Doctoral Dissertation

The cognitive and neural mechanisms underlying prospective memory development

(Mecanismos cognitivos y neurales subyacentes al desarrollo de la memoria prospectiva)

International PhD Candidate

Ana B. Cejudo García

Advisor

Mª Teresa Bajo Molina

PhD in Psychology

Department of Experimental Psychology

University of Granada

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Autor: Ana Belén Cejudo García
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Front cover designed by Alejandro Castilla with some participants´ drawings.

A mi madre y a mi padre.

A mi hermana.

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Introductory note

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The content of this doctoral dissertation has been drawn up according to the regulations of the University of Granada to obtain the International Doctorate Mention in the Psychology Doctoral Program. In according with this, the majority of the thesis has been written in English. Specifically, in Chapters I a theoretical introduction to the subject of the investigation is presented in English. Next, the empirical chapter (Chapter II) also proceeds in English. Finally, the general discussion and concluding remarks are written both in English (Chapter III) and in Spanish (Chapter IV).

Preface

Dear reader:

Prospective memory (PM), or the act of remembering intentions, is essential in our daily lives. Imagine going to a medical specialist and forgetting to bring an X-ray or forgetting to pay taxes on time. Individuals can be very forgetful. Further, since there are individual differences in the ability to remember future intentions, people who wish to avoid embarrassing or dangerous situations should be aware of their own challenges. It is not uncommon for mothers or fathers to leave their babies in their car because they forgot to drop them off at day care before going to work. In addition, people with memory problems due to illnesses affecting brain functioning (e.g. Alzheimer's) often have problems remembering both the past and actions they wish to perform in the future. Although an inability to remember past life events or learn new things is the most perceptible effect of advanced phases of Alzheimer's and other types of dementia, the first observable effects often include forgetting to do such intentions as turning off the oven or taking the house keys before leaving. Thus, these types of memory lapses may help in the early detection of illness.

In addition, at much younger ages, when the brain is still developing and children are still acquiring new cognitive abilities, difficulties in remembering intentions and using strategies that facilitate better memory performance might lead to prospective forgetting of certain daily life activities (e.g. bringing homework to school). Imagine a mother telling a six-year-old child leaving for school, "Your permission slip is inside your bag. Don't forget to be bring it to your teacher, and don't forget that this Friday, we are going on vacation, so you need to finish your homework on Thursday". While the child is in class and focusing on various school activities, she must also keep both intentions in mind and complete at least one of them before leaving class. If she forgets, it could affect the teacher's perception of her work and class performance. Similarly, if a child forgets to return a toy she borrowed from a friend or if she forgets a friend's birthday, her social life may be affected. When performing an ongoing task (OT), children of different ages have been shown to differ in their ability to remember intentions when the cue to remember do the action is non-focal (i.e. not part of the OT), when the cue does not explicitly appear during the OT or when it is not salient. Imagine that a child must remember to put her allergy spray inside her schoolbag while she is setting her pencils on her bedroom desk (OT). If the allergy spray (the cue) is on the desk, it will be easier to remember the intention because the cue "allergy spray" is embedded in the activity the child is doing. However, if the allergy spray is in the kitchen, it will be harder for the child to remember to pack it. The present work explores the effects of different types of cues on PM performance during childhood.

The first chapter discusses the main theoretical models that have tried to formalise the process involved in PM, the neural activity that has been identified as relating to PM processing, the studies that have addressed the development of PM and the methodological issues that have been identified as points of concern when studying PM during childhood. In the second chapter, we discuss three experiments in which we assessed the PM of children aged 6 to 11 years old. In these experiments, we attempted to identify the main mechanisms underlying PM development. To accomplish this, we manipulated the focality of the PM cue with respect to the OT (Experiments 1 and 2) and compared event cues with activity cues (Experiment 3). In Experiment 1, we explored the development of strategic monitoring processes by looking at the cost of PM during the

