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Prospective memory monitoring and aftereffects of deactivated intentions across the lifespan

Milvia Cottini[a,b,c,*], Beat Meier[c]

[a] Free University of Bolzano-Bozen, Italy
[b] University of Pavia, Italy
[c] University of Bern, Switzerland

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ABSTRACT

The purpose of this study was to compare, across the lifespan, different costs that can occur in a prospective memory task. Specifically, we were interested in investigating the costs of responding to both activated (i.e., monitoring costs) and deactivated intentions (i.e., aftereffects). In two experiments, children, younger, and older adults performed an event-based prospective memory task consisting of four blocks (a baseline block, a prospective memory block without the occurrence of prospective memory cues, a prospective memory block with the occurrence of prospective memory cues, and a deactivation block in which unexpected no-more-relevant prospective memory cues occurred). The results revealed that monitoring costs and aftereffects were present in all age groups. Although children engaged in monitoring, their prospective memory performance was lower than for young and older adults. Moreover, aftereffects of responding to deactivated intentions were more pronounced in children and older adults. In Experiment 2, we were interested in examining whether these costs would be modulated by the type of prospective memory cues (semantic vs. perceptual). In fact, aftereffects were modulated by cue type with semantic cues producing higher costs than perceptual cues. These outcomes shed light on the different sources and the extent of cognitive costs resulting from responding to activated and deactivated intentions across the lifespan.

1. Introduction

Remembering to perform an intended action at the appropriate moment such as buying milk when passing by a grocery store, taking medicine with a meal, paying a bill in time, or making a phone call after a meeting is defined as prospective memory[1] (Einstein & McDaniel, 1990). This ability is important in everyday life, influencing individual's autonomy and independence from others across the entire lifespan. Developmental research has shown that prospective memory improves considerably during childhood and adolescence, while it decreases in older age (Zimmermann & Meier, 2006, 2010). Besides remembering to execute intentions, recent studies have highlighted also the importance of forgetting intentions (e.g., Scullin & Bugg, 2013). For instance, failing to deactivate a completed intention can lead to erroneously perform it again (e.g., taking a medicine twice). Although the ability to forget, inhibit or

* Corresponding author at: Faculty of Education, Free University of Bolzano-Bozen, Regensburger Allee 16, 39042 Bressanone-Brixen, Italy.
E-mail address: milvia.cottini@unibz.it (M. Cottini).

[1] Researchers have distinguished different types of prospective memory tasks, such as event-based, time-based, activity-based and habitual. In this article we will specifically focus on event-based prospective memory in which a particular event signals the appropriate occasion for performing the prospective memory task.

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deactivate intentions has been increasingly studied in the last few years, little is known about its development over the lifespan. The purpose of the present study was to investigate both the ability to remember and to forget intentions as well as their related costs across the lifespan.

1.1. Remembering intentions and its development across the lifespan

The ability of remembering intentions is typically studied in laboratory-based experiments in which participants are engaged in an ongoing activity and at the same time have to remember to execute an intention whenever a particular event occurs (i.e., prospective memory cue). Only few studies have investigated prospective memory across the lifespan, mainly finding an inverted U-shaped developmental trajectory (e.g. Zimmermann & Meier, 2006, 2010). Studies comparing children, adolescents, and young adults found a consistent increase in prospective memory performance with increasing age (Kretschmer-Trendowicz & Altgassen, 2016; Kvavilashvili, Messer, & Ebdon, 2001; Smith, Bayen, & Martin, 2010; Ward, Shum, McKinlay, Baker-Tweney, & Wallace, 2005). Executive functions and control processes which enable us to flexibly change and adapt our own behavior to specific tasks or goals (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Miyake et al., 2000; Zelazo, Craik, & Booth, 2004), have shown to support developmental changes in prospective memory (see Mahy, Moses, & Kliegel, 2014; Zuber & Kliegel, 2019). For instance, working memory (i.e., temporarily storing and processing information), inhibition (i.e., inhibiting irrelevant automatic responses), switching (i.e., shift our attention from one task to another), as well as metacognition (i.e., knowledge about the own cognitive processes and the ability to control and monitor these processes) have shown to be related to prospective memory performance during childhood (Spiess, Meier, & Roebers, 2016; Cottini, Basso, & Palladino, 2018; Cottini, Basso, Saracini, & Palladino, 2019; Redshaw, Vandersee, Bulley, & Gilbert, 2018; Spiess, Meier, & Roebers, 2015; Ward et al., 2005; Yang, Chan, & Shum, 2011; Zuber, Mahy, & Kliegel, 2019).

The role of executive processes in prospective memory has been further shown in studies examining monitoring costs which are typically studied by comparing ongoing task response times (RTs) between conditions with and without embedded prospective memory cues (Smith, 2003; Smith & Bayen, 2004). Accordingly, successfully responding to prospective memory cues is accompanied by an ongoing task performance slowing which is interpreted as the cost related to the strategic allocation of attentional resources towards the detection of prospective memory cues (i.e., monitoring). For instance, Kretschmer-Trendowicz and Altgassen (2016) found that compared to adolescents, young adults and older adults, 5-year-old children did not show any costs, and concluded that children's cognitive resources might not be sufficiently developed for strategic monitoring. Smith et al. (2010) compared 7- and 10-year-old children with young adults, showing that all three age groups engaged strategic monitoring processes. However, children had a significantly lower prospective memory performance than adults, suggesting that monitoring was less functional for children. Similarly, Cejudo, Gómez-Ariza, and Bajo (2019) revealed monitoring costs in both 6- and 11-year-old children.

On the other end of the lifespan, from adulthood to older age, prospective memory performance has often shown to decrease (see Henry, MacLeod, Phillips, & Crawford, 2004). Prospective memory deficits in older age seem to be mainly related to age-related declines in inhibition and switching (Schnitzspahn, Stahl, Zeintl, Kaller, & Kliegel, 2013; Zimmermann & Meier, 2006). Studies examining monitoring costs have shown that older adults usually struggle to maintain engagement of monitoring processes over longer intervals because of their reduced cognitive resources (e.g., Bisiacchi, Tarantino, & Ciccola, 2008; Smith & Bayen, 2006). For instance, Smith and Bayen (2006) found that monitoring costs were greater in younger adults than in older adults, and that higher costs were related to better prospective memory performance. However, studies on the adults lifespan did not always reveal a decline with older adults sometimes performing as well as young adults (e.g., Einstein & McDaniel, 1990; Reese & Cherry, 2002).

According to the *multiprocess* view (Einstein & McDaniel, 2005), prospective remembering can rely either on monitoring or on spontaneous processes and that age-related declines are more evident in prospective memory tasks which require preparatory monitoring resources. One key feature that has shown to influence the involvement of monitoring via automatic processes is cue-focality or concurrent overlap, that is, the degree with which stimulus processing of the prospective memory task overlaps with stimulus processing of the ongoing task (i.e., *task appropriate processing*; Maylor, 1996; Maylor, Darby, Logie, Della Sala, & Smith, 2002). Less monitoring resources seem to be required when the processing of the prospective memory task is highly overlapping (i.e., focal) rather than low overlapping (i.e., non focal) with the processing of the ongoing task (e.g., both semantic/perceptual or one semantic and one perceptual, respectively; Meier & Graf, 2000; Meiser & Schult, 2008; Walter & Meier, 2016). Other factors that enhance monitoring are when the prospective memory task is ill-specified (i.e., belonging to a category) rather than well-specified (e.g., Hicks, Marsh, & Cook, 2005; Meier, Zimmermann, & Perrig, 2006), when a prospective memory cue is perceptually not salient rather than when it stands out (e.g., Einstein, McDaniel, Manzi, Cochran, & Baker, 2000), when cognitive load is high (Meier & Zimmermann, 2015), or when the importance of the prospective memory task is highlighted (see Walter & Meier, 2014).

1.2. Forgetting intentions and its development across the lifespan

Executive processes seem to be important also for the ability to forget intentions. Individual differences in executive functions have shown to be negatively related to the likelihood of failing to deactivate an intention (Scullin, Bugg, McDaniel, & Einstein, 2011; Scullin, Bugg, & Mcdaniel, 2012). In a typical intention-deactivation paradigm, participants are initially engaged in an ongoing activity with embedded prospective memory task, after which they are told that the prospective memory task requirement has been completed and that it is not to be performed anymore. Subsequently, they perform the same ongoing task again and occasionally, former prospective cues occur nevertheless as ongoing task stimuli. Responding to no-more-relevant prospective memory cues can produce aftereffects such as performance slowing or even commission errors which both reflect a failure to deactivate the intention (Scullin & Bugg, 2013; Scullin et al., 2011; Walser, Fischer, & Goschke, 2012).

To date, aftereffects on deactivated intentions have been investigated only in the adult lifespan (Bugg, Scullin, & McDaniel, 2013; Bugg, Scullin, & Rauvola, 2016; Scullin et al., 2011, 2012). For instance, in a series of studies, Scullin and colleagues compared young and older adults' ability to deactivate intentions after performing a lexical decision task including specific prospective memory cues which were focal to the ongoing task (e.g., pressing the *Q* key whenever the word "dancer" appears). Results showed that compared to young adults, older adults had significantly slower RTs to no-more-relevant prospective memory cues rather than to neutral ongoing task stimuli (Scullin et al., 2011). Moreover, older adults have shown to be more likely to make commission errors, that is, to erroneously respond to no-more-relevant prospective memory targets, compared to young adults (Bugg et al., 2016; Scullin et al., 2012). Age-related declines in the ability of deactivating intentions have shown to be more pronounced for salient focal and specific prospective memory cues than for non-salient ones (Scullin et al., 2012). Moreover, the likelihood to display more failures on deactivated intentions in older age has shown to be related to a decrease in executive functions, such as inhibitory control (Scullin et al., 2011).

