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Future thinking instructions improve prospective memory performance in adolescents

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ABSTRACT

Studies on prospective memory (PM) development in adolescents point to age-related increases through to adulthood. The goal of the present study was to examine whether instructing adolescents to engage in an episodic prospection of themselves executing future actions (i.e., future thinking) when forming an intention would improve their PM performance and reduce age-related differences. Further, we set out to explore whether future thinking instructions result in stronger memory traces and/or stronger cue–context associations by evaluating retrospective memory for the PM cues after task completion and monitoring costs during PM task processing. Adolescents and young adults were allocated to either the future thinking, repeated-encoding or standard condition. As expected, adolescents had *fewer* correct PM responses than young adults. Across age groups, PM performance in the standard condition was lower than in the other encoding conditions. Importantly, the results indicate a significant interaction of age by encoding condition. While adolescents benefited most from future thinking instructions, young adults performed best in the repeated-encoding condition. The results also indicate that the beneficial effects of future thinking may result from deeper intention-encoding through the simulation of future task performance.

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Prospective memory (PM) refers to the ability to remember to carry out future intentions at a certain time (time-based PM, such as remembering to attend a tennis training session at 2 p.m.) or following a specific external cue (event-based PM, such as remembering to give a permission slip for the next school trip to your parents to sign; see Ellis, 1996). PM is critically important for developing autonomy and being able to live independently in adolescence and young adulthood. Prospective remembering comprises multiple phases that rely on different cognitive processes (Ellis, 1996). First, the intention needs to be formed. During this intention-encoding phase, it is planned when and how the intention will be performed. Then, the intention is stored in retrospective memory, while the individual is busily engaged in other ongoing activities and may monitor for the PM target cue or target time. When the moment for execution

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of the intention arises, the intended action has to be retrieved, other ongoing activities have to be inhibited, and the individual has to switch to the prospective intention and perform it as planned. Thus, in addition to retrospective memory, executive functions such as planning, monitoring for the PM cue, inhibition and switching play a critical role in the PM process (Kliegel, Martin, McDaniel, & Einstein, 2002; Schnitzspahn, Stahl, Zeintl, Kaller, & Kliegel, 2013). Given that PM paradigms require participants to work simultaneously on an ongoing activity and a PM task, both tasks compete for (limited) attentional resources (Kliegel, Martin, McDaniel, & Einstein, 2001, 2004). In their influential multi-process framework, McDaniel and Einstein (2000) suggest that the extent to which the retrieval of delayed intention relies on automatic processes as opposed to strategic processes which demand the use of executive control depends on various factors such as the characteristics of the task (e.g., its importance) and the individual itself (e.g., available resources; see Kliegel, Altgassen, Hering, & Rose, 2011). In contrast, the preparatory attentional and memory processes (PAM) model (Smith, 2003; Smith & Bayen, 2004) states that PM performance is never automatic, but always relies on effortful, capacity-consuming processes due to consistent monitoring for the PM cue. Slower reaction times in the ongoing task with a PM task embedded compared to reaction times in the ongoing task alone (so-called monitoring costs) have been interpreted as evidence for monitoring activities. Both the multi-process framework and the PAM model predict larger age differences in PM tasks which require high levels of executive control, as attentional resources are still developing across childhood and adolescence (Gathercole, 1998).

Early studies on PM development have indicated age-related increases in PM performance across childhood and adolescence, yet they have been predominantly descriptive in nature (for a review on childhood, see Mahy, Moses, & Kliegel, 2014; for studies comprising adolescents, see Wang et al., 2011; Wang, Kliegel, Yang, & Liu, 2006; Zimmermann & Meier, 2006) and it is only now that research is beginning to explore the underlying mechanisms of such age-related effects. Developmental improvements in PM performance have mainly been attributed to the parallel development of executive functions (e.g., Altgassen, Vetter, Phillips, Akgün, & Kliegel, 2014; Wang et al., 2011), and thus the ongoing development of the prefrontal cortex into young adulthood (Casey, Tottenham, Liston, & Durston, 2005; Luciana, Conklin, Hooper, & Yarger, 2005). In general most research on age differences in PM has examined the role of the person or task characteristics during the phases of intention initiation and execution by manipulating the extent to which executive-control resources are needed (Kliegel et al., 2013; Wang et al., 2011) or available to perform the PM task (Mahy et al., 2015; Voigt et al., 2014). In line with the predictions of the multi-process framework and PAM model, these studies report larger age differences in PM tasks requiring more executive control or when fewer executive control resources are available.