OT in focal and non-focal tasks. In our second experiment, we explored the process underlying the PM development of three groups of children (6 to 7 years old, 8 to 9 years old and 10 to 11 years old) by looking at their brain activity [electroencephalography (EEG) recording] while performing focal and non-focal tasks. Finally, in Experiment 3, we compared event-based to activity-based school-related natural tasks. We carried out this third experiment with 6- to 7-year-old and 10- to 11-year-old children and adapted the difficulty of the OT to the ages of the participants, since this has been an important methodological concern in developmental PM studies. Additionally, we explored whether motivation modulated the effect of PM cue type or the age differences typically found in PM tasks. Finally, chapter three summarises the main contribution of this work and discusses its relevance for PM development.

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CHAPTER I: SUMMARY INTRODUCTION AND AIMS

"Memory is fallible, even for tasks that are very important.

As soon as intention leaves awareness, there's no guarantee

that it's going to be retrieved again."

Mark McDaniel, (2007, April 16).
Personal interview with Alison Drain.

Remembering to complete actions in the future is part of our daily life: going to a medical appointment, picking a package at the post office and paying taxes on time are critical for normal functioning. Failures to remember delayed intentions could also involve risks to our health if, for example, we forget to take medication (Brandimonte, Einstein, & McDaniel, 1996). In a study by Terry (1988), 50 university students were asked to take daily notes on the things they remembered or forgot to do throughout the day. Analyses of these data indicated that 70% of the participants reported memory failures involving forgetting to complete future actions. Similarly, Gardner and Ascoli (2015) asked young and older adult participants to indicate whether they were currently experiencing an autobiographical memory, a prospective memory, or neither. Specifically, participants were asked to categorize their current thoughts on whether they were recalling a specific event from their personal past (e.g., remembering their first job interview), actions or events from their personal future (e.g., imagining what needs to be done at work today), or neither (e.g., focusing on the task at hand). Whereas young adults had approximately 13 autobiographical and 17 prospective memory thoughts per hour, the estimated rate of prospective memory thoughts for older adults was twice that for younger adults. In contrast, their frequency of autobiographical thoughts was similar to that of the younger adults. Thus, it appears that younger and, especially, older adults spend a great deal of their mental lives thinking about their futures. A more recent study in which university students were asked to verbalize what they were thinking (Anderson & McDaniel, 2018) confirmed previous studies by showing that participants reported thinking about the future more often than thinking about the past (30% compared to 13%). The ability to remember future intentions is crucial not only for adults, but also for the daily lives of school-age children. Forgetting to complete intentions could affect children's academic performance (e.g., forgetting to bring their homework to school) or their social relationships (e.g., forgetting to give back a friend´s book). Such memory failures could even affect children's health (e.g., forgetting to use an allergy spray before going out to play). The type of memory involving remembering intentions has been defined as prospective memory (PM; McDaniel & Einstein, 2000).

Unlike retrospective tasks, in which the experimenter directly asks participants to search for an associated previously studied item in the presence of a retrieval cue, a typical feature of PM tasks is that they do not include a direct request to search in the participants' memory at the moment of retrieval. For example, in remembering to buy bread on the way home, no one is there to remind you that you planned to buy something when passing the grocery store (Tulving, 1983). In addition, performance in PM tasks involves both prospective and retrospective memory components. The prospective component involves remembering an intention to do something either at a given time or in the presence of a specific event, whereas the retrospective component involves remembering to perform the intended action, but also remembering what the intended action was (Smith, Bayen, & Martin, 2010). Following the previous example, remembering to buy bread on the way home involves the prospective component of remembering that you have to do something on the way home, but also the retrospective component of remembering the intention of buying the bread when you pass the grocery. The prospective component has been associated with executive control processes, such as monitoring, inhibition, and working memory, which are essential for detecting the prospective cue, whereas the retrospective component has been related to memory processes involved in retrieving cues and intentions (McDaniel & Einstein, 2000).