According to the *intention superiority hypothesis* (Goschke & Kuhl, 1993) intention-related memory materials have a higher activation and persist longer after deactivation compared to other memory materials. Walser et al. (2012), who consistently found aftereffects in young adults with a paradigm including categorical (non-focal) cues, argued that the level of activation of an intention after its completion may be related to the amount of preparatory monitoring processes engaged during the active prospective memory phase. On the other hand, according to the multiprocess views (Einstein & McDaniel, 2005; McDaniel, Umanath, Einstein, & Waldum, 2015; Shelton & Scullin, 2017) monitoring processes are not necessarily needed to perform an intention, which can be spontaneously triggered by a strong link to the prospective memory cue. Consequently, a previously relevant intention can be spontaneously retrieved after being completed without a previous engagement of monitoring processes. Executive processes are then needed to inhibit the automatic response (Scullin & Bugg, 2013; Bugg et al., 2016). Spontaneous retrieval processes have shown to be well developed in children (see Mahy et al., 2014) and preserved in older adults (see McDaniel et al., 2015; Mullet et al., 2013). On the contrary, executive processes have shown to be disrupted in older adults and to be still developing in school-aged children (see Williams, Ponesse, Schachar, Logan, & Tannock, 1999; Zelazo et al., 2004). Consequently, it is likely that aftereffects of responding to deactivated intentions may be more pronounced in children and older adults than in young adults. However, aftereffects have never been investigated across the lifespan, and so far no study has tested whether the size of the aftereffect differs between high overlapping and low overlapping intentions.

1.3. The present study

The aim of the present study was to investigate both the ability to remember and to forget categorical and resource-demanding intentions as well as their related costs in different age groups across the lifespan. Based on the task-appropriate processing hypothesis (Maylor, 1996; Maylor et al., 2002), in Experiment 2, a further aim was to compare these effects across different prospective memory tasks with either high overlapping (i.e., focal) or low overlapping (i.e., non-focal) features to the ongoing task (cf. Meier & Graf, 2000; Walter & Meier, 2016). Towards these goals, we adopted a prospective memory task previously used in a lifespan study (Zimmermann & Meier, 2006). We then combined different experimental paradigms used for the investigation of monitoring (Loft, Kearney, & Remington, 2008) and aftereffects in prospective memory (e.g., Scullin et al., 2012). Consequently, we created a within-subjects experimental design which consisted of four consecutive blocks: 1) a baseline block, 2) a prospective memory block without the occurrence of prospective memory cues, 3) a prospective memory block with the occurrence of prospective memory cues; 4) a deactivation block in which unexpected no-more-relevant prospective memory cues (i.e., lures) occurred. In both Experiments, prospective memory cues were categorical (i.e., resource-demanding) and embedded in the same ongoing task which required perceptual stimulus processing. In Experiment 1, we compared prospective memory performance, monitoring costs and aftereffects on a task including semantic prospective memory cues (i.e., low overlapping). In Experiment 2, we compared performance on tasks including either semantic (i.e., low overlapping) or perceptual (i.e., high overlapping) prospective memory cues (between subjects).

First, we expected to replicate the inverted U-shaped trajectory of prospective memory development with a performance increase from childhood to young adulthood and a decrease in older age (Zimmermann & Meier, 2006, 2010). Since in both experiments prospective memory cues were categorical, thus quite resource demanding (Hicks et al., 2005), we expected a general ongoing task performance slowing as soon as the prospective memory instructions were given (Block 2) and that this would persist when the expected prospective memory targets were presented (Block 3). We anticipated that there would be differences in the extent of these costs across the lifespan. Children were expected to display fewer monitoring costs as well as lower prospective memory performance than young and older adults (Kretschmer-Trendowicz & Altgassen, 2016; Smith et al., 2010). Older adults were expected to engage less in monitoring and to have also lower prospective memory performance than young adults (Smith & Bayen, 2006). Second, we expected that all age groups would have slower RTs on no-more-relevant prospective memory cues (lures) than on neutral ongoing task trials in the prospective memory deactivation block (Block 4). Although using a different paradigm, Walser et al. (2012) consistently revealed aftereffects in young adults by using categorical cues. However, it is likely that aftereffects would be more pronounced in children and older adults because of their limited inhibitory control abilities (see Scullin et al., 2011).

In Experiment 2, in the semantic and low-overlapping condition, we expected to replicate findings of Experiment 1. On the other hand, we expected age differences in prospective memory performance and monitoring costs to be less pronounced in the perceptual and high-overlapping condition (Maylor et al., 2002). If this would be the case, this would support the task appropriate processing hypothesis and multiprocess view, according to which responding to prospective memory cues with high-overlapping features to the ongoing task should involve fewer monitoring resources than when cues have low-overlapping features (Maylor, 1996; Einstein & McDaniel, 2005; McDaniel et al., 2015). Moreover, we expected to replicate results of Experiment 1 concerning aftereffects in the semantic condition, with more pronounced RTs slowing on no more-relevant prospective memory targets in children and older adults. On the other hand, these effects were expected to be lower or absent in the perceptual condition, since aftereffects on high overlapping formerly-relevant prospective memory targets have not always been revealed, unless they were salient (Scullin et al., 2012).

2. Experiment 1

2.1. Method

2.1.1. Participants

One hundred three participants participated in Experiment 1. Eighteen were 7-year-old children (age range = 7-8; M_{age} = 7.80; SD = 0.25; 11 females), 21 were 8-year-old children (age range = 8-10; M_{age} = 8.48; SD = 0.38; 13 females), 21 were young adults (age range = 18-27; M_{age} = 22.35; SD = 2.77; 10 females), 21 were young-old adults (age range = 49-66; M_{age} = 59.69; SD = 6.40; 12 females) and 22 were older adults (age range = 67-75; M_{age} = 70.70; SD = 2.51; 15 females). Children were recruited in local schools, whereas both young and older adults were recruited by word of mouth. All participants had normal or correct-to-normal visual acuity and none reported to have any neurological disorder. For children we collected teachers' and parents' reports to ensure that none of them had developmental disorders. For all participants, German was the first spoken language. In addition to demographic information (which was collected for all participants), the Mini-Mental Examination (Folstein, Folstein, & McHugh, 1975) was administered to the young-old and older adults in order to evaluate the presence of cognitive impairments. None of them scored below 24 indicating that they had all normal cognitive functioning (M = 27.79, SD = 1.62). All participants, and for children their legal caretakers, gave informed consent for participating to the study. The study was approved by the ethics committee of the University of Bern (title of the project: "Executive Functions and prospective memory across the lifespan"; protocol number: 2016-10-000006).

2.1.2. Materials and procedure

As ongoing task, we used a picture comparison task adapted from Zimmermann and Meier (2006). The task consisted of a total of 209 colored identical or nearly identical easy-to-name picture pairs. Every picture pair was presented on a white background in the center of the screen. The non-identical picture pairs differed for one perceptual feature (for an example, see the second and third picture pair in the sequence in Fig. 1a). Half of the picture pairs were identical and half were not. The pictures represented everyday living and non-living things belonging to various categories (e.g., food, plants, buildings, toys, instruments, vehicles, etc.). The pictures were previously standardized and used in earlier studies including different age groups (e.g., Spiess et al., 2015, 2016; Zimmermann & Meier, 2006). From the 209 picture pairs, ten were used as practice trials, 190 for the ongoing task, six were used as prospective memory targets and three as prospective memory lures. Prospective memory targets and lures were picture pairs from the animal-category (i.e., dog, cow, frog, swan, deer, fox, cat, horse and chicken).

The picture comparison task was programmed and run on the E-prime software (Schneider, Eschman, & Zuccolotto, 2002). Each picture pair was presented one by one on a computer screen until a response was given, preceded by a fixation cross (250 ms) and followed by a blank screen (500 ms). The ongoing task consisted of deciding whether each picture pair was identical or not by pressing the C key highlighted in green or the M key highlighted in red, respectively. The prospective memory task consisted of pressing the Y key (instead of the red or green key) whenever a picture pair of an animal appeared during the ongoing task. The task lasted 25 − 30 min in total and was divided into four consecutive blocks with a 10 min break between Block 1 and 2 (prospective memory task instructions and filler task) and between Block 3 and 4 (prospective memory task deactivation instructions). Fig. 1b shows a schematic representation of the experimental procedure.

Every participant was prompted to be as fast and accurate as possible. Instructions were given as follows: First, participants received information for the ongoing task only. They were instructed to press the green key for identical and the red key for non-identical picture pairs. After performing a practice block consisting of ten trials, they performed Block 1 (baseline block), including 30 ongoing task trials. After that, instructions for the prospective memory task (Block 2 and Block 3) were provided. Participants were instructed to press the Y key, instead of the green or red key, whenever the picture pair of an animal appeared during the ongoing task. Participants were required to repeat prospective memory instructions in their own words to ensure that they understood the task procedure. Before beginning the prospective memory blocks, a filled retention interval of about 10 min was created by using a paper-pencil task (spatial reasoning task). Subsequently, participants began to perform the prospective memory blocks (Block 2 and 3). The two blocks were presented sequentially without interruptions. Block 2 included only ongoing task stimuli (n = 30), whereas Block 3 included 90 ongoing task stimuli and six additional prospective memory targets. The latter were presented randomly but always on the same position, that is, every 15 trials starting from the beginning of Block 3. Although the two blocks were presented to the participants as one block, during analysis we divided it in two parts, in order to evaluate the effects of the presence or absence of prospective memory targets. After performing Block 2 and 3, there was a brief interruption, in which participants were first asked to recall task instructions, in order to be sure that prospective memory failures were not due to misunderstanding or forgetting of prospective memory instructions (see Kvavilashvili, Kyle, & Messer, 2008); and second, they were introduced to Block 4. They were instructed not to respond to the prospective memory targets anymore. This block consisted of 30 ongoing task trials and three prospective memory lures which belonged to the animal category but were different from the specific stimuli presented as prospective memory targets. Prospective memory lures were presented every ten ongoing task trials, randomly but always on the same position starting from the sixth trial in the sequence. Ongoing task trials in each block and also those presented between the prospective