Only recently has the research started to explore the usefulness of encoding strategies during the intention-formation phase to improve later PM performance (Chasteen, Park, & Schwarz, 2001; Zimmermann & Meier, 2010). Despite the consistently-reported poorer PM performance of children and adolescents compared to young adults (Altgassen et al., 2014; Voigt et al., 2014), these studies have mainly focused on younger and/or older adults. This lack of research on possible strategies to improve PM in children and adolescents is surprising given that it is considered to be an essential precursor of independent living (Kliegel, Jäger, Altgassen, & Shum, 2008).

In terms of targeted strategies to improve PM performance, previous studies have applied so-called implementation intentions which are specific if-then plans that "specify the when, where, and how of responses leading to goal attainment", such as "when situation *x* arises, I will perform response *y*" (Gollwitzer, 1999, p. 494). Implementation intentions are assumed to support automatic rather than consciously-controlled, goal-directed behavior by linking a specific, situational cue (the if-component) to a goal-directed behavior (the then-component; see McDaniel, Howard, & Butler, 2008; Webb & Sheeran, 2003; Wieber, Von Suchodoletz, Heikamp, Trommsdorff, & Gollwitzer, 2011). The underlying assumption is that the (increased) automaticity preserves attentional resources for other cognitive processes and goal-directed responses, and consequently enhances participants' PM performance. Consistently, Zimmermann and Meier (2010) found improved PM performance in older adults (but *not* in adolescents and young adults) when participants were prompted to form implementation intentions in comparison to standard PM instructions (for similar findings in older adults, see McFarland & Glisky, 2011).

Recently, studies applying implementation intentions have augmented the verbal if-then statement with an imaging component by asking participants to imagine how they will perform the PM task later in the experiment (Kardiasmenos, Clawson, Wilken, & Wallin, 2008; McDaniel et al., 2008; McDaniel & Scullin, 2010; Schnitzspahn & Kliegel, 2009). For instance, Chasteen et al. (2001) reported that older adults who were asked to form an implementation intention and then imagine themselves executing the intended action performed better than those who only rehearsed the instructions. Following this line of research, Addis, Wong, and Schacter (2008) have noted that there seems to be considerable overlap between PM and future thinking, and have drawn particular attention to the close relation between the processes involved in future thinking and those in the implementation of intentions. The authors point out that the implementation of an intention involves associating the intention with a specific future context, which closely resembles the episodic simulation involved in future thinking (Leitz, Morgan, Bisby, Rendell, & Curran, 2009; Schacter, Addis, & Buckner, 2008).

Moreover, the brain regions that are involved in projecting oneself into the future (the frontal and medial temporal–parietal lobes; Spreng, Mar, & Kim, 2009) seem to overlap with those involved in PM (Cona, Scarpazza, Sartori, Moscovitch, & Bisiacchi, 2015; West, 2011). Accordingly, there is evidence that—similar to PM development—future thinking continues to increase from childhood to adolescence (Gott & Lah, 2014). Furthermore, these assumed underlying neural areas (Casey et al., 2005; Luciana et al., 2005) show continuous development into adolescence and early adulthood. Importantly, however, the formation of an intended action is not automatically accompanied by a mental simulation of the future situation (Szpunar, 2010) and the extent to which individuals spontaneously imagine future scenarios when forming intentions remains an open question (Kliegel, Martin, McDaniel, Einstein, & Moor, 2007).

In line with the conceptual, neurological and developmental similarities between future thinking and PM described above, studies first provided correlational evidence for significant relations between the two constructs. For instance, Nigro, Brandimonte, Cicogna, and Cosenza (2014) investigated PM and future thinking in 4- to 7-year-olds. Both cognitive functions were significantly related in 7-year-olds, but not in the younger age groups. Atance and Jackson (2009) addressed the relations between PM and mental time travel in 3- to 5-year-olds and found significant correlations. However, when partialling out age, the relations were no longer significant. Taken together, these initial studies show relations between PM and future thinking in children but also indicate that this correlation might only emerge later in childhood, and that only older children may be able to make use of their ability to move themselves forward in time to support their PM performance (Nigro et al., 2014). Surprisingly, studies on relations between PM and future thinking in adolescence are yet to be undertaken.