After the intention has been encoded, successful completion of a prospective task involves keeping the intention active in mind while other activity is being performed. As mentioned, this second activity (e.g., answering general knowledge questions) is called the OT. In addition, at the appropriate moment (time-based task; e.g., pressing a particular key after a seven-minute delay) or when the prospective cue appears (event-based task; e.g., pressing a particular key whenever the word 'president' appears), the person must stop doing the ongoing activity to perform the intention (McDaniel & Einstein, 2007).

Time-based PM tasks (TBPMs) usually involve more than one PM trial, during which the participants are asked to perform the encoded intention several times during the OT at a particular time or after a specific time period. For instance, participants could be instructed to perform the PM action 4, 8, 12 and 16 minutes after the start of the ongoing task (McDaniel & Einstein, 2007) for an ongoing task lasting just over 20 minutes. An essential feature of these paradigms is that the time (e.g., a clock, watch, or other device) is not in direct view of the participants. The most common way of measuring the accuracy of the PM response that is, whether the participant responded on time with the PM intention considers *on-time responses* when they occur within a specific time window after the target time (e.g., sending an abstract to a conference once the call is open and before the deadline arrives). To perform a TBPM task efficiently, people must be able to interrupt the ongoing activity deliberately to check whether sufficient time has elapsed to initiate the intended action (Harris & Wilkins, 1982). Hence, participants must monitor the time and initiate retrieval of the intention in the absence of any environmental event signalling that the time is appropriate to perform the task, since no one is there to remind them that they should check whether the call is open and when the deadline is. In other words, no external cues are available to support prospective remembering in time-base PM paradigms (McDaniel & Einstein, 2007).

In contrast, in laboratory PM event-based tasks (EBPMs), participants are asked to do an ongoing task (e.g., pleasantness ratings) and to remember to perform the PM intention whenever a particular cue appears (e.g., “press a designated key whenever you see the word rake in the context of the ongoing task”). For cued recall, participants must associate the target item with the cue word and, sometime later, recall the target word when the cue is presented. In a PM task, such as remembering to press a key when seeing the target word “rake,” participants must associate the target action (pressing the designated key) with the cue (“rake”). Successful prospective remembering requires that participants switch from seeing “rake” as an OT item to seeing it as a cue for performing an action (Einstein & Mcdaniel, 2005).

Hence, a set of parameters must be taken into account when designing a PM task (McDaniel & Einstein, 2007). As mentioned, in a PM task, the execution of the intended action is not immediate and is not cued by explicit instructions from the experimenter at the time of recall, but some time earlier and with instructions to wait for a specific time or a specific event. In addition, the PM task is usually inserted into an OT, the performance of which must be interrupted or suspended by the participant to execute the PM task. In addition, successful remembering only happens when the intention is remembered within the time window of opportunity (McDaniel & Einstein, 2007). Hence, a typical laboratory paradigm for studying PM involves: presenting participants with instructions and practice trials for an ongoing task to ensure the participants understand it, then presenting participants with PM instructions. After a delay period, the OT is reintroduced without reminding participants of the PM task. The PM tasks occur several times in the OT, and PM performance is measured by the proportion of times participants remember to complete the intention (Einstein & McDaniel, 2005). The type of cognitive processes needed to complete PM retrieval have been addressed in two broad theoretical frameworks. In the next section, we will review the preparatory attentional and memory (PAM) theory (Smith, 2003) and the dual process framework theory (McDaniel, Umanath, Einstein, & Waldum, 2015).