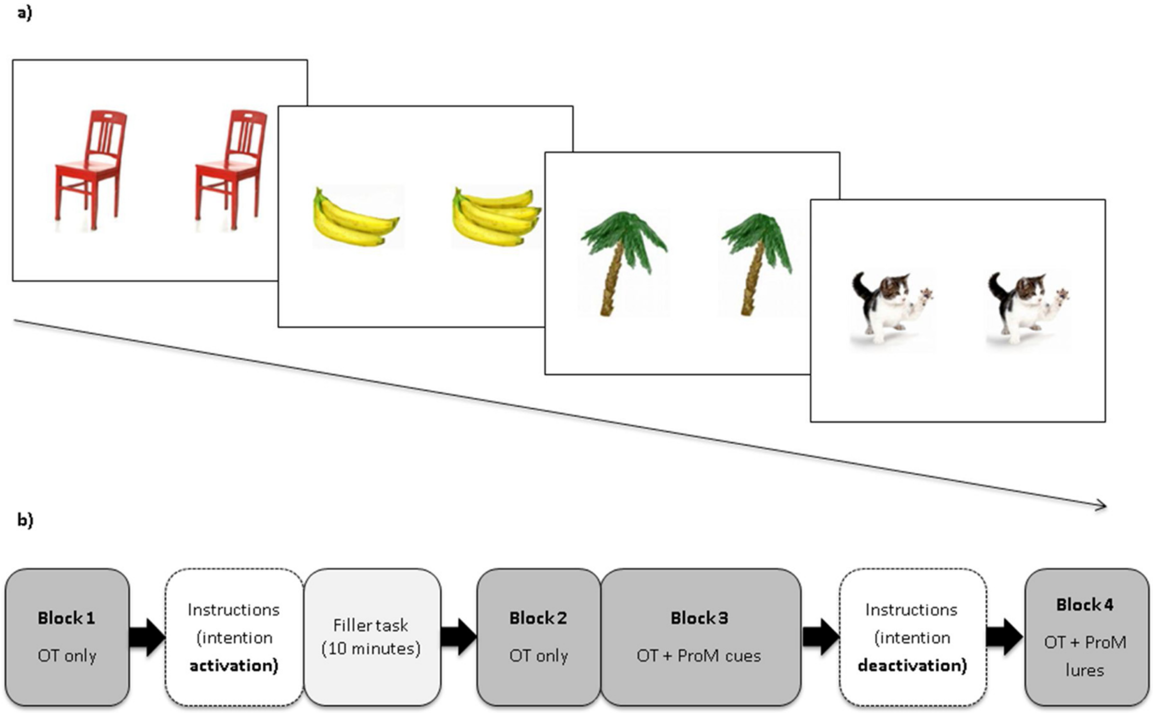

Fig. 1. (a) Schematic representation of the ongoing task (OT) including sequentially (from left to right) an identical, two non-identical, and one identical picture pair. The first and second picture pair (i.e., red chair and yellow bananas, respectively) are examples for prospective memory (ProM) cues used in Experiment 2 for the perceptual condition where the prospective memory task consisted of pressing the Y key whenever a red/yellow object occurred. The last picture pair (i.e., cat) is an example for a prospective memory cue for the semantic condition (Experiment 1 and 2). **(b)** Schematic representation of the experimental procedure including the four consecutive blocks: Block 1 (baseline; $n = 30$); Block 2 (prospective memory block without expected prospective memory targets; $n = 30$); Block 3 (prospective memory block with expected prospective memory targets; 90 OT and 6 ProM stimuli); Block 4 (intention deactivation block with unexpected prospective memory lures; 30 OT stimuli and 3 ProM lures) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

memory targets and lures were pseudo-randomized and balanced, so that in each block half of the stimuli were identical and half were not. Of the prospective memory targets and lures, 4 were composed of identical pairs and 5 were not.

2.2. Data analysis

For ongoing task and prospective memory performance, we computed–for each participant separately–accuracy (proportion of correct responses), mean response times (RTs) in milliseconds (ms) for correct responses only. Ongoing task RTs which were faster than 300 ms and slower than 2 standard deviations (*SD*) above the individual's mean were excluded in order to control for abnormal RTs (see Einstein et al., 2005). Moreover, the three ongoing task stimuli following each prospective memory cue were excluded from RT analyses in order to remove task-switching-related costs (Meier & Rey-Mermet, 2012, 2018). Subsequently, data were screened and corrected for outliers within each age group. Three children, two young adults and two older adults were excluded because their ongoing task accuracy or RTs was respectively 2 *SD* below or above the sample group's mean value. The final sample consisted of 96 participants, eighteen 7-year-old and eighteen 8-year-old children, nineteen young adults, twenty young-old and twenty-one older adults. Additional to raw scores, we calculated rate residual scores which include information regarding both accuracy and speed by calculating the difference between rates of correct responses per second for ongoing task blocks (Hughes, Linck, Bowles, Koeth, & Bunting, 2014). Higher rate residual scores represent lower costs, that is, a more efficient performance.

Monitoring costs were analyzed by comparing ongoing task performance differences between Block 1 (i.e., baseline) and Block 2 (i.e., prospective memory block without the occurrence of prospective memory cues), and between Block 1 and Block 3 (i.e., prospective memory block with the occurrence of prospective memory cues). For evaluating aftereffects on deactivated intentions, we compared performance on no-more-relevant prospective memory targets (lures) with all neutral ongoing task trials in Block 4 (intention deactivation block), with exception of the three trials following each lure. Additionally, ongoing task performance in Block 4 (i.e., deactivation block) was compared with the baseline. For all statistical analyses we set an alpha level of 0.05 and effect sizes are indicated as partial η^2 values. Greenhouse-Geisser adjustments are reported where required.

Table 1
Prospective memory and ongoing task performance across the lifespan in Experiment 1.

Age group	n	ProM accuracy	ProM RTs	ProM rate residual score
7-year-old children	18	0.60 (0.06)	2258 (303)	0.26 (0.05)
8-year old children	18	0.63 (0.06)	2503 (303)	0.26 (0. 05)
Young adults	19	0.88 (0. 06)	1321 (269)	0.64 (0. 05)
Young-old adults	20	0.87 (0. 06)	3851 (269)	0.44 (0. 05)
Older adults	21	0.87 (0. 06)	5518 (255)	0.42 (0. 05)

Note: Mean proportion of correct responses (and standard errors) for prospective memory (ProM) and ongoing task (OT) performance (accuracy, RTs in ms, and rate residual scores).

3. Results and discussion

3.1. Prospective memory performance across the lifespan

Prospective memory performance is displayed in Table 1 separately for each age group. An Analysis of Variance (ANOVA) with the between-subjects factor age group was performed on prospective memory proportion of correct responses, RTs and rate residual scores separately. For *proportion of correct prospective memory responses* the effect of age group was significant, $F(4, 91) = 5.15$, $p = 0.001$, $\eta_p^2 = 0.19$. Post-hoc tests showed that 7- and 8-year-old children had similar accuracy rates ($p = .775$), and that both groups of children had lower accuracy rates than young, young-old and older adults ($p < .01$). The three adult groups did not differ in accuracy ($p > .10$). The effect of age group was significant also for *RTs* of correctly detected prospective memory targets, $F(4, 84) = 37.92$, $p < 0.001$, $\eta_p^2 = 0.64$. Post-hoc tests showed that 7- and 8-year-old children had equal RTs to prospective memory targets ($p = .568$) and that they were significantly slower than the three adult groups ($p < .05$). Young adults had the fastest prospective memory RTs. They were significantly faster than the two groups of children ($p < .05$) and the two groups of older adults ($p < .001$). The older adults had the slowest RTs. They were significantly slower than young-old adults, young adults and the two groups of children ($p < .001$). Analyses on *rate residual scores* for prospective memory performance revealed a significant effect of age group $F(4, 91) = 9.83$, $p < .001$, $\eta_p^2 = .30$. The two groups of children did not differ ($p = .992$), whereas young adults outperformed both children ($p < .001$) and the two groups of older adults ($p < .01$). Young-old and older adults also did not differ ($p = .757$) but outperformed the two groups of children ($p < .05$).

Consistent with previous lifespan studies, prospective memory performance improved considerably from childhood to adulthood (e.g., Smith et al., 2010; Zimmermann & Meier, 2006). Although older adults had slower RTs compared to young adults and children, their prospective memory performance did not show a significant decrease compared to young adults. This was against our expectations but was in line with some previous studies. In fact, adult lifespan studies have sometimes reported mixed results, indicating that there is not always an evident decline in prospective memory performance with increasing age (e.g., Einstein & McDaniel, 1990; Kretschmer-Trendowicz & Altgassen, 2016). Many studies have shown that older adults struggle to engage monitoring processes over longer periods due to their limited executive functions (e.g., Bisiacchi et al., 2008; Smith & Bayen, 2006). On the other hand, there is evidence that spontaneous retrieval processes are preserved in older adults (e.g., Mullet et al., 2013) and this might play a role in eliciting temporary monitoring permitting to successfully perform a prospective memory task (see Shelton & Scullin, 2017). Recent studies have also shown that stressing the importance of responding to a prospective memory task during the ongoing task can also reduce age-related differences across the adult lifespan (see Walter & Meier, 2014). Since the instructions focused on the prospective memory task in the present study, it is likely that this has contributed to the lack of age-related differences between young and older adults.

3.2. Monitoring costs and ongoing task performance across the lifespan

Table 2 shows mean ongoing task performance across blocks as well as monitoring costs in Block 2 and Block 3, represented by the difference scores in RTs with the baseline block (Block 1). To evaluate monitoring costs in Block 2 and 3 we compared ongoing task RTs between Block 1 and Block 2, and Block 1 and Block 3, respectively, performing a series of mixed ANOVAs with the within-subjects factor block and between-subjects factor age group.