It seems very likely that participants should benefit from a mental simulation of the intended PM task during encoding. In fact, empirical evidence suggests that simulating a future situation may help to translate future-oriented cognition into action (Taylor, Pham, Rivkin, & Armor, 1998; Taylor & Schneider, 1989). So far, there have been four studies investigating the effects of future thinking as an encoding strategy on PM performance in younger and/or older adults. Altgassen et al. (2014) gave the participants of their study instructions to imagine themselves performing the PM tasks at a later point during the testing session, and reported beneficial effects of future thinking instructions on PM performance and plan adherence in both younger and older adults. Similarly, Neroni, Gamboz, and Brandimonte (2014) reported positive effects of future thinking on PM in a student sample. Leitz et al. (2009) and Paraskevaides et al. (2010) both tested whether the provision of future thinking instructions would reduce the PM deficits associated with acute alcohol consumption in young adults. Results indicated that future thinking did significantly improve PM performance compared to a control condition. However, a within-subjects design was used and the two conditions were not counterbalanced; the standard condition was always administered first, followed by the future thinking condition. Thus, the improvements in PM performance may be explained by practice effects. Taken together however, these studies give initial support to the prospect of future thinking having a beneficial effect on PM performance in adults. Therefore, the first goal of the present study was to test if these beneficial effects extend to adolescents.

Another issue that is still under debate is the nature of the mechanisms underlying the beneficial effects of future thinking on PM performance. Two hypotheses have been put forward to explain the positive effects of imagining the specific visuospatial context in which the intention will later be executed on PM performance: a) deeper encoding of the intention in retrospective memory (thus, stronger memory traces), and b) formation of an association between the specific visuospatial context and the intention which may later lead to the (somewhat) automatic retrieval of the intention during the delayed performance interval (thus, stronger cue–context association; Paraskevaides et al., 2010). Consistent with the latter hypothesis, Brewer and Marsh (2010) have reported that the stronger the cue-to-context association formed at encoding, the better the subsequent event-based PM performance. Specifically, they compared three conditions that varied in the extent to which an association between PM cues and context (i.e., the ongoing task) was possible. The participants performed poorest in the no-association condition (here, immediate PM instructions were given before any information regarding the ongoing task was received, which prevented the creation of any association between prospective intention and the ongoing task), better in the standard condition (here, the ongoing task was first introduced and thereupon the PM task) and best in the strong-association condition (here, participants were asked to form an implementation intention and to imagine themselves responding to PM target cues while working on the ongoing task). However, whilst this study suggests that stronger cue-to-context association leads to better PM performance, it does not provide any evidence as to whether this improvement follows due to an increase in the automaticity of intention retrieval and thus reduced monitoring demands. Further, supporting the assumption that future-event simulation leads to "pre-experiencing" the future context, Paraskevaides et al. (2010) found significantly larger effects of future thinking for event- than time-based PM tasks in young adults. Event-based tasks provide external cues that may prompt retrieval of the intended action during the delayed-performance interval. Imagining later encountering these cues during intention formation may be easier and more specific than imagining intention execution in a time-based task, which does not provide an external cue indicating the right moment to initiate the planned action and instead requires self-initiated time monitoring (Altgassen, Schmitz-Hübsch, & Kliegel, 2010; Einstein & McDaniel, 1996). However, these differential effects of future thinking on event- versus time-based tasks were not replicated by Altgassen et al. (2014), suggesting that future thinking may not influence PM through stronger cue–action association. Possibly, the additional time that participants get to think about the PM task when receiving future thinking instructions is sufficient to lead to deeper encoding and thereby improve performance. Thus, taken together, it is still unclear what makes future thinking instructions effective: is it deeper intention encoding, stronger cue-to-context association, or both?

Therefore, the second goal of the present study was to address this open question by experimentally exploring whether future thinking improves PM performance not only when compared to a standard condition but also beyond the effects of a condition solely focusing on intention encoding. During the latter condition, participants were given time, after a brief delay, to repeatedly read through the PM instructions. This repetition of the task instructions should (primarily) deepen the memory traces for the intention in retrospective memory without affecting the cue–context association. We expected that overall participants would show better performance in both the future thinking and repeated-encoding conditions compared to the standard condition. If future thinking primarily enhances PM through better intention encoding, PM performance in the future thinking and repeated-encoding conditions should be comparable, and both conditions should show similar levels of retrospective PM cue recall. However, if future thinking is effective by simultaneously influencing intention encoding and the cue–context association then participants in the future thinking condition should outperform participants in the repeated-encoding condition, and they should show increased automaticity, which should be reflected in reduced monitoring costs. This research goal is especially relevant from a conceptual perspective, as it helps to clarify the mechanisms underlying the positive future thinking effects on PM performance observed in earlier studies.