1. Theoretical Models of Prospective Memory and the Focality Effect

1.1. PAM Theory

According to the PAM theory, the processes required for PM completion consume attention and generate a cost to the OT (Kliegel, Martin, McDaniel, & Einstein, 2002; Smith, 2003; Smith et al., 2010). Thus, to detect the PM cue and retrieve the intention, people should be able to monitor the environment and maintain a state of readiness during the OT that allows them to recognise the cue that signals retrieval of the PM intention. Although we might not be aware of these processes, they are assumed to consume resources and impair OT performance. This assumption has been supported by experiments comparing OT accuracy and response times under conditions in which the OT task is performed by itself or concurrently with the PM task and reporting faster and better performance when the OT is performed by itself (control condition) than when it is performed while trying to remember an intention (Anderson, Craik, & Naveh-Benjamin, 1998; Craik et al., 1996; Park, Hertzog, Kidder, Morrell, & Mayhorn, 1997; Smith, 2003; Smith, Hunt, Mcvay, & Mcconnell, 2007). In this way, Smith (2003) found that participants were 300 milliseconds (ms) faster in performing a lexical decision task (deciding whether or not a string of letters contained a word) when they performed the task by itself (control condition) than when they were also instructed to remember a particular word (PM intention) when the cue was encountered (see also Smith et al., 2010 for similar result with a colour-matching OT and a PM involving pressing a key when a particular image appeared on the screen). Overall, experiments comparing OTs with and without a concurrent PM task have reported results indicating that strategic monitoring of the environment for PM cues is attention-consuming, imposing a cost on the OT.

Strategic attentional allocation to the PM task has also been associated with working memory (WM) capacity, since WM is required to keep the intention active while monitoring the environment, to update the task goal, and to switch to the PM task when a cue is encountered (Einstein, McDaniel, Manzi, Cochran, & Baker, 2000). Supporting this assumption, Smith and Bayen (2005) reported data indicating that WM capacity predicted the degree to which participants engaged in strategic monitoring to be prepared to perform the PM task. Thus, participants with higher WM capacity showed larger PM costs while performing the OT than participants with lower WM capacity, indicating that high-span participants were more prone to engage in preparatory attentional processes. Similar results have also been reported by others (Mahy & Moses, 2011; Smith & Bayen, 2005; Wang, Kliegel, Liu, & Yang, 2008).

OT costs have been found in adult populations, but also in children. For example, Leigh and Marcovitch (2014) reported PM costs in young children (4, 5, and 6 years old) categorising images (as animals/non-animals or food/non-food) when they were also asked to press a smiley face button whenever they saw a particular image. Similarly, Cheie, Macleod, Miclea and Visu-Petra (2017) showed that increasing processing demands on the OT or imposing an additional WM span on 10-year-old children compromised their performance. However, although some studies have included OT performance as a covariate (Kliegel & Jäger, 2007; Kvavilashvili, KyLe, & Messer, 2008), few studies have focused on PM costs during OT performance by themselves, and these effects are not completely understood (Cheie et al, 2017; Leigh & Marcovitch, 2014).

In general, the PAM theory suggests that successfully remembering an intention involves a number of processes (forming an intention, maintaining the intention until the appropriate cue or time is present, initiating the intended action when the cue is detected, and executing the intention) requiring preparatory attentional and working memory processes that will impose a cost on any activity being performed during the period the intention is formed and executed (Kliegel et al., 2002).

1.2. Dual process framework

The main assumption of the PAM theory regarding mandatory attentional and memory processes for prospective remembering has not always received support, and many studies have shown no OT with successful PM performance (Harrison & Einstein, 2010; Knight, Meeks, Marsh, Cook, Brewer, & Hicks, 2011; Scullin et al., 2011; Scullin, McDaniel, & Einstein, 2010). Thus, the dual process framework proposes that retrieval of a prospective intention could be spontaneous or effortful, depending on the demands of the task (Einstein, Smith, McDaniel, & Shaw, 1997; McDaniel et al., 2015). Thus, in some conditions, cue monitoring might not be attentionally costly, explaining successful PM retrieval with no cost to the OT.

More direct evidence for the dual process framework (McDaniel et al., 2015) comes from studies manipulating the attentional/monitoring demands of the PM task by using different type of cues or by manipulating cue-intention association or cue-response delays. In the following sections, we review some of this evidence.