3.2.1. Monitoring costs in Block 2

Statistical analysis on *RTs* revealed a significant effect of block and age group, $F(1,91) = 6.59$, $p = 0.012$, $\eta_p^2 = 0.07$, $F(4, 91) = 3.85$, $p = 0.006$, $\eta_p^2 = 0.15$, respectively, whereas the Block × Age Group interaction was not significant, $F(4, 91) = 1.04$, $p = 0.393$, $\eta_p^2 = 0.04$. Post-hoc tests showed that all age groups had significantly slower ongoing task RTs in Block 2 than in the baseline, indicating that they were all monitoring as soon as instructions for the prospective memory task were given. Post-hoc tests on the effect of age group showed that young adults were generally faster than young-old and older adults and 8-year-old children ($p < .05$). On the other hand, young adults did not differ from 7-year-old children ($p = .394$) who were generally faster than 8-year-old children ($p = .035$) and young-old adults ($p = .026$) but similar to older adults ($p = .149$). Analyses on *accuracy* showed that only the effect of age group was significant, $F(4, 91) = 21.17$, $p < .001$, $\eta_p^2 = .49$. Neither the effect of block nor the Block × Age interaction were significant, $F(1, 91) = 1.33$, $p = .251$, $\eta_p^2 = .01$, $F(4, 91) = 1.51$, $p = .207$, $\eta_p^2 = .06$, respectively. The two children's

Table 2
Ongoing task performance in each block and monitoring costs across the lifespan in Experiment 1.

	Age group				
	7-year-old children	8-year-old children	Young adults	Young-old adults	Older adults
Response Times					
Block 1	3558 (232)	4158 (232)	3146 (226)	4211 (220)	4001 (215)
Block 2	3599 (228)	4342 (228)	3483 (222)	4323 (216)	4034 (211)
Block 3	3588 (242)	4061 (242)	3427 (236)	4506 (230)	4149 (224)
Block 4	3206 (237)	3515 (237)	3169 (230)	4179 (225)	4023 (219)
Monitoring in Block 2	+ 41 (127)	+ 184 (127)	+ 337 (124)	+ 112 (120)	+ 33 (118)
Monitoring in Block 3	+ 30 (151)	− 97 (151)	+ 281 (147)	+ 295 (143)	+ 148 (139)
Accuracy					
Block 1	0.76 (0.02)	0.76 (0.02)	0.91 (0.02)	0.90 (0.02)	0.83 (0.02)
Block 2	0.78 (0.01)	0.81 (0.01)	0.90 (0.01)	0.88 (0.01)	0.84 (0.01)
Block 3	0.76 (0.01)	0.78 (0.01)	0.90 (0.01)	0.88 (0.01)	0.83 (0.01)
Block 4	0.69 (0.02)	0.73 (0.02)	0.89 (0.02)	0.83 (0.02)	0.81 (0.02)
Rate residual scores					
Block 1	0.26 (0.02)	0.21 (0.02)	0.32 (0.02)	0.22 (0.02)	0.24 (0.02)
Block 2	0.26 (0.02)	0.22 (0.02)	0.29 (0.02)	0.22 (0.02)	0.24 (0.01
Block 3	0.24 (0.02)	0.22 (0.02)	0.30 (0.02)	0.20 (0.01)	0.23 (0.01)
Block 4	0.25 (0.02)	0.22 (0.02)	0.31 (0.02)	0.20 (0.02)	0.23 (0.02)

Note: Response times (RTs) are presented in milliseconds and for accuracy, means (and standard errors) for proportions of correct responses are reported. Monitoring costs represent the difference score between mean performance in Block 1 (baseline block) and the two prospective memory blocks (Block 2 and 3). Positive values indicate that performance was slower in the prospective memory block compared to the baseline block (i.e., monitoring costs).

group performed similarly (p = .399), young adults performed similar to young-old adults (p = .394) who both outperformed children and older adults ($p < .01$). Analyses on *rate residual scores* showed significant effects of age $F(4, 91) = 5.95$, $p < .001$, $\eta_p^2 = .21$ and of the Block × Age interaction $F(4, 91) = 3.081$, $p = .020$, $\eta_p^2 = .119$. The effect of block was not significant, $F(1, 91) = 0.88$, $p = .351$, $\eta_p^2 = .01$. Young adults were more efficient than children and older adults ($p < .05$). The two older adults' groups did not differ ($p = .344$) being also similar to the children's groups ($p > .100$). Seven- and 8-year-old children did not differ significantly ($p = .07$). Post-hoc comparisons on the Block × Age interaction showed that only young adults were less efficient in Block 2 compared to Block 1 ($p = .001$), while children's and older adults' rate residual scores were similar in Block 1 and 2 ($p > .10$).

3.2.2. Monitoring costs in Block 3

Statistical analyses on *RTs* revealed a significant effect of block and age group, $F(1, 91) = 4.05$, $p = 0.047$, $\eta_p^2 = 0.04$, $F(4, 91) = 4.03$, $p = 0.005$, $\eta_p^2 = 0.15$, respectively, whereas the Block × Age Group interaction was not significant, $F(4, 91) = 1.28$, $p = .286$, $\eta_p^2 = .05$. Post-hoc tests showed that all age groups had significantly slower ongoing task RTs in Block 3 than in the baseline, indicating that they all continued to monitor for the prospective memory targets. In general, young adults were faster than 8-year-old children and older adults ($p < .05$), while they did not differ from 7-year-olds ($p = .363$), who had similar RTs to 8-year-olds ($p = .096$) and older adults ($p = .106$) and were faster than young-old adults ($p = .013$). Analyses on *accuracy* showed that only the effect of age group was significant, $F(4, 91) = 27.73$, $p < .001$, $\eta_p^2 = .55$. Neither the effect of block nor the Block × Age interaction were significant (all Fs < 1.00). The two children's group did not differ ($p = .547$); young adults and young-old adults did not differ ($p = .378$), but outperformed children and older adults ($p \leq .001$). Analyses on *rate residual scores* revealed that the effects of block and age group were significant, $F(1,91) = 8.47$, $p = 0.005$, $\eta_p^2 = 0.09$, $F(4, 91) = 7.18$, $p < 0.001$, $\eta_p^2 = 0.24$, while their interaction was not, $F(4, 91) = 1.78$, $p = 0.141$, $\eta_p^2 = 0.07$. All age groups were less efficient in Block 3 compared to Block 1 and adults were generally more efficient than children and older adults ($p < .01$) who did not differ significantly ($p > .10$).

3.2.3. Ongoing task performance after deactivation (Block 4)

Analyses on *RTs* showed that the effect of block, the Block × Age Group interaction and the effect of age were significant, $F(1, 91) = 6.51$, $p = .012$, $\eta_p^2 = .07$, $F(4, 91) = 2.85$, $p = .028$, $\eta_p^2 = .11$, $F(4, 91) = 4.31$, $p = .003$, $\eta_p^2 = .16$, respectively. Post-hoc analyses on the Block × Age Group interaction showed that the two children's groups became significantly faster in Block 4 compared to the baseline ($p < .05$), while young, young-old and older adults had similar RTs in the baseline and Block 4 ($p > .100$). Analyses on *accuracy* revealed the significant effects of block and age group, $F(1, 91) = 19.22$, $p < .001$, $\eta_p^2 = .17$, $F(4, 91) = 20.99$, $p < .001$, $\eta_p^2 = .48$, whereas the Block × Age Group interaction was not significant $F(4, 91) = 1.27$, $p = .287$, $\eta_p^2 = .05$. The two children's group performed similarly ($p = .315$), young adults performed similar to young-old adults ($p = .100$) who both outperformed children and older adults ($p < .05$). Analyses on *rate residual scores* showed that only the effect of age group was significant $F(4, 91) = 7.85$, $p < 0.001$, $\eta_p^2 = 0.26$, whereas neither the effect of block nor the Block × Age Group interaction were significant, $F(1,91) = 1.78$, $p = 0.185$, $\eta_p^2 = 0.02$, and $F(4, 91) = 0.89$, $p = 0.472$, $\eta_p^2 = 0.04$. Young adults were more efficient than all the other groups ($p < .01$), whereas children did not differ ($p > .100$).

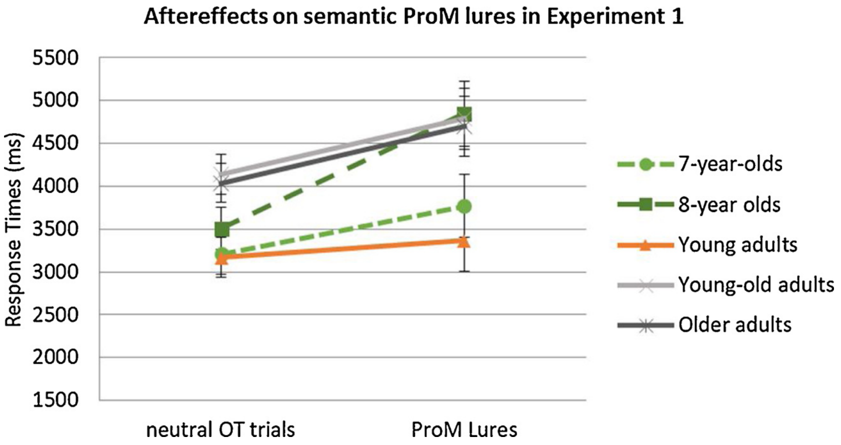

Fig. 2. Aftereffects on deactivated intentions in Experiment 1. Mean response times of correct responses only to neutral ongoing task (OT) trials and prospective memory (ProM) lures in Block 4 separately for each age group. Error bars represent standard errors.

In line with previous studies, results showed that ongoing task performance slowed down when a prospective memory task was added (Kretschmer-Trendowicz & Altgassen, 2016; Smith & Bayen, 2006; Smith et al., 2010; Zimmermann & Meier, 2010). Importantly, this slowing was revealed in all age groups and in both prospective memory Blocks (Block 2 and 3), indicating that they were all monitoring to detect the prospective memory targets. This result was partly confirmed by the analyses on rate residual scores which showed that in Block 3 all age groups performed less efficiently whereas in Block 2 only adults displayed a performance cost compared to the baseline. However, children's monitoring abilities seem to be less developed and less functional compared to young and older adults. Although children engaged in monitoring, their prospective memory performance was lower than for young and older adults. This may indicate that children are less able to engage strategic monitoring processes (see Mahy et al., 2014). Results on accuracy rates revealed that children were less accurate than young and older adults in performing the ongoing task. This may indicate that the task was more difficult for children and that they may had less available resources to successfully perform the prospective memory task. At this age, executive resources are still limited and it is likely that they deplete gradually when a task is particularly demanding (see Brocki & Bohlin, 2004).