Further, we expected the young adults to show better PM performance than the adolescents. Two different sets of predictions are possible regarding the general impact of encoding strategies on age effects in PM performance. On the one hand, age effects may be expected to be reduced in both treatment (future thinking and repeated-encoding) conditions compared to the standard condition: adolescents are assumed to have fewer attentional and executive control resources (Best, Miller, & Jones, 2009), therefore, their PM performance should benefit more from the automatic retrieval and deepened encoding induced by future thinking and repeated encoding, respectively, compared to the performance of young adults. On the other hand, there is evidence that the ability of adolescents to engage in future-oriented cognitions (Gott & Lah, 2014) and the related underlying brain areas (Blakemore & Choudhury, 2006) are still developing. Therefore, instructions that emphasize the need to engage in future thinking might in fact be less beneficial for the PM performance of adolescents than that of young adults. Similarly, adolescents may be less able than young adults to make use of the additional encoding time provided in the repeated-encoding condition, given the ongoing development of the capacity to monitor one's cognitive abilities and put in place strategies to overcome potential weaknesses across adolescence (Paulus, Tsalas, Proust, & Sodian, 2014).

Taken together, the first goal of the present study was to test if the beneficial effects of future thinking that have been reported in older adults extend to adolescents. Further, the second goal was to explore the underlying mechanisms of the beneficial effects of future thinking on prospective remembering (deeper encoding, stronger cue-to-context association, or both).

Method

Participants

A total of 49 adolescents (age: M = 14.43, SD = 0.71, 21 males) and 60 young adults (age: M = 21.18, SD = 2.38, 18 males) took part in the present study. The adolescents and young adults were randomly assigned to one of the three encoding conditions (for an overview of the exact group sizes, see Table 1). Age groups were parallel for verbal ability, as measured by age-normalized scores on the vocabulary test of the Wechsler intelligence scales (adolescents: M = 10.69, SD = 3.55; young adults: M = 10.22, SD = 2.76, F < 1); depending on the age of the participants, either the Wechsler Intelligence Scale for Children – Third Edition (WISC-III; Wechsler, Golombok, &

Table 1. Ongoing Task (OT) Performance and Recall of PM Cues.

	Adolescents			Young Adults		
	Standard n = 16 M (SD)	Future thinking n = 17 M (SD)	Repeated-encoding n = 16 M (SD)	Standard n = 20 M (SD)	Future thinking n = 20 M (SD)	Repeated-encoding n = 20 M (SD)
OT hits, single task	.80 (.12)	.86 (.17)	.79 (.15)	.88 (.13)	.87 (.16)	.89 (.09)
OT hits, dual-task	.83 (.06)	.85 (.15)	.85 (.13)	.91 (.06)	.89 (.05)	.92 (.04)
Monitoring costs	3.37 (47.12)	38.03 (78.89)	49.47 (60.27)	1.05 (81.14)	38.58 (62.91)	9.71 (94.88)
Recalled PM cues	.85 (.13)	.98 (.06)	.99 (.06)	.99 (.06)	.99 (.06)	.95 (.13)

Note. PM hits, OT hits and recalled PM cues are presented as proportions of correct responses.

Rust, 1992) or the Wechsler Adult Intelligence Scale – Fourth Edition (WAIS-IV; Wechsler, 2008) was applied. The adolescents and young adults were recruited from local schools and universities, respectively. Exclusion criteria were any presence or history of psychiatric or neurological disorders, as well as substance abuse. The study was approved by the local ethics committee and conducted in line with the Helsinki declaration. Each participant was tested individually and before testing, all participants (as well as parents for adolescents) gave written informed consent.

Materials

For the ongoing task, participants were presented with a picture-based two-back working-memory task (for a similar procedure, see Zinke et al., 2010). Black-and-white line drawings of familiar objects from the Snodgrass and Vanderwart (1980) picture system were displayed one by one on a computer screen. With each display a new picture was presented. Participants were to decide whether or not the present picture had occurred two stimuli ago by pressing one of two highlighted buttons on the keyboard. Items were presented for 1500 ms with an inter-stimulus interval of 500 ms between trials. In the course of the *n*-back task, 25% of all the stimuli presented were hit items. Participants were first presented with a printout showing four ongoing task trials to illustrate the task and were then asked to complete a practice block consisting of 8 trials. This was followed by 24 ongoing task trials (a single ongoing task block), after which the PM task was introduced.

For the PM task, participants were instructed to press another highlighted button whenever one of four specific pictures appeared. Participants were shown a printout of the PM cues until they indicated that they had learned them. Thereupon, participants were asked to write down the prospective cues. This was repeated until the participants correctly reproduced all cues. Further, participants were instructed—upon presentation of the PM cues—to first respond to the PM cues and then to perform the ongoing task. To ensure that participants had understood the instructions before starting the test, they were required to repeat what they were supposed to do within the PM and ongoing task. In total, four PM cues and 89 ongoing task trials were presented during the dual-task block. The PM cues and *n*-back hit items never occurred at the same time. At the end of the experiment, the participants were asked to recall all prospective cues, followed by a recognition task in case not all PM cues were remembered. The dependent variables were PM hits and correct ongoing task responses (both in proportion). Responses were scored as correct if they were made before the next picture was presented. Monitoring costs were assessed by subtracting the mean reaction times for the ongoing task trials which were responded to correctly in the dual-task condition from those in the single-task condition.