1.2.1. Focality of the prospective cue

The focality of the prospective cue has been manipulated under the assumption of the dual process framework (McDaniel et al., 2015) that the degree to which attentional resources are demanded for cue monitoring depends on whether the PM task involves focal or non-focal cues. Focal cues involve processing the same features needed to perform the OT. For example, if the OT involves lexical processing to categorise strings of letters as words/non-words, a focal cue should also involve lexical processing of the presented stimuli: for example, pressing another key whenever a predetermined target word appears (Einstein & McDaniel, 2005). Therefore, when the cues are focal, attentional monitoring of the environment is not needed, since OT processing is enough to process and detect the cue. By contrast, in non-focal PM tasks, monitoring for external cues is necessary because there is no overlap between the information needed for the OT and that needed for PM performance. In this case, effortful monitoring should be invested to detect the PM cue and to switch from the OT to the PM. Because non-focal tasks involve PM cues that are not part of the information extracted from the OT for accurate performance (e.g., deciding whether the word on the left is a member of the category on the right as an OT and pressing another key whenever the word includes the syllable “tor,” they involve attentional and memory processes to monitor for the cue and retrieve the intention (Einstein & McDaniel, 2005). In focal PM tasks, the OT forces processing of the PM target, potentially requiring spontaneous non-attentional retrieval. According to this assumption, cue focality should show effects on monitoring and cue detection because the ability to strategically monitor for environmental cues depends on whether the OT orients attention to the relevant contextual PM cue (Einstein & McDaniel, 2005; Rose, Rendell, McDaniel, Aberle, & Kliegel, 2010; Wang, Liu, Xiong, Akgün, & Kliegel, 2011). For example, Ball and Bug (2018, Experiment 1) reported the results of a study in which participants performed a lexical decision task as the OT. They were also asked to detect a syllable embedded in some words as the concurrent PM task. In the focal condition, participants were informed that the embedded syllable occurred in words, but that it would never appear in non-words. In the non-focal condition, they were told that the embedded syllable would appear in items (words and non-words) starting with consonants. The results showed that an OT cost for the PM condition relative to the single-OT control condition was present only in the focal condition and was not evident in the non-focal condition. These findings suggest that strategic monitoring is dependent on how PM cues interact with the features of the OT.

1.2.2. Cue salience

Other features of the PM cues critically determine the degree to which attentional demands are required during PM retrieval. In particular, PM cues that are distinctive or salient produce very high levels of PM performance relative to non-distinctive versions of these cues (Brandimonte & Passolunghi, 1994; Mahy, Moses, & Kliegel, 2014; Uttl, 2005). Brandimonte and Passolunghi (1994) observed that performance in a PM task was facilitated when the cue was unfamiliar and/or distinctive (house vs. chrism). In addition, Uttl (2005) demonstrated that the physical salience of the PM cue also facilitates PM performance. Uttl used an OT (sorting cards) in which information appeared on the centre of a computer screen. While participants were sorting the cards (OT), pictures of objects of various sizes were presented in the four corners of the screen with pictures representing the PM cue. Occasionally, a picture of the PM target was presented. If participants did not detect the PM target during the trial, the picture was presented again a few trials later in a larger size. The results showed that more participants were likely to notice and respond to the PM target as it became larger or more salient. These findings support the idea that perceptual salience is likely to direct extra attention to the cue and to facilitate disengagement from the OT and, in turn, retrieval of the PM intention. It is likely that salient PM cues are used in everyday strategies to facilitate successful PM. For example, in a study by Moscovitch (1982) in which participants' strategies were recollected while they were trying to remember a PM intention (e.g., calling the experimenter at the appointed time), some of the best strategies consisted of using very distinctive cues (e.g., leaving a shoe on the table an unusual and salient place next to the telephone). More importantly, however, these data suggest that cue salience determines whether PM involves effortful retrieval or more spontaneous retrieval of the intention.