3.3. Aftereffects on deactivated intentions across the lifespan

To evaluate aftereffects on deactivated prospective memory targets in Block 4, we compared performance (RTs, accuracy, and rate residual scores) on neutral ongoing task trials with those on former prospective memory targets (lures), that is, trials belonging to the animal category but different from the specific stimuli used for the prospective memory task. Mixed ANOVAs were performed considering trial type in Block 4 (neutral, lures) as within-subjects factor and age group (7- and 8-year-old children, young, young-old and older adults) as between-subjects factor. Mean RTs of each age group to neutral ongoing task stimuli and lures in Block 4 are shown in Fig. 2.

The analysis on *RTs* revealed that the effects of both trial type and age group were significant, with $F(1, 88) = 27.45$, $p < .001$, $\eta_p^2 = .24$, and $F(4, 88) = 4.12$, $p = .004$, $\eta_p^2 = .16$, respectively. The interaction between trial type and age group was not significant, $F(4, 88) = 1.92$, $p = .114$, $\eta_p^2 = .08$. All age groups had significantly slower RTs on prospective memory lures than on neutral ongoing task trials ($p < .001$). Young adults were generally faster than 8-year-old children ($p = .021$), young-old ($p = .002$) and older adults ($p = .004$). Seven-year-old children tended to be faster than 8-year-old children ($p = .081$) and were significantly faster than young-old ($p = .012$) and older adults ($p = .021$). Finally, 8-year-old children's RTs did not differ from those of young-old and older adults ($p > .10$).

Mean *accuracy* on prospective memory lures in Block 4 was 0.51 ($SE = 0.06$) for 7-year-old children, 0.57 ($SE = 0.06$) for 8-year-old children, 0.84 ($SE = 0.06$) for young adults, 0.80 (0.06) for young-old adults, and 0.68 (0.06) for older adults. Only one child and one older adult made commission errors, resulting in a total of proportions of errors of 0.04 ($SE = .04$) and 0.01 ($SE = .01$) for the child and the older adult, respectively. The ANOVA on *accuracy* revealed significant effects of trial type and age group, with $F(1, 91) = 16.81$, $p < .001$, $\eta_p^2 = .16$, and $F(4, 91) = 10.42$, $p < .001$, $\eta_p^2 = .31$, respectively. The Trial Type × Age Group interaction was not significant, $F(4, 91) = 1.32$, $p = .270$, $\eta_p^2 = .06$. Performance of all age groups was lower when responding to prospective memory lures compared to neutral ongoing task stimuli ($p < .001$). Performance differed significantly between the five age groups, with young adults having generally higher accuracy rates than children ($p < .001$) and older adults ($p = .011$) and performing similar to young-old adults ($p = .277$). The two groups of children had similar accuracy rates ($p = .294$) but performed worse than adults ($p < .001$), young-old ($p < .001$), and older adults ($p < .001$). Finally, young-old and older adults' accuracy rates were not significantly different ($p = .131$). Mean *rate residual scores* for lures in Block 4 were: 0.15 ($SE = 0.02$) for 7-year-old children, 0.15 ($SE = 0.02$) for 8-year-old children, 0.28 ($SE = 0.02$) for young adults, 0.18 ($SE = 0.02$) for young-old adults and 0.17 (0.02) for older adults. Analyses revealed significant effects for trial type and age group, $F(1, 90) = 34.63$, $p < .001$, $\eta_p^2 = .28$, $F(4, 90) = 7.97$,

$p < .001$, $\eta_p^2 = .26$, and a trend to the significance threshold for the Trial Type × Age Group interaction, $F(4, 90) = 2.22$, $p = .073$, $\eta_p^2 = .09$. Post-hoc analyses showed that all age groups were less efficient when responding to lures than to neutral ongoing task trials in Block 4 ($p < .001$). Age-group comparisons showed that young adults were generally more efficient than children and young-old and older adults ($p < .001$). On the other hand, 7- and 8-year-old children, young-old, and older adults had all similar rate residual scores ($p > .100$).

Our results showed that RTs were significantly slower on former prospective memory trials compared to neutral ongoing task trials. Although commission errors were rare (less than 1 %), we found that accuracy rates were considerably lower on prospective memory lures compared to neutral trials. In line with our hypothesis, aftereffects were present in all age groups. Although the interaction between age group and trial type in the deactivation block did not reach the significance threshold, the pattern seemed to suggest that young adults' aftereffects were less pronounced than in the other age groups. This may have been due to the heterogeneity of the age groups in the present experiment.

In order to follow up on this interpretation, we reduced age-variance between and within groups in Experiment 2. Moreover, as in Experiment 1, the ongoing task stimuli were presented in a fixed pseudo-randomized order, it is possible that the performance slowing may have been due to trial characteristics, such as difficulty, presentation order or familiarity of the category to which the prospective memory lures belonged. To rule out this possible source of bias, in Experiment 2, we used a completely randomized presentation order. In addition, in Experiment 2, we manipulated the overlap between prospective memory and ongoing task using either low-overlapping (i.e., semantic) or high-overlapping (i.e., perceptual) prospective memory cues. Besides expecting to replicate results of Experiment 1 in the semantic condition, we anticipated prospective memory performance and monitoring costs to be less pronounced in the perceptual and high overlapping condition than in the semantic and low overlapping condition (Maylor, 1996; McDaniel & Einstein, 2000; McDaniel et al., 2015; Meier & Graf, 2000; Meiser & Schult, 2008). Moreover, we expected aftereffects to be less marked or even absent in the perceptual condition since aftereffects were not always found with high overlapping (i.e., focal) cues (e.g., Scullin, Einstein, & McDaniel, 2009, Scullin et al., 2012).

4. Experiment 2

4.1. Method

4.1.1. Participants

A total of 182 participants took part in Experiment 2. None of them had participated in Experiment 1. Sixty-four were children aged between 6 and 9 years ($M_{age} = 7.27$; $SD = 0.86$; 35 females), 60 were young adults aged between 18 and 27 years, ($M_{age} = 21.02$; $SD = 2.03$; 32 females), and 58 were older adults between 65 and 79 years of age ($M_{age} = 70.29$; $SD = 3.80$; 30 females). Recruiting procedure was similar to that in Experiment 1. All participants had normal or correct-to-normal visual acuity and none reported to have any neurological disorder. For children we collected teachers and parents' reports to ensure that none of them had developmental disorders. For all participants, German was the first spoken language. In addition to demographic information (which was collected for all participants), the Mini-Mental Examination was administered to the older adults in order to evaluate the presence of cognitive impairments (Folstein et al., 1975). Mean value for the Mini-Mental Examination was 27.54 ($SD = 2.36$). Participants were randomly assigned to either the semantic (i.e. animals or ships) or the perceptual (i.e. yellow or red) condition. All participants, and for children their legal caretakers, gave informed consent for participating to the study, and the local ethics committee approved the execution of the study (see participants section of Experiment 1).

4.1.2. Materials and procedure

Materials and procedure were similar to those used in Experiment 1 with the exception of prospective memory cues and randomization. In Experiment 2, participants were divided into two groups: one group had to perform a categorical and semantic (i.e., low overlapping) prospective memory task (i.e., pressing the Y key whenever a predefined category appeared); and the other group performed a categorical and perceptual (i.e., high overlapping) prospective memory task (i.e., pressing the Y key whenever the pictures had a predefined color). In the perceptual condition, the prospective memory cues were either red (i.e., chair, fire truck, cherry, can, shoes, double-decker, frisbee, fire-extinguisher, lawn mower) or yellow objects (i.e., flower, bobsled, violin, helmet, lemonade, racing car, school bus, torch, measuring tape). In the semantic condition prospective memory cues belonged to the animal (same as in Experiment 1) or the ships category (i.e., steamboat, Greek ship, gondola, motorboat, sailboat, submarine, yacht, large cruise liner, small cruiser). As in Experiment 1, prospective memory cues and lures were presented randomly but always on the same position. In contrast to Experiment 1, ongoing task trials were completely randomized (rather than pseudo-randomized in a fixed order).

4.1.3. Data analysis

For ongoing task and prospective memory performance, we computed–for each participant separately–accuracy (proportion of correct responses), mean RTs for correct responses only and rate residual scores. Similar to Experiment 1, ongoing task RTs were corrected for outliers by eliminating RTs which were faster than 300 ms and slower than 2 *SD* above each participants' mean (Einstein et al., 2005). Additionally, the three ongoing task stimuli presented immediately after each prospective memory cue were excluded from RT analyses in order to remove task-switching-related costs (Meier & Rey-Mermet, 2012, 2018). Subsequently, data were screened and corrected for outliers within each age group. Seven children, three young adults and six older adults were excluded because their OT performance was either 2 *SD* above or below the group's mean value. Out of these, four children, one young adult,

Table 3
Prospective memory and ongoing task performance across the lifespan and conditions in Experiment 2.

Age group	Condition	n	ProM accuracy	ProM RTs	Rate residual score
Children	Semantic	32	0.61 (0.05)	2210 (134)	0.27 (0.04)
	Perceptual	25	0.45 (0.05)	2753 (172)	0.21 (0.04)
Young adults	Semantic	30	0.85 (0.05)	1568 (129)	0.57 (0.04)
	Perceptual	27	0.83 (0.05)	1423 (136)	0.60 (0.04)
Older adults	Semantic	27	0.80 (0.05)	2294 (136)	0.35 (0.04)
	Perceptual	25	0.76 (0.05)	2764 (142)	0.31 (0.04)

Note: Mean proportion of correct responses (and standard errors) for prospective memory (ProM) and ongoing task (OT) performance (accuracy, RTs in ms, and rate residual scores).

and three older adults had more than 13 % of false alarms on the ongoing task (i.e., pressing the Y key on ongoing task trials). The final sample consisted of 166 participants, 57 children, 57 adults, and 52 older adults. For statistical analyses, we used the same approach as in Experiment 1, with the additional between-subjects factor condition (semantic vs. perceptual). Participants were randomly assigned to these conditions.