The adolescents and young adults were randomly assigned to one of the three encoding conditions (i.e., standard, repeated-encoding or future thinking). In the *standard condition*, participants were introduced to the ongoing and PM task as described above, and performed the PM task after a filled delay, during which the vocabulary test was performed. In the *repeated-encoding condition*, after having been introduced to the ongoing and PM tasks, participants completed a different cognitive test (i.e., the Stroop test, 1935) and were then presented again with the printouts of the ongoing task outline and the four PM cues, and asked to study both tasks for two minutes. Thereafter, they also performed the vocabulary test as a filled delay and completed the PM task. After having performed the PM task, participants were asked to write down what they did during the two minutes and to outline any strategies they may have used. In the *future thinking condition*, after having been introduced to the ongoing and PM task, participants were first instructed to practice future thinking with an example which was unrelated to the present task (i.e., imagine passing a message to your mother/flatmate when coming home). Participants were asked to imagine how this event could take place with as much detail as possible. This training component took about two minutes. Subsequently, participants were told to apply this encoding strategy to the present task and vividly imagine themselves executing the PM and ongoing tasks on the computer. Based on the future thinking literature (D'Argembeau & Van Der Linden, 2004; Szpunar & McDermott, 2008), participants were encouraged to close their eyes and imagine as many sensory details (e.g., sights, sounds) as possible to ensure the development of a vivid personal experience of the event. Participants were first instructed to say aloud what they were imagining for 20 s before they were given a further 20 s to silently imagine the same task (Altgassen et al., 2014). After applying the future thinking strategy to the present task, participants were asked to rate on a five-point scale the vividness of their imagination as well as the degree of "living the experience", hence, how much the imagined experience had felt like being in the actual situation. Thereafter, they also performed the vocabulary test as a filled delay and then completed the PM task. The length of the first delay—between the initial PM instructions (including the PM cue learning) and the imagination of the later task performance, or repeated exposure to PM cues and the ongoing task—was the same for both treatment conditions, as was as the total time spent imagining performing the PM task or rehearsing the PM task instructions.

Results

A 2 (age group: adolescents, young adults) × 3 (encoding condition: standard, repeated-encoding, future thinking) analysis of variance (ANOVA) was conducted to explore the effects of age and encoding condition on participants' PM performance. Significant main effects for age, $F(1, 103) = 14.62$, $p = .001$, $\eta^2_p = .12$, and encoding condition, $F(2, 103) = 5.30$, $p = .006$, $\eta^2_p = .09$, and a significant interaction effect, $F(2, 103) = 6.01$, $p = .003$, $\eta^2_p = .11$, were found. The young adults had more PM hits than the adolescents (see Figure 1). Overall, participants performed best during the repeated-encoding condition, followed by the future thinking condition and lastly the standard condition. Further analysis of the interaction with tests of simple effects revealed that the adolescents did not perform as well as the young adults in the standard, $F(1, 103) = 14.51$, $p = .001$, $\eta^2_p = .12$, and repeated-encoding, $F(1, 103) = 11.94$, $p = .001$, $\eta^2_p = .10$, conditions, but not in the future thinking condition, $F < 1$, $\eta^2_p = .004$. Further comparisons also revealed that encoding condition was a simple main effect for the adolescents, $F(2, 103) = 5.06$, $p = .008$, $\eta^2_p = .09$. Significant differences were observed between the standard and future thinking conditions ($p = .003$), and between the standard and repeated-encoding conditions ($p = .02$), but the future thinking and repeated-

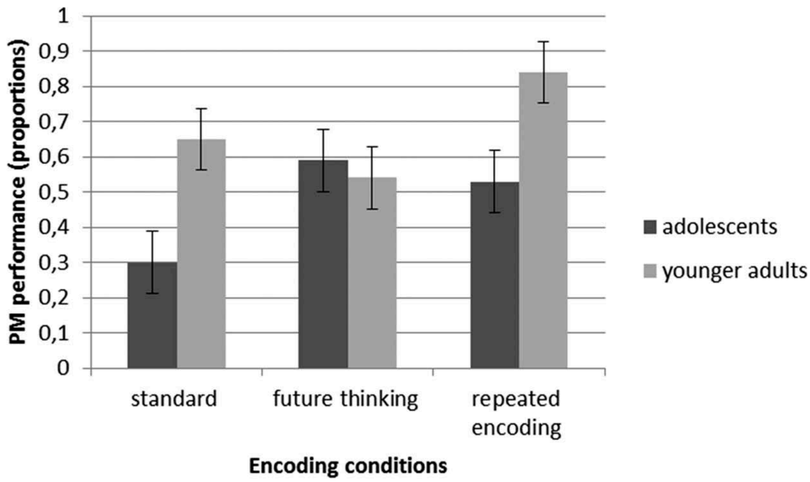

Figure 1. PM performance as a function of age groups and encoding conditions.
Note. Error bars represent one standard error of the mean.