1.2.3. Event-based vs. activity-based PM tasks

Related to salience and attentional demands, some studies have also manipulated whether PM tasks are event- or activity-related (Kvavilashvili & Ellis, 1996). In event-based PM tasks, retrieval of the intention occurs because some external cue signals the retrieval and execution of the previously formed intention (e.g., remembering to deliver a message when you meet your colleague). In contrast, activity-based tasks require that the intentions be retrieved and executed upon completing some other tasks (e.g., remembering to deliver a message to your colleague when you finish reading an article). Results with adult participants indicate that activity-based tasks are more difficult to remember than event-based tasks (Brewer et al., 2011). For example, Brewer et al. (2011) asked adult participants to complete nine OTs with different types of PM cues. When the PM cue was activity-based (e.g., saying “now” when an activity involving numbers came to an end), participants correctly responded 23% of the time. By comparison, when the PM cue was event-based (e.g., saying “now” when the OT involved numbers), their performance increased to 60%. The better performance on the event-based tasks seemed to be associated with the high salience of the event-based cues that appeared explicitly during the OT performance. Hence, in Experiment 2, they also manipulated cue saliency. As an OT, the authors asked participants to generate exemplars of specific categories. Then, the respondents were also asked to remember to place a check mark close to the category label when they encountered fruits and insects (event-based condition) or when the time to generate category exemplars had ended (activity-based condition). Additionally, in the salient conditions, participants were instructed to draw a line underneath the last category member and to write the number of generated exemplars close to the line when the experimenter pronounced the word “stop”. The results showed that salience only affected activity-based performance, which was greatly improved by making the end-of-category generation salient. Therefore, activity-based PM tasks seem to also require more effortful retrieval processes for successful PM performance, and this greater difficulty seemed to be due, at least in part, to the low salience of the end-of-activity cue.

1.2.4. Cue-target association

Several PM studies have found benefits in PM performance when the target cue and the intended action were highly associated. For example, Loft and Yeo (2007) manipulated the degree of association between the cue and the intention in the PM task. In the high-association PM condition, participants learned word pairs like actor-actress, and their PM task was to press a key and type the second member of the pair (actress) when they saw the first member (actor). In the low-association PM condition, participants received unrelated pairs, such as mouth-actress. In both conditions, participants were asked to perform a lexical decision task as the OT and to respond with the second member of the word pair when they were presented with the first. Reaction times on lexical decisions for items presented immediately before successfully recalled PM targets indicated that lexical decisions were slower when the PM pairs were minimally associated; however, these slower responses were not present when the cue and the intention were highly associated. This pattern suggests that, in the high-association condition, participants remembered to perform the PM response regardless of whether or not they had been thinking of the PM task immediately prior to the occurrence of the target, whereas, in the low-association condition, successful prospective remembering of the intention involved some monitoring and processing of the intention before cue presentation (McDaniel & Einstein, 2007). These results supported the interpretation that PM retrieval can occur with little monitoring when there is a strong association between the target cue and the intended action, while low cue-target associations require greater involvement of monitoring processes. These results further indicate that the nature of PM retrieval (spontaneous or reflexive, requiring monitoring or not) depends on such factors as the nature of the cues or the cue-target relation.

1.2.5. Length of the prospective interval (delay–execute PM tasks)

Like factors related to the cue, there is evidence that even very brief delays between PM cue and the execution of an intention lead to more effortful retrieval and impaired PM performance. For example, seeing a colleague may serve as a cue to retrieve an intention to deliver a message from the Chair of the Department; however, seeing a colleague talking to another person may prompt us to hold onto the intention and keep doing the task at hand until the colleague has finished talking. Although we might be able to hold the intention in working memory during this period of time, this involves additional attentional resources, as well as the risk of forgetting. This situation has been studied through the delay–execute procedure. The delay–execute PM task usually involves performing blocks of OT trials (e.g., answering questions), and instructing participants to perform a PM task (pressing a key) if a salient cue (e.g., a change in the colour of the screen) is presented during the block, but holding execution until the block is finished (Ball, Knight, Dewitt, & Brewer, 2013). Usually, participants' performance is impaired relative to a condition in which they perform the intention immediately after cue presentation (Ball et al., 2013; Einstein et al., 2000). For example, in a study by Einstein et al. (2000) comparing younger and older adults' PM performance, age differences were present when the execution of the response was delayed for a brief period of time following the presentation of the PM cue (5 to 15 minutes), whereas performance was nearly perfect for both younger and older adults when they were asked to perform the intended action as soon as the PM cue occurred. This pattern suggests that the lower PM performance among older adults in the delayed condition was due not to problems in initial retrieval (when participants were allowed to perform the intention immediately after the PM cues they were able to retrieve), but, rather, to problems in keeping the intention active after it had been retrieved. Additional research with young adults has also shown that performance in delay–execute procedures requires attentional resources (Ball, et al., 2013; Einstein et al., 2000; Kliegel, Mackinlay & Jäger, 2008). Again, these results suggest that some task conditions increase attentional demands during some of the processes involved in PM performance. In the particular case of a delay between PM cue and execution of the intention, the demands are made over maintenance in working memory of the PM intention following initial retrieval. In general, then, these patterns support the dual process framework and provide evidence that monitoring and retrieval during PM might involve effortful attention-demanding processes or more spontaneous and automatic retrievals of the intention with little monitoring cost (McDaniel et al., 2015).