5. Results and discussion

5.1. Prospective memory performance across the lifespan as a function of prospective memory cue type

Prospective memory performance is displayed in Table 3 separately for each age group and condition. ANOVAs with the between-subjects factors age group and condition (semantic, perceptual) were performed on prospective memory performance and RTs separately. For *proportion of correct prospective memory responses*, the effect of age group was significant, $F(2, 160) = 20.97$, $p < .001$, $\eta_p^2 = .21$, whereas both condition and the Age Group × Condition interaction did not reach significance, $F(1, 160) = 3.09$, $p = .081$, $\eta_p^2 = .02$ and $F(2, 160) = 1.31$, $p = .273$, $\eta_p^2 = .02$, respectively. Children had significantly lower prospective memory performance than young adults and older adults ($p < .001$). The latter two groups did not differ significantly ($p = .220$). For prospective memory *RTs*, the effects of age group, condition and the Age Group × Condition interaction were significant, with $F(2, 148) = 36.17$, $p < 0.001$, $\eta_p^2 = 0.33$, for age group, $F(1, 148) = 6.20$, $p = 0.014$, $\eta_p^2 = 0.04$, for condition, and $F(2, 148) = 3.73$, $p = 0.026$, $\eta_p^2 = 0.05$, for their interaction. Young adults had faster RTs to prospective memory targets than children and older adults ($p < .001$), whereas the two latter groups did not differ significantly ($p = .750$). RTs were significantly slower on perceptual than on semantic prospective memory targets ($p = .014$). Pairwise comparisons revealed that the difference in RTs between semantic and perceptual prospective memory targets was significant in children ($p = .014$) and older adults ($p = .018$) but not in young adults ($p = .442$). Analyses on *rate residual scores* revealed that the effect of age group was significant, $F(1, 160) = 39.10$, $p < .001$, $\eta_p^2 = .33$, whereas neither the effect condition nor the Age group × Condition interaction were significant, $F(1, 160) = 0.40$, $p = .531$, $\eta_p^2 < .01$, and $F(1, 160) = 0.58$, $p = .564$, $\eta_p^2 < .01$, respectively. Young adults performed significantly better than older adults and children ($p < .001$), who performed worse than older adults ($p = .025$).

In general, the results replicated those in Experiment 1, with prospective memory performance improving from childhood to young adulthood, and remaining stable in older age. Although older adults had slower prospective memory RTs than young adults, their prospective memory performance did not differ. The results of the perceptual condition were similar to the semantic condition but since both the ongoing and the prospective memory task required perceptual processing we had expected an overlap advantage in prospective memory performance (see McBride & Abney, 2012, for similar results). A closer look at the descriptive data on prospective memory performance suggests that performing the perceptual prospective memory task may have been even more difficult than performing the semantic task, in particular for children and older adults. This was also evident in the RTs analysis, showing that children and older adults were significantly slower on perceptual compared to semantic prospective memory targets, while young adults' RTs did not differ between conditions. It is likely that children and older adults struggled to recognize and memorize the target colors. This interpretation is supported by the lower ongoing task performance of both children and older adults compared to young adults. Moreover, it is worth to mention that compared to young adults ($n = 1$), a higher number of children ($n = 4$) and older adults ($n = 3$) had more than 13 % of false alarms on the ongoing task, that is, pressing the Y key on ongoing task trials (these were previously excluded from analyses because they resulted as outliers from the data screening procedure). Although stimuli which had similar colors to the target stimuli or had yellow or red parts were a priori excluded from the ongoing task, children and older adults made more false alarms on brown stimuli. This suggests that they may have mistaken them for yellow or red ones.

5.2. Monitoring costs and ongoing task performance across the lifespan as a function of prospective memory cue type

Table 4 shows mean ongoing task performance in the four blocks as well as monitoring costs represented by the difference scores between RTs in Block 1 (baseline) and the two prospective memory blocks separately for each age group and condition. To evaluate monitoring costs in Block 2 and 3 we compared ongoing task RTs between Block 1 and Block 2 and Block 1 and Block 3, respectively, performing a series of mixed ANOVAs on ongoing task RTs with the within-subjects factor block and between-subjects factors age group (children, young adults, older adults) and condition (semantic, perceptual).

Table 4
Ongoing task performance in each block and monitoring costs across the lifespan and conditions in Experiment 2.

	Age group					
	Children		Young adults		Older adults	
	Semantic	Perceptual	Semantic	Perceptual	Semantic	Perceptual
Response Times						
Block 1	3213 (182)	2755 (205)	2928 (188)	3168 (198)	4191 (198)	3994 (205)
Block 2	3420 (186)	3177 (210)	3434 (192)	3352 (202)	4650 (202)	4205 (210)
Block 3	3126 (165)	2950 (186)	2993 (170)	2950 (179)	4425 (179)	4054 (186)
Block 4	3018 (157)	2542 (178)	3024 (162)	2863 (171)	4243 (171)	3924 (178)
Monitoring Block 2	+ 207 (122)	+ 422 (157)	+ 506 (95)	+ 184 (94)	+ 459 (157)	+ 211 (133)
Monitoring Block 3	− 87 (137)	+ 195 (147)	+ 65 (126)	− 218 (133)	+ 234 (167)	+ 60 (139)
Accuracy						
Block 1	0.75 (0.02)	0.67 (0.02)	0.84 (0.02)	0.83 (0.02)	0.83 (0.02)	0.80 (0.02)
Block 2	0.74 (0.02)	0.66 (0.02)	0.88 (0.02)	0.84 (0.02)	0.84 (0.02)	0.77 (0.02)
Block 3	0.71 (0.01)	0.66 (0.01)	0.88 (0.01)	0.83 (0.01)	0.86 (0.01)	0.81 (0.01)
Block 4	0.71 (0.02)	0.63 (0.02)	0.90 (0.02)	0.85 (0.02)	0.88 (0.02)	0.84 (0.02)
Rate residual scores						
Block 1	0.27 (0.01)	0.28 (0.02)	0.32 (0.02)	0.30 (0.02)	0.22 (0.02)	0.21 (0.02)
Block 2	0.25 (0.01)	0.26 (0.02)	0.31 (0.02)	0.30 (0.02)	0.20 (0.02)	0.20 (0.02)
Block 3	0.26 (0.01)	0.26 (0.02)	0.33 (0.01)	0.31 (0.02)	0.21 (0.02)	0.21 (0.02)
Block 4	0.27 (0.02)	0.28 (0.02)	0.35 (0.02)	0.33 (0.02)	0.21 (0.02)	0.22 (0.02)

Note: Means (and standard errors) of RTs on ongoing task trials (correct responses only). RTs are presented in milliseconds. Monitoring costs in Block 2 represent the difference between mean performance in Block 2 (prospective memory expectation block) and Block 1 (baseline block). Monitoring costs in Block 3 represent the difference between mean performance in Block 3 (prospective memory task block) and Block 1 (baseline block). Positive values indicate that performance was slower in the prospective memory blocks compared to the baseline block (i.e., monitoring costs).

5.2.1. Monitoring costs in Block 2

Statistical analysis on *RTs* revealed a significant effect of block and age group, $F(1, 160) = 40.54$, $p < 0.001$, $\eta_p^2 = 0.20$, $F(2, 160) = 21.54$, $p < 0.001$, $\eta_p^2 = 0.21$, respectively. The Block × Age Group × Condition interaction did not reach the significance threshold, $F(2, 160) = 2.48$, $p = 0.087$, $\eta_p^2 = 0.03$, whereas the effect of condition, and all the remaining interactions were non-significant, largest $F(1, 160) = 1.65$, $p = 0.201$, $\eta_p^2 = 0.01$. Post-hoc tests showed that all three age groups had significantly slower ongoing task RTs in Block 2 than in the baseline ($p < .001$), indicating that in both conditions they engaged monitoring processes as soon as instructions for the prospective memory task were given. Post-hoc tests on the effect of age group showed that in general older adults were slower than young adults and children ($p < .001$). On the other hand, young adult's RTs did not differ significantly from those of children ($p = .688$). Analyses on *accuracy* showed that the effects of condition and age group were significant, $F(1, 160) = 20.39$, $p < 0.001$, $\eta_p^2 = 0.11$, $F(2, 160) = 53.95$, $p < 0.001$, $\eta_p^2 = 0.40$, whereas the effect of block, $F(1, 160) = 0.26$, $p = 0.608$, $\eta_p^2 < 0.01$, as well as the interactions between the main effects were not (all $Fs \leq 2.00$). All age groups performed generally worse in the perceptual than in the semantic condition. Young adults outperformed both older adults and children who obtained the lowest accuracy rates ($p < .01$). Analyses on *rate residual scores* revealed significant effects of block and age group, $F(1, 160) = 30.67$, $p < 0.001$, $\eta_p^2 = 0.16$, $F(2, 160) = 19.02$, $p < 0.001$, $\eta_p^2 = 0.19$. All three age groups were less efficient in Block 2 compared to the baseline and young adults were generally more efficient than children and older adults ($p < 0.01$) who were the less efficient ($p < 0.01$). All the remaining effects and interactions were non-significant (all $Fs < 1.00$).

5.2.2. Monitoring costs in Block 3

Statistical analysis on *RTs* showed that age group was the only significant effect, $F(2, 160) = 28.94$, $p < 0.001$, $\eta_p^2 = 0.27$, whereas none of the other effects or their interactions resulted to be significant, largest $F(2, 160) = 2.19$, $p = 0.115$, $\eta_p^2 = 0.03$. Older adults were generally slower than children and young adults ($p < .001$), who did not differ ($p = .978$). Analyses on *accuracy* showed that the effects of condition, age group and the Block × Age Group interaction were significant, $F(1, 160) = 20.99$, $p < 0.001$, $\eta_p^2 = 0.12$, $F(2, 160) = 83.13$, $p < 0.001$, $\eta_p^2 = 0.51$, and $F(2, 160) = 3.34$, $p = 0.038$, $\eta_p^2 = 0.04$. All age groups performed generally worse in the perceptual than in the semantic condition. Young and older adults, who performed similarly ($p = .196$), outperformed children ($p < .001$). Analyses on *rate residual scores* showed that age group was the only significant effect, $F(2, 160) = 23.80$, $p < 0.001$, $\eta_p^2 = 0.23$, with young adults being more efficient than children and older adults who were less efficient than children ($p \leq .001$). None of the other effects or interaction were significant, largest $F(2, 160) = 2.03$, $p = 0.135$, $\eta_p^2 = 0.03$ for the Block × Condition × Age group interaction (all remaining $Fs < 1.00$).

5.2.3. Ongoing task performance after deactivation (Block 4)

Analyses on *RTs* showed that the effect of age was significant, $F(2, 160) = 30.70$, $p < 0.001$, $\eta_p^2 = 0.28$, whereas the effect of block and condition were not significant, $F(1, 160) = 2.82$, $p = 0.095$, $\eta_p^2 = 0.02$, $F(2160) = 2.41$, $p = 0.122$, $\eta_p^2 = 0.02$ (all remaining $Fs < 1.00$). Children were as fast as young adults ($p = .452$) whereas older adults had slower RTs than children and young adults ($p < .001$). For *accuracy*, the effects of condition, age group and the Block × Age Group interaction were significant: $F(1,$

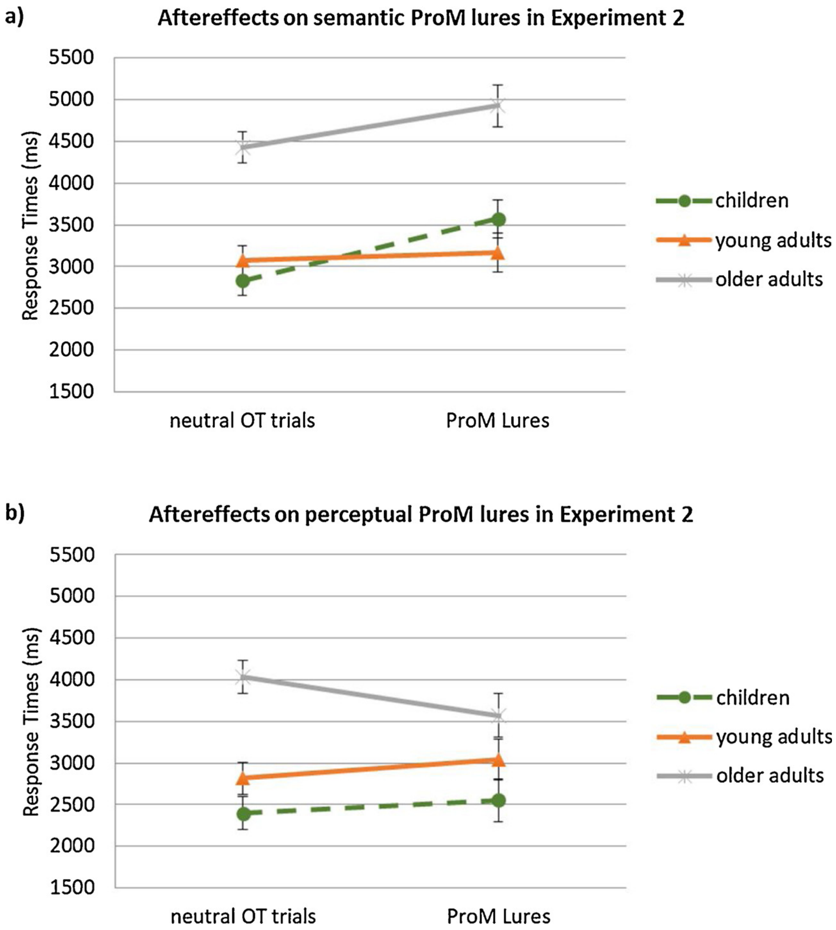

Fig. 3. (a) Aftereffects on deactivated intentions in Block 4 (semantic condition). Mean response times of correct responses only on neutral ongoing task (OT) trials compared to prospective memory (ProM) lures for each age group. Error bars represent standard errors. **(b)** Aftereffects on deactivated intentions in Block 4 (perceptual condition). Mean response times of correct responses only on neutral ongoing task (OT) trials compared to prospective memory (ProM) lures for each age group. Error bars represent standard errors.

160) = 19.23, $p < 0.001$, $\eta_p^2 = 0.11$, $F(2160) = 94.83$, $p < 0.001$, $\eta_p^2 = 0.54$, $F(2,160) = 10.24$, $p < 0.001$, $\eta_p^2 = 0.11$. The effect of block did not reach the significance threshold, $F(1, 160) = 3.51$, $p = 0.063$, $\eta_p^2 = 0.02$, whereas all the remaining interactions were not significant, largest $F(2, 160) = 1.95$, $p = 0.146$, $\eta_p^2 = 0.02$ for the Age Group × Condition interaction (all remaining *F*s < 1.00). All age groups performed generally worse in the perceptual than in the semantic condition. Young and older adults, who performed similarly ($p = .268$), outperformed children ($p < .001$). Analyses on *rate residual scores* showed that the effect of age group was significant, whereas the effect of block did not reach the significance threshold, $F(2, 160) = 23.33$, $p < 0.001$, $\eta_p^2 = 0.23$, $F(1160) = 3.53$, $p = 0.062$, $\eta_p^2 = 0.02$. All the remaining effects and interactions were not significant (all *F*s ≤ 1.00). Adults were more efficient than children and older adults ($p \leq .001$) who were less efficient than children ($p = .001$).

Results of Experiment 2 replicated those of Experiment 1 showing that ongoing task performance slowed down as soon as the prospective memory task instructions were given. Similar to Experiment 1, this slowing was evident in all three age groups, suggesting that they were all engaging monitoring processes. However, it seems that this cost was functional only for the two adult groups, since children were less successful in the prospective memory tasks. Finally, there were no differences in monitoring costs between the semantic and the perceptual condition indicating that, as for prospective memory performance, there was no overlap advantage for monitoring.

5.3. Aftereffects on deactivated intentions across the lifespan and as a function of prospective memory cue type

To evaluate aftereffects of responding to deactivated prospective memory targets in Block 4 we compared performance on neutral ongoing task trials with those on former prospective memory targets (lures), that is, ships/animals in the semantic condition and yellow/red stimuli in the perceptual condition. Consequently, we performed mixed ANOVAs with trial type (neutral, lures) as within-subjects factor, and age group (children, young adults, older adults) and condition (semantic, perceptual) as between-subjects factors. Fig. 3 shows mean RTs across the lifespan in Block 4 on neutral ongoing task trials and lures in the semantic and perceptual condition, respectively.

For *RTs* all the main effects were significant, with $F(2, 160) = 25.95$, $p < .001$, $\eta_p^2 = .25$, for age group, $F(1, 160) = 13.90$, $p < .001$, $\eta_p^2 = .08$, for condition, and $F(1, 160) = 6.87$, $p = .010$, $\eta_p^2 = .04$, for trial type. Moreover, the Trial Type × Condition, as well as the Trial Type × Condition × Age Group interactions were significant, with $F(1, 160) = 11.01$, $p = .001$, $\eta_p^2 = .06$, and $F(2, 160) = 3.93$, $p = .022$, $\eta_p^2 = .05$, respectively. The remaining interactions were not significant (all *F*s ≤ 1.00). RTs were generally slower in the semantic than in the perceptual condition ($p < .001$). Older adults were generally slower than children and young adults ($p < .001$), whereas children's and young adults' RTs did not differ ($p = .586$). Pairwise comparisons on the Trial Type × Condition × Age Group interaction revealed that in the perceptual condition performance did not differ between neutral stimuli and lures, neither in children ($p = .950$), young adults ($p = .357$) nor in older adults ($p = .079$). On the other hand, in the semantic condition RTs were significantly slower on lures compared to neutral stimuli in both children ($p = .002$) and older adults ($p < .001$), whereas they were comparable in young adults ($p = .430$).

Mean proportion of correct responses on prospective memory lures in the semantic condition was 0.74 ($SE = 0.03$) for children, 0.83 ($SE = 0.04$) for young adults, and 0.90 ($SE = 0.04$) for older adults, whereas the perceptual condition 0.76 ($SE = 0.04$) for children, 0.88 ($SE = 0.04$) for young adults, and 0.87 (0.04) for older adults. Only one child (in the perceptual condition) and two young adults (one in the perceptual and one in the semantic condition) made commission errors, resulting in proportions of 0.02 ($SE = .02$) and 0.04 ($SE = .02$) for the child and the young adults, respectively. Analyses on *accuracy rates* revealed a significant effect of age group, $F(2, 160) = 35.74$, $p < 0.001$, $\eta_p^2 = 0.31$, whereas the effect of trial type did not reach the significant threshold and the effect of condition was not significant, $F(1, 160) = 3.42$, $p = 0.066$, $\eta_p^2 = 0.02$, and $F(1, 160) = 1.57$, $p = 0.212$, $\eta_p^2 < 0.01$, respectively. On the other hand, the Trial Type × Age Group and the Trial Type × Condition interactions were significant, $F(2, 160) = 3.44$, $p = 0.034$, $\eta_p^2 = 0.04$, and $F(1, 160) = 4.13$, $p = 0.044$, $\eta_p^2 = 0.03$, respectively. The remaining interactions were not significant (all *F*s < 1). Children were generally less accurate than young and older adults ($p < .001$) who did not differ ($p = .744$). While young and older adults' performance did not change as a function of trial type ($p = 0.487$ and $p = 0.372$), children performed better on lures compared to neutral stimuli ($p = .003$). Participants' accuracy rates were similar for neutral stimuli and lures in the semantic condition ($p = .893$), whereas they were better on lures in the perceptual condition ($p = .009$). Analyses on *rate residual scores* revealed that the effects of age group and the Trial Type × Condition interaction were significant, $F(2, 160) = 16.61$, $p < .001$, $\eta_p^2 = .17$, and $F(1, 160) = 12.46$, $p = .001$, $\eta_p^2 = .07$, respectively. The effect of condition did not reach significance, $F(1, 160) = 3.55$, $p = .061$, $\eta_p^2 = .02$, all the remaining effects and interactions were also non-significant (all *F*s < 1.00). Post-hoc comparisons showed that young adults performed better than children ($p = .021$) and older adults ($p < .001$), whereas the letter had a lower performance compared to children ($p = .002$). The pairwise comparison related to the Trial Type × Condition interaction showed that in the semantic condition all three age groups tended to perform worse on lures compared to neutral ongoing task trials ($p = .071$). On the contrary, in the perceptual condition all three age groups performed better on lures than on neutral ongoing task trials ($p < .01$).

The results of Experiment 2 showed that aftereffects of responding to no-more-relevant prospective memory targets differed as a function of age and prospective memory task type. First, when prospective memory targets were semantic, aftereffects were present in children and older adults but not in young adults. Children and older adults had significantly slower RTs on no-more-relevant prospective memory targets compared to neutral ongoing task trials, whereas young adults had comparable RTs on the two trial types. This was in line with our initial hypothesis based on adult lifespan studies which showed that older adults had difficulties in inhibiting the automatic response triggered by a formerly relevant intention (Bugg et al., 2016; Scullin et al., 2011). Second, the results showed that aftereffects were not present when the prospective memory targets were perceptual. This was in line with our hypothesis according to which responding to perceptual prospective memory targets would have produced smaller aftereffects.

6. General discussion

The aim of the present study was to shed light on the different costs related to responding to activated and deactivated intentions across the lifespan. We compared 1) prospective memory performance; 2) monitoring costs; and 3) aftereffects on deactivated prospective memory targets in a semantic (Experiment 1 and 2) and a perceptual (Experiment 2) prospective memory task in children, young adults and older adults.

6.1. Prospective memory performance across the lifespan

First, we hypothesized to replicate the inverted U-shaped trajectory of prospective memory development, with a performance increase from childhood to young adulthood and a decrease of performance in older age (Zimmermann & Meier, 2006, 2010). Results of the present study were partly in line with our first hypothesis. In both experiments prospective memory performance increased from childhood to young adulthood, replicating previous findings (Kretschmer-Trendowicz & Altgassen, 2016; Smith et al., 2010; Zimmermann & Meier, 2006). On the contrary, we did not find any performance decrease from young to older adulthood, neither in the semantic (Experiment 1 and 2) nor in the perceptual condition (Experiment 2). Similar results were obtained in previous lifespan studies showing that prospective memory decline is not always evident in older age (e.g., Einstein & McDaniel, 1990; Kretschmer-Trendowicz & Altgassen, 2016). Since prospective memory performance was rather high, one possibility could be that performance in young and older adults was not different due to a ceiling effect. A further explanation is that because the emphasis of the prospective memory task instructions was on the prospective memory task rather than on the ongoing task, the importance of the prospective memory task may have overshadowed differences between conditions. Studies have shown that stressing the importance of the prospective memory task during instructions can eliminate age-related differences between young and older adults (see Walter & Meier, 2014).

Similarly, an overlap effect, that is, higher prospective memory performance for the perceptual (i.e., high overlapping) than the semantic (i.e., low overlapping) condition may not have materialized due to the emphasis on importance. Moreover, the fact that children and older adults tended even to perform worse in the perceptual compared to the semantic condition, may indicate that the perceptual prospective memory task was simply more demanding. This interpretation is supported by the lower ongoing task performance as well as the higher number of false alarms on ongoing task trials in the perceptual condition. Thus, it is likely that children and older adults struggled to recognize and remember the right target colors, and this may have concealed the potential benefit of a processing overlap. In fact, we seem not to have been successful in creating a higher overlap between processing requirement in the ongoing and the prospective memory task. Finally, it can also be argued that the lack of overlap-effects as well as the small age-differences in the adult lifespan was due to the type of category used for the semantic prospective memory cues, namely animals. Ongoing task stimuli all belonged to non-living categories and animal-cues might have stood out producing a saliency effect. However, notably, the results were replicated in Experiment 2, although prospective memory cues belonged to a different category (ships). Thus, this possibility cannot account for the whole pattern of results.

6.2. Monitoring costs across the lifespan

We expected that the ability to engage monitoring processes would change across the lifespan, with monitoring costs being less pronounced in children and older adults compared to young adults (Kretschmer-Trendowicz & Altgassen, 2016; Smith & Bayen, 2006, 2010). This was confirmed in part, as children were indeed less able to monitor for successfully performing the prospective memory task. Importantly, monitoring costs were present in all three age groups. Notably, children tended to become faster across blocks in the ongoing task suggesting that they disengaged from monitoring. This may have resulted in lower prospective memory performance. That is, they were less able than young and older adults to efficiently engage in strategic monitoring. Alternatively, children may have been discouraged faster to continue monitoring as the first prospective memory target occurred only after many ongoing task trials. It is also possible that the ongoing task was more difficult for children, given their lower accuracy compared to the adult's groups, and that ongoing task absorption hindered them to deploy resources for cue detection (cf. Meier & Zimmermann, 2015).

Older adults were engaging monitoring processes similar to young adults and showed also comparable prospective memory performance. Given that metacognitive abilities as well as spontaneous retrieval processes seem to be relatively preserved in older adults, these might help them to temporary monitor and successfully perform a prospective memory task (see Shelton & Scullin, 2017). In fact, several studies did not find any age-differences in monitoring costs between young and older adults (see Anderson, Strube, & McDaniel, 2019).

6.3. Aftereffects on deactivated intentions across the lifespan

We also tested whether the deactivation of a prospective memory task would result in aftereffects, that is, a slowing of performance or the presence of commission errors on no-more-relevant prospective memory trials (lures), and whether these aftereffects would be more pronounced in children and older adults than in young adults. The results were in line with our expectations, showing that RTs were significantly slower on formerly relevant prospective memory cues compared to neutral ongoing task trials presented in the deactivation block. Moreover, aftereffects were more pronounced in children and older adults compared to young adults, likely due to difficulties to inhibit the prospective memory response after deactivation of the intention. In fact, ongoing task RTs in the deactivation block were similar to those in the baseline indicating that participants did not monitor anymore since the prospective memory task was finished and thus suggesting that the former prospective memory target triggered the intention spontaneously. This supports the multiprocess views (McDaniel & Einstein, 2000) according to which prospective memory retrieval can occur spontaneously, without monitoring. Thus, cognitive control processes were engaged to suppress the automatic response to the no-more-relevant prospective memory trials. Spontaneous retrieval processes have shown to be relatively well developed in school-aged children (see Mahy et al., 2014) and to be preserved in older adults (Mullet et al., 2013). In contrast, cognitive control processes are still developing in children (Davidson, Amso, Anderson, & Diamond, 2006) and declining in older adults making it more difficult for them to inhibit automatic responses (e.g., Williams et al., 1999). As a consequence, compared to young adults, both children and older adults have slower RTs and/or make more commission errors on deactivated intentions (Bugg et al., 2016; Scullin et al., 2011).

We also hypothesized that aftereffects would be more pronounced on semantic rather than perceptual prospective memory lures. Our results confirmed our expectations showing that there were no aftereffects on perceptual prospective memory lures in either age group. Since performing the perceptual prospective memory task required the engagement of monitoring processes, the lack of aftereffects cannot be explained by the residual activation view based on the intention superiority hypothesis (see Walser et al., 2012). Accordingly, engaging monitoring processes during the prospective memory activation phase would strengthen the prospective memory cue-intention association which in turn would persist for a longer period after its deactivation. Consequently, a stronger engagement in monitoring should result in higher aftereffects on completed intentions. An alternative interpretation by Scullin and Bugg (2013) suggests that ongoing task RTs slowing during the active prospective memory phase could reflect fatigue which impaired executive functions needed to subsequently deactivate the finished intention. In the present experiment, no evident aftereffects were found on no-more-relevant prospective memory targets in the perceptual condition, although monitoring processes were engaged to respond to them when the intention was activated. It is likely that the absence of aftereffects in the perceptual condition and the presence of aftereffects in the semantic condition were indeed related to a stronger cue-intention association in the latter task. However, this stronger association might have been related to the particular nature (i.e., semantic relevance) of the prospective memory cue rather than to the level of engagement in monitoring. Further studies are needed to support this explanation.

7. Summary and conclusions

This is the first study examining both monitoring costs and aftereffects in prospective memory across the lifespan. The results showed that the ability to remember and to forget intentions changed across the lifespan. Prospective memory performance and monitoring abilities improved from childhood to young adulthood. Even children engaged in monitoring processes, but nevertheless their prospective memory performance was lower compared to adults and older adults. In the present study, older adults were as able as young adults to efficiently engage monitoring processes obtaining also a similar prospective memory performance. Lifespan changes were also revealed in the ability to forget intentions. Children and older adults displayed more difficulties than young adults in inhibiting responses to deactivated intentions. These results suggest that different processes guide developmental changes in prospective memory across the lifespan. Executive processes are likely to underlie developmental changes in monitoring abilities and prospective memory performance from childhood to adulthood. Executive processes are probably also related to age-related changes in the ability to forget and inhibit deactivated or completed intentions. On the other hand, spontaneous retrieval processes and metacognitive abilities seem to help preventing decline in prospective memory in older age. Taken together, the present study shows that children already use strategic monitoring in response to prospective memory task demands. Moreover, both children and older adults are less efficient inhibiting semantic intentions when they are no longer relevant. In contrast, we found no evidence of age differences for perceptual intentions. The latter result emphasizes the importance of distinguishing the specific requirements of different prospective memory tasks, particularly in developmental studies.

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