encoding conditions did not differ significantly from each other (p = .50). Encoding condition was also a simple main effect with the young adults, F(2, 103) = 6.29, p = .003, η^2_p = .11. Here, there were no significant differences between the standard and future thinking conditions (p = .19), but both conditions differed significantly from the repeated-encoding condition (standard, p = .001; future thinking, p = .03), in which the young adults performed best.

To analyze the effects of age group, encoding condition and task block (single, dual-task block) on participants' ongoing-task performance, a 2 × 3 × 2 mixed measures ANOVA was conducted. Significant main effects were found for age group, F(1, 103) = 10.44, p = .002, η^2_p = .09, and task block, F(1, 103) = 5.00, p = .03, η^2_p = .05. The adolescents did not perform as well as the young adults and, overall, the participants' performance improved from the single- to the dual-task block (see Table 1). All other effects were not significant, all Fs < 1.11. A 2 × 3 ANOVA was conducted to analyze the monitoring costs caused by the additional PM task on ongoing task response latencies due to target monitoring (see Table 1). The main effect of encoding condition was approaching significance, F(2, 103) = 2.33, p = .10, η^2_p = .04. Age group, F < 1, and the interaction effect, F < 1, were not significant.

A 2 × 3 ANOVA was carried out to explore differences in recalled PM cues after having completed the PM task. There was an almost significant age effect, F(1, 103) = 3.91, p = .051, η^2_p = .04, a significant effect for encoding condition, F(2, 103) = 5.11, p = .008, η^2_p = .09, and a significant interaction effect, F(2, 103) = 8.91, p = .001, η^2_p = .15. The young adults outperformed the adolescents. Overall, the participants of the future thinking and repeated-encoding conditions remembered more PM cues correctly than those of the standard condition (see Table 1). Further analysis of the interaction with tests of simple effects revealed that the young adults only performed better than the adolescents in the standard condition, F(1, 103) = 20.10, p = .001, η^2_p = .16, but not in the repeated-encoding, F < 1.45, η^2_p = .01, or future thinking, $F < 1$, $\eta^2_p = .000$, conditions. Further comparisons also revealed that encoding condition was a simple main effect for the adolescents, $F(2, 103) = 11.71$, $p = .001$, $\eta^2_p = .19$, but not for the young adults, $F < 1.19$, $\eta^2_p = .02$. For the adolescents, performance in the standard condition differed significantly from that in the future thinking, $p = .001$, and repeated-encoding, $p = .001$, conditions.

Further, ANOVAs were conducted to study possible age-related differences in the vividness of their imagination and degree of "living the experience" during the future thinking condition. There were no significant age effects for vividness of imagination—adolescents: $M = 3.44$, $SD = 0.96$; young adults: $M = 3.50$, $SD = 0.89$, $F < 1$—or living the experience—adolescents: $M = 2.75$, $SD = 1.00$; young adults: $M = 2.35$, $SD = 0.88$, $F(1, 34) = 1.64$, $p = .21$. With regard to spontaneously-applied strategies during the 2-minute interval in the repeated-encoding condition, the following activities were reported: just looking at the provided task material (8 adolescents, 6 young adults), actively rehearsing PM cues and instructions (7 adolescents, 6 young adults), looking at the provided task material and actively rehearsing PM cues and instructions (2 adolescents, 7 young adults) and imagining later task performance (0 adolescents, 1 young adult).

Discussion

The first goal of the present study was to test if PM in adolescents and young adults can be improved by future thinking. The second goal was to explore the mechanisms underlying the beneficial effects of future thinking on PM and to try to disentangle whether future thinking improves PM due to stronger memory traces and/or stronger cue–context association. To this end, the adolescents and young adults were allocated to either the standard, repeated-encoding or future thinking conditions.