2. Prospective memory development

In favour of the involvement of attentional control in PM, developmental research with PM tasks suggests continuous development of the processes underpinning PM across childhood and adolescence (see Mattli, Zöllig, & West, 2011; Zimmermann & Meier, 2006; Zöllig et al., 2007). Numerous studies have found that both the prospective and retrospective components involved in remembering intentions develop with age. In a study with younger and older adults, Mattli, Schnitzspahn, Studerus-Germann, Brehmer and Zöllig (2014) observed that the error rate in the prospective component was higher in older than younger adults. In addition, although both younger and older adults had lower performance in the prospective than in the retrospective component of the task, the group of older participants also showed impaired performance relative to the younger adults, particularly in trials in which PM was correct. This suggests that both prospective and retrospective components should be considered when studying developmental changes, at least with older adults. Zöllig et al. (2007) has provided evidence that this might also be true when comparing adults and adolescents. In their study, participants were asked to decide whether two words presented on the centre of the computer screen belonged to the same/different semantic categories (OT). Additionally, they were asked to press the target key when a word pair was presented in the target colour (PM task). The results of the study showed significantly more errors in PM lure trials for the adult group. Errors in PM lure trials are associated with the retrospective component of PM, since participants erroneously make prospective responses to wrong cues (e.g., pressing a key when a word is printed in grey when the correct prospective cue is a word printed in green and grey). This suggests that participants correctly monitored the context for cues, but failed to remember the right one. Differences in the retrospective component have also being found by Smith et al. (2010) when comparing 8- to 9-year-old and 12- to 13-year-old children. However, studies with children and adolescents do not always show clear patterns regarding the role of the retrospective component in development. Some studies with adolescents have reported age differences for the prospective but not for the retrospective component (Wang et al., 2011; Zimmermann & Meier, 2006), and some studies with younger children have concluded that, while 2-year-old children have difficulty remembering an intention (Kliegel & Jäger, 2007), 3- and 4-year-old children are able to remember the intention they should complete (Ford, Driscoll, Shum, & Macaulay, 2012; Mahy & Moses, 2011).

2.1. Executive functions and PM performance

Because the retrospective component does not always show a clear developmental pattern, most developmental studies have focused on assessing the prospective component (Mahy et al., 2014). For example, some studies have tried to relate changes in PM performance with the development of executive functions (EFs). Theoretical analyses of PM tasks indicate that EFs should underlie PM performance. For example, working memory (WM) is needed for intention maintenance, and cognitive flexibility and inhibition are needed to stop the OT and switch to the PM task to initiate the intention. Numerous studies of adults have associated good PM performance with WM capacity. Basso, Ferrari and Palladino (2010) manipulated the WM demands of the OT to explore the extension of the cost of the PM over the OT performance. The OT was a lexical decision task or a WM-updating task involving higher or lower WM demands. Additionally, participants were asked to press a particular key whenever a specific word appeared (PM task). PM only affected OT performance when the task involved a high WM load. By contrