wilhelm, Wagner, & Born, 2013; Scullin & McDaniel, 2010).

Another well-known factor affecting memory performance and cognitive functioning more generally is age (e.g., Balota, Burgess, Cortese, & Adams, 2002; Meier, Rey-Mermet, Rothen, & Graf, 2013; Nyberg, Lövdén, Riklund, Lindenberger, & Bäckman, 2012; Salthouse, Atkinson, & Berish, 2003). While age-related memory decline may be absent for prospective memory tasks under naturalistic settings due to compensatory strategies (e.g., Maylor, 1996), there is typically a reliable age-related prospective memory decline under laboratory conditions. Generally, it is larger for tasks with fewer target events which support spontaneous retrieval than for tasks with repeated target events which support strategic monitoring (Uttl, 2008, 2011). Since every prospective memory cue serves as a reminder for subsequent prospective memory cues, more cues make it less likely to forget a successfully encoded intention.

In order to investigate prospective memory retrieval as a function of time-of-day and age, we tested younger and older adults in the morning and evening, and we assessed their performance in an ongoing concreteness-judgment task including four target events that were previously specified. We expected a performance increase when participants are tested on-peak as compared to off-peak if predominantly controlled processes are recruited. By contrast, we expected a performance decrease when participants are tested on-peak as compared to off-peak if predominantly automatic processes are recruited. Moreover, we predicted higher prospective memory performance in the younger group in comparison to the older group.

2. Methods

2.1. *Participants*

Two-hundred-and-forty-two healthy volunteers participated in this experiment. Fourteen were excluded due to chance performance or extreme reaction times (cf. Section 2.4). The final sample consisted of 115 young participants (age *M* = 23.05 years, *SD* = 3.53, *range* = 18–34; male = 49 and 66 female; years of formal education *M* = 14.73, *SD* = 2.11; 113 native German speakers and 2 fluent in German but different first language; D-MEQ[1] score *M* = 49.51, *SD* = 9.58, *range* 24–73) and of 113 older participants (age *M* = 67.58 years, *SD* = 5.97, *range* = 56–95; male = 45 and 68 female; years of formal education *M* = 13.67, *SD* = 3.64; 109 native German speakers and 4 fluent in German but different first language; D-MEQ[1] score *M* = 60.37, *SD* = 8.95, *range* 34–77). The study protocol was approved by the local ethics committee of the University of Bern.

2.2. *Materials*

The word stimuli for the ongoing task were selected from the Handbuch deutschsprachiger Wortnormen (Hager & Hasselhorn, 1994). The practice phase consisted of 48 German words (concreteness *M* = 3.52, *SD* = 13.62, *range* = −13.47-19.40 with a positive value denoting concreteness and a negative value denoting abstractness). The test phase (excluding the prospective memory cues) consisted of 200 German words (concreteness *M* = 3.64, *SD* = 13.49, *range* = −14.92-19.20). In both phases, half of the words were concrete and half abstract. The German words *Insekt* (insect; concreteness = 14.53), *Pferd* (horse; concreteness = 18.60), *Schlange* (snake; concreteness = 16.33), and *Vogel* (bird; concreteness = 15.73) served as prospective memory cues. We used the German version of the Morningness-Eveningness Questionnaire (D-MEQ) to assess the chronotype (Griefahn et al., 2001; cf. Cicogna & Nigro, 1998; Fabbri, Tonetti, Martoni, & Natale, 2015; Grundgeiger, Bayen, & Horn, 2014).

2.3. *Procedure*

Participants were randomly assigned to a morning session (between 8:00 and 12:00) or an evening session (between 16:00 and 20:00) and were tested individually. They were seated in front of a computer monitor and were instructed that they will be presented with words at the center of the monitor and asked to decide whether the words were concrete or abstract by pressing one of two keys on the computer keyboard ("b"-key for concrete and "n"-key for abstract). First, participants performed the baseline phase of the ongoing task consisting of 48 trials. A trial consisted of a blank screen presented for 500 ms, followed by the word stimulus presented for a maximum duration of 1500 ms, if no response was made the word stimulus was replaced with the message "Please respond!" in German. The next trial started immediately after a response was made either during the presentation of the stimulus word or the message which prompted a response. The words were presented in black on a white background in Courier New 18-point bold print. The words were presented in random order without replacement.