As expected and in line with previous findings (Wang et al., 2006; Zöllig et al., 2007), the adolescents gave *fewer* correct PM responses compared to the young adults. Across the groups, the treatment conditions led to better PM performance than the standard condition. Overall, the participants performed best during the repeated-encoding condition, followed by the future thinking condition and lastly the standard condition. Importantly with regard to possible conclusions about the underlying mechanisms of the beneficial effects of future thinking on PM, analyses indicated a significant interaction of age group by encoding condition. Further analyses of the interaction effect revealed that the young adults performed better than the adolescents in the standard and repeated-encoding conditions, while there were no significant age differences in the future thinking condition. This might indicate that future thinking did indeed lead to deeper memory encoding and stronger cue–context association, which in turn may have increased the automaticity of cue detection and reduced the strategic-processing demands, which was especially beneficial for the adolescents, who generally showed reduced attentional resources in comparison to the young adults. However, further comparisons also revealed that the adolescents performed significantly better in the future thinking *and* repeated-encoding conditions compared to the standard condition, while there are no statistical differences between both treatment conditions. Of course, this result does not completely rule out the possibility that future thinking affects PM both by generating stronger memory traces for the intention in retrospective memory and strengthening the association between cue and task at the same time. However, given that the future thinking instruction did not improve PM performance beyond the effects observed after simply exposing the participants to printouts of the PM cues and the ongoing task, the present findings suggest that purely repeated encoding, and thus stronger memory traces of the PM task, may be the driving force for improving PM performance in adolescents, and that this mechanism may also underlie the beneficial effects of future thinking on PM. This conclusion is further supported by the finding that in the adolescents, both the future thinking and repeated-encoding conditions similarly improved the recall of PM cues compared to the standard condition. Further, it is consistent with previous empirical evidence (Altgassen et al., 2014) showing no differential effects of future thinking on event- and time-based PM tasks, which differ in the extent to which the moment and context of intention initiation can be imagined. Given that previous research shows that PM impairments in adolescents are mainly caused by the retrospective and not by the prospective component of PM (Einstein & McDaniel, 1990; Zöllig et al., 2007), it makes sense that this age group would especially benefit from strategies supporting the encoding of the target cues and the associated action.

For the young adults, different effects of encoding condition emerged. In contrast to the adolescents, the young adults showed significantly better PM performance in the repeated-encoding condition compared to the other two conditions, which did not differ from each other. Descriptively, the young adults achieved even less correct PM responses in the future thinking condition. This finding is somewhat surprising, given comparable recall of PM cues across all three encoding conditions and, importantly, previous evidence of beneficial effects of future thinking in young adults (Altgassen et al., 2014; Neroni et al., 2014). However, the current results are in line with various studies on implementation intentions and imagery that have also not consistently found beneficial effects on PM performance in younger adults (Zimmermann & Meier, 2010). For example, McDaniel et al. (2008) did not find any differences between a control and an imagery condition; only a combination of imagery and implementation intentions improved PM performance in young adults. Kardiasmenos et al. (2008) only reported positive effects of imagery in combination with implementation intentions in individuals with multiple sclerosis when a resource-demanding PM task was used, and not in a task that encouraged automatic processing. The mixed results of Schnitzspahn and Kliegel (2009) revealed that 60- to 75-year-olds benefited from imagery plus implementation intentions whereas 76- to 90-year-olds did not, even finding detrimental effects of this strategy in the latter group when a simple task was used. Chasteen et al. (2001) found positive effects of imagery in combination with implementation intentions when a non-focal PM task was used, but the same effect was not found in a focal PM task. Thus, it appears that imagery does not always lead to improved PM performance, and the extent to which imagery is beneficial for prospective remembering is influenced by both the specific task demands and the characteristics of the individual carrying out the task. Further, although imagery (especially in combination with implementation intentions) may not exactly resemble future thinking, there is likely considerable overlap with regard to underlying mechanisms, which may suggest similar influencing factors for future thinking.

In the present study, it is possible that the future thinking instructions interfered with the strategies that young adults may apply spontaneously while encoding the PM intention and later performing the PM task, for which they had ample time during the repeated-encoding condition, therefore resulting in best PM performance. When we look at the strategies that the participants spontaneously applied during the time provided in the repeated-encoding condition, we can see two main types being used: looking at the provided task material or rehearsing the PM cues and instructions (or both). Descriptively, more young adults reported rehearsal of the PM cues and instructions and especially a combination of looking at the task material and rehearsing compared to the adolescents. Rehearsal of cues and instructions probably leads to deeper encoding than merely looking at the task material. Interestingly, only one participant (a young adult) spontaneously imagined later task performance and thus applied a strategy similar to future thinking. Thus, it is possible that adolescents might be less likely to spontaneously apply *efficient* strategies to support their PM performance compared to young adults, an assumption that would be in line with the empirical evidence for the ongoing development of metacognitive strategies throughout adolescence (Best & Miller, 2010; Weil et al., 2013). However, given that we did not ask participants to verbalize what they were doing during the 2-minute repeated-encoding interval, we have only their subjective descriptions, given subsequent to task performance, and thus cannot draw any firm conclusions about their cognitive processes or applied strategies, Further, participants may have had difficulties in consciously accessing and/or verbalizing their strategies, or might not even have been aware that imagining a future situation is considered as a strategy. Therefore, future studies should not ask participants to freely report their strategies but to choose from a checklist of possible strategies.