After the baseline phase, participants were instructed for the prospective memory task. They were informed that we were interested in how well they could remember to carry out an action in the future. The action was to press the "1"-key on the keyboard every time they saw one of the following words: *bird, horse*, *insect*, and *snake*. They were further instructed that they should press the "1"-key even if they noticed with some delay that a critical word has been presented. Participants had to repeat the instructions in their own words to make sure they were understood and the prospective memory cues were properly encoded.

Next, participants were presented with an unrelated filler task which lasted about 15–20 min. Then, the test phase was started without mentioning the prospective memory task again. The task was identical to the baseline phase with the following exceptions. It consisted of a total of 204 trials, among them the prospective memory cues which appeared on the 50th, 100th, 150th, and 200th trials. The order of prospective memory cues was random without replacement for each participant. After the end of the experiment a recognition test was conducted to probe memory for the prospective memory targets. As all participants were able to do so, these data are not discussed any further.[2] Finally, participants completed the D-MEQ.

2.4. *Analysis*

Participants were excluded if their performance in the ongoing task (i.e., practice or testing phase) was around or below chance performance (i.e., proportion correct below .65) or if their median RT exceeded 3000 ms. Eleven participants were excluded on the basis of their accuracy (i.e., five young and six old) and three participants were excluded due to their reaction times (i.e., all old). The remaining participants are referred to as the final sample which is described in Section 2.1.

We considered potential training effects (e.g., familiarity with the task, learning the response mapping etc.) and excluded the first 18 of the 48 trials of the practice phase. Prospective memory trials and the three subsequent trials were excluded from the analyses of the ongoing task (cf. Meier & Rey-Mermet, 2012). A prospective memory cue was classified as correct if the required action (i.e., press "1"-key) was fulfilled during the presentation of the prospective memory cue or the three subsequent trials. If this was not the case, the prospective memory cue was classified as missed.

The scores of the D-MEQ were normally distributed (*Mean* = 54.89, *Median* = 55, *min* = 24, *max* = 77, *skewness* = −.13, *kurtosis* = −.54) and the mean and median were in the range of what would be regarded as neutral-type (i.e., 42–58). In order to use the data of all participants and to use the morningness-eveniningness tendencies of those who scored in the neutral range, we applied a median-split to the scores of the D-MEQ in order to assign participants to morning- and evening-types for a first set of analyses.

We observed more young evening-type than young morning-type participants and more old morning-type than old evening type-participants (cf. Figure A1 in the Appendix). In order to maintain statistical power, we collapsed the factors *Testing time* (morning vs. evening) and *Chronotype* (morning type vs. evening type) into the single factor *Testing time* (on-peak vs. off-peak).

Accuracy and reaction times of the ongoing task trials were analyzed with a mixed three-factorial analysis of variance (ANOVA) with the between subject factors *Age group* (young vs. old) and *Testing time* (on-peak vs. off-peak) and the within subject factor *Phase* (baseline vs. test). Prospective memory performance (i.e., proportion correct) was analyzed with a two-factorial ANOVA with the between subject factors *Age group* (young vs. old) and *Testing time* (on-peak vs. off-peak).

Because median-splits can lead to biased results, we conducted a regression analysis with the between subject factors *Age group* (young vs. old), *Testing time* (morning vs. evening), and *Chronotype* (i.e., the score of the D-MEQ) to acknowledge the continuous nature of the D-MEQ score, but expected weaker effects due to the reduced statistical power of the three-factorial design. Because chronotype is confounded with age (see Figure A1 in the Appendix), the focus of this analysis is on the triple interaction.

The alpha level was set to .05 for all statistical analyses and *t*-tests were two-tailed. Reported effect sizes denote partial eta squared (η_p^2).

3. Results

3.1. Ongoing task

The average proportion of correct responses for the ongoing task was .90 or higher in all conditions (Table 1). The mixed three-factorial ANOVA with the between subject factors *Age group* (young vs. old) and *Testing time* (on-peak vs. off-peak) and the within subject factor *Phase* (baseline vs. test) revealed a significant main effect *Age group*, $F(1, 224) = 5.67$, $p = .018$, $\eta_p^2 = .02$, due to better performance in the older group. The factor *Phase* was also significant, $F(1, 224) = 13.49$, $p < .001$, $\eta_p^2 = .06$, due to increased accuracy in the test phase (i.e., practice effect). Moreover, there was a trend for a

Table 1. Descriptive statistics (mean values and standard errors in parenthesis) for accuracy (ACC) and reaction time (RT).

Age group	Testing time	*N*	Baseline (ACC)	Test (ACC)	Baseline (RT)	Test (RT)
Young	On-peak	62	.90 (.010)	.91 (.010)	897 (20)	889 (18)
Young	Off-peak	53	.90 (.012)	.92 (.007)	879 (25)	930 (34)
Old	On-peak	63	.93 (.010)	.94 (.007)	1193 (42)	1074 (35)
Old	Off-peak	50	.91 (.011)	.94 (.008)	1110 (34)	1031 (29)

significant *Testing time* × *Phase* interaction, $F(1, 224) = 2.94$, $p = .088$, $\eta_p^2 = .01$. There were no other significant effects, all $Fs(1, 224) < 0.68$, all $ps > .409$.

In order to calculate the cost in ongoing task performance as a result of the prospective memory intention (i.e., prospective memory load), we compared the reaction times of the baseline phase and the testing phase (Table 1). The mixed three-factorial ANOVA with the between subject factors *Age group* and *Testing time* and the within subject factor *Phase* revealed a significant main effect *Age group*, $F(1, 224) = 50.35$, $p < .001$, $\eta_p^2 = .18$, due to faster reaction times in the young than the old group. There was also a significant main effect *Phase*, $F(1, 224) = 11.61$, $p = .001$, $\eta_p^2 = .05$, due to faster reaction times in the testing phase than the learning phase (i.e., practice effect). Moreover, there was a significant *Age group* × *Phase* interaction, $F(1, 224) = 28.10$, $p < .001$, $\eta_p^2 = .11$. Subsequent *t*-tests revealed a significant difference between baseline and test in the old group, but not the young group, as the source of the interaction, $t(112) = 6.31$, $p < .001$ and $t(114) = 1.19$, $p = .236$, respectively. That is, the older participants showed faster reaction times in the test phase in comparison to the practice phase. This was not the case for the younger participants. Furthermore, there was a significant *Testing time* × *Phase* interaction, $F(1, 224) = 4.69$, $p = .031$, $\eta_p^2 = .02$. Subsequent *t*-tests revealed a significant difference between practice and test phase for the on-peak but not the off-peak condition, $t(124) = 4.47$, $p < .001$ and $t(102) = 0.61$, $p = .542$, respectively. *T*-tests comparing the on- and off-peak conditions in the practice and testing phase were not significant, $ts(226) < 1.53$, $ps > .130$. That is, the participants in the on-peak condition were faster in the test phase in comparison to the practice phase. This was not the case for the participants in the off-peak condition. However, the on-peak and off-peak conditions did not differ significantly in the practice and testing phase, respectively. Thus, we will not discuss this effect any further. The ANOVA revealed no other significant effects, all $Fs(1, 224) < 1.67$, all $ps > .198$.

3.2. *Prospective memory task*

Prospective memory performance as a function of age group and testing time is presented in Figure 1. The two-factorial ANOVA with the between subject factors *Age group* (young vs. old) and *Testing time* (on-peak vs. off-peak) revealed a significant main effect *Age group* because younger participants outperformed older participants, $F(1, 224) = 55.87$, $p < .001$, $\eta_p^2 = .20$. Also the interaction *Age group* × *Testing time* was significant, $F(1, 224) = 6.44$, $p = .012$, $\eta_p^2 = .03$. Subsequent *t*-tests revealed the performance difference between testing times in the young group but not the old group as the source of the interaction, $t(113) = 2.70$, $p = .008$ and $t(111) = 1.10$, $p = .273$, respectively. The main effect *Testing time* was not significant, $F(1, 224) = 0.63$, $p = .426$.

The regression analysis included the factors *Age group* (young vs. old), *Testing time* (morning vs. evening), *D-MEQ score* and all potential interaction terms. The results showed a trend for a triple interaction, $ß = 0.46$, $t = 1.66$, $p = .098$. This pattern confirms the *Age group* × *Testing time* (on-peak vs. off-peak) interaction of the median-split based ANOVA. Nevertheless, this result has to be treated with caution due to the confound of chronotype with age (for further explanation, see Section 2.4 and Figure A1 in the Appendix).

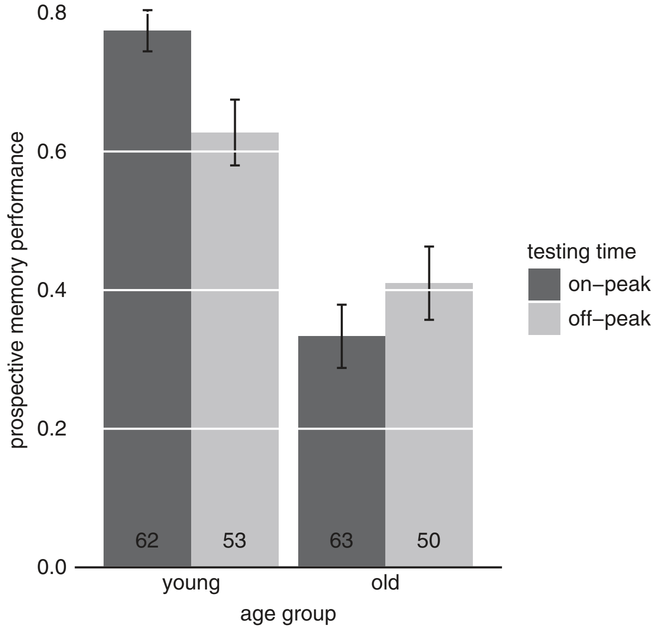

Figure 1. Prospective memory performance (proportion correct) as a function of *Testing time* and *Age group*. Error bars represent standard errors and the numbers on the bars indicate the number of participants per condition.

4. Discussion

We investigated time-of-day effects in prospective memory retrieval as a function of age. The results showed that younger but not older participants had better prospective memory performance on-peak in comparison to off-peak. Moreover, younger participants outperformed older participants across all conditions.

The finding that prospective memory performance in younger participants is enhanced during the optimal time-of-day relative to the nonoptimal time-of-day suggests that controlled rather than automatic processes are affected. Importantly, prospective memory retrieval resembles an orienting reaction based on multiple stages such as from noticing a cue to inhibiting the ongoing activity, and switching the task to perform the prospective intention (Graf, 2005; Marsh, Hicks, & Watson, 2002; Meier & Rey-Mermet, 2012; Rothen & Meier, 2014). Noticing the prospective memory cue may still be based on automatic processes while the subsequent retrieval is in fact controlled. Hence, the observed time-of-day effect might actually be based on the retrospective component of prospective memory which reflects “what” needs to be done (i.e., retrospective memory search), as opposed to the preceding prospective component which reflects realizing “that” something is special about the stimulus (i.e., noticing the prospective memory cue). Although there is no direct way to test for this explanation with the current data, future studies could use paradigms that allow the separate assessment of the prospective and retrospective components (cf. Kliegel, Guynn, & Zimmer, 2007; Rothen & Meier, 2014; Zimmermann & Meier, 2006, 2010).

Moreover, it is likely to be the case that controlled processes are engaged in prospective memory retrieval whenever the necessary resources are available (but cf. Rummel & Meiser, 2013 for the role of metacognition in prospective memory). Indeed, the results suggest that the overall cognitive load was rather low for the group of younger participants (cf. Meier & Zimmermann, 2015). Namely, there were four specific prospective memory cues which all belonged to the same category. Specific intentions are more likely to be successfully retrieved than categorical intentions (Brandimonte & Passolunghi, 1994; Einstein, McDaniel, Richardson, Guynn, & Cunfer, 1995; Marsh, Hicks, Cook, Hansen, & Pallos, 2003; Meier, Von Wartburg, Matter, Rothen, & Reber, 2011; Rothen & Meier, 2014). Furthermore, the ongoing task involved semantic processing of the presented words. Hence, there was considerable overlap between the ongoing task and the prospective memory task. Greater overlap between the ongoing task and the prospective memory task increases the chances of successful prospective memory retrieval (Meier & Graf, 2000).

By contrast, individuals are less likely to engage in controlled processes if fewer processing resources are available. Thus, older individuals are more susceptible to distracting information than younger individuals; however, they can also benefit more from irrelevant information than younger individuals in certain situations (Lourenço & Maylor, 2015). As the prevalent explanation for time-of-day effects is that inhibitory processes are weakened during nonoptimal times, material which is not at the focus of attention can be processed more easily than during optimal times (e.g., Anderson et al., 2014; Schmidt et al., 2007). The observation that prospective memory performance was numerically reduced on-peak compared to off-peak in the older group supports this explanation.

Overall, our results support that optimal time-of-day affects predominantly controlled and not automatic processes. Specifically, young participants outperformed older participants because they have probably more resources available. This is supported by the fact that young participants show better prospective memory performance when tested on-peak where controlled processes are predominant over automatic processes in contrast to testing at the nonoptimal time of the day (off-peak) when automatic processes are predominant over controlled processes. Numerically, elderly participants showed the opposite pattern. Namely, elderly participants showed better prospective memory performance when tested at the nonoptimal time of the day in comparison to the optimal time of the day, which suggests that they primarily relied on automatic processes because they may have been unable to engage in controlled processes due to limited resources.

More generally, our results indicate that time-of-day effects cannot explain age-related differences in prospective memory. As testing is mostly conducted by young experimenters and their preferred testing time is in the afternoon, it has been suggested that typically older participants are tested at their nonoptimal time of day while young participants are tested at their optimal time of day (e.g., Intons-Peterson et al., 1998; May et al., 1993). By contrast, our data suggest reliable performance differences in prospective memory irrespective of the time of testing.

Notes

1. More details on this measure can be found in Section 2.2 and Section 2.4 of this article.
2. This was confirmed for the first 80 participants under the assumption that this specific result would not change for the remaining participants.

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Appendix

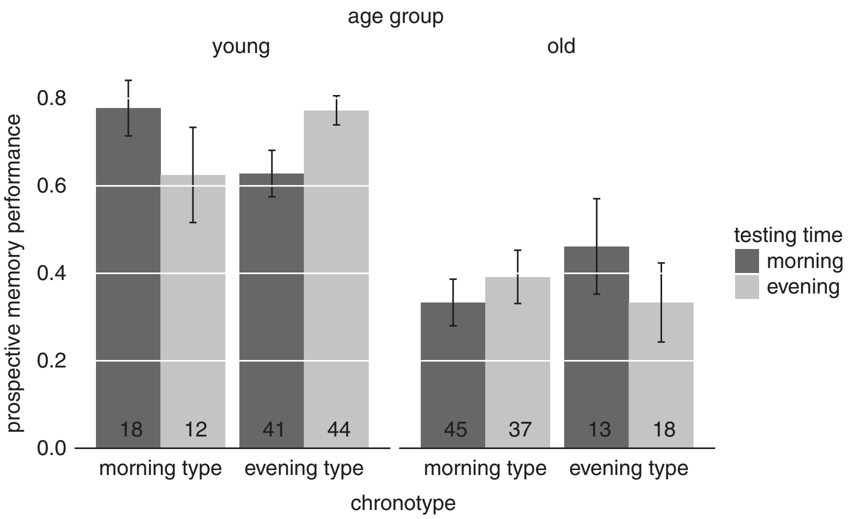

Figure A1. Prospective memory performance (proportion correct) as a function of *Testing time, Chronotype* and *Age group*. The young group shows better prospective memory performance when tested on-peak (i.e., morning types in the morning and evening types in the evening) in comparison to off-peak (i.e., morning types in the evening and evening types in the morning). In contrast, the same comparison does not reveal a relevant difference for the old group. Overall, the young group outperforms the old group. Error bars represent standard errors and the numbers on the bars indicate the number of participants per condition.