Importantly, despite the differential effects of treatment condition on PM performance in adolescents and young adults, there were no age-related differences regarding vividness of imagination or degree of living the experience in the future thinking condition, indicating that both age groups were equally able to apply the suggested future thinking encoding procedure. Regarding ongoing task performance, the young adults performed better than the adolescents, which is in line with prior research (Altgassen et al., 2014; Zöllig et al., 2007). Overall, the participants' performance improved from the single- to the dual-task block, indicating practice effects. There were no significant differences in performance between the three encoding conditions, and no interaction effects. Thus, the beneficial treatment effects on PM performance did not cause costs in terms of reduced ongoing task accuracy and cannot be explained by a preferential treatment of one of the two tasks.

Further, to directly test whether the performance benefits in the treatment conditions were based on higher levels of automatic processing or more monitoring due to the perceived higher importance of the PM task following emphasis of the task, we examined the monitoring costs during the dual-task block of the ongoing task. Importantly, there were no significant effects with regard to monitoring costs, which were comparable for the adolescents and young adults, and greater for the repeated-encoding and future thinking conditions compared to the standard condition. This pattern of monitoring costs, in conjunction with the trend towards significance of a main effect of encoding, suggest that both treatment conditions led to increased perceived importance of the PM task, which in turn led to increased monitoring. The costs also imply that the beneficial effects of future thinking on PM were not the result of enhanced cue–context association, which would have facilitated more automatic, rather than strategic, processes, thereby reducing costs rather than increasing them.

As briefly mentioned above, one possible limitation of the present study is that although the results indicate that beneficial future thinking effects in adolescents are mainly caused by improved retrospective memory for the PM target cues, they do not rule out the possibility that the cue–context association was also influenced but did not affect performance beyond the repeated encoding. To further distinguish between the two mechanisms potentially underlying future thinking effects on PM, future studies should add neural measures to the behavioral ones. Studies on PM using event-related brain potentials could help to identify differential neural correlates associated with processes underlying maintenance of the intention and detection of prospective cues (West & Ross-Munroe, 2002) and the retrieval of an intention (West, 2011). A recent meta-analysis (Cona et al., 2015) on the neural underpinnings of PM showed that frontal processes are primarily involved in the encoding and maintenance of an intention, while parietal processes mainly support the retrieval of the intention. Both neural areas are known to develop throughout childhood and adolescence (Giedd et al., 1999). If future thinking mainly influences PM through stronger memory traces and not following an enhanced cue–context association, it should especially influence those neural processes that are associated with intention retrieval but not with cue detection. More research is needed that does not only manipulate executive-control (thus, frontal) processes, but also retrospective-memory (thus, temporal-parietal) processes (e.g., by varying retrospective memory load; Okuda et al., 2003).

Future studies should also consider using different types of PM tasks such as naturalistic tasks that have to be performed in everyday life such as measuring one's blood pressure several times per day (Brom & Kliegel, 2014) or sending a text message to the experimenter at pre-specified dates (Aberle, Rendell, Rose, McDaniel, & Kliegel, 2010). Although participants in the present study reported that they were able to imagine the PM task quite vividly, they only reported medium levels of "living the experience". The current PM task was rather abstract and probably new to most of the participants. Furthermore, testing took place in an unfamiliar laboratory environment. These factors might make it difficult to develop a strong episodic foresight. Thus, from an applied perspective it would be especially interesting to examine if the effectiveness of a future thinking instruction on PM performance may be influenced by the setting in which the task takes place and former experience of the task.

A further limitation may be that the repeated-encoding group performed two interpolated tasks (rather than one) between forming the PM intention and commencing the PM task, which may have led to ego depletion and diminished PM performance. To control for this possibility future studies should double the encoding time relative to the standard condition.[1]

Taken together, adolescents showed poorer PM performance than young adults, and overall the participants benefited from future thinking instructions and performance of repeated encoding. Importantly, however, differential effects of the encoding condition on PM performance were observed for the adolescents and young adults. In contrast to the adolescents, who benefited most from the future thinking instructions, the young adults performed better in the repeated-encoding condition than in the future thinking condition. Further analyses indicate that the beneficial effects of future thinking may result from deeper memory-encoding following prolonged exposure to the PM task, and not from a stronger cue–context association.

Notes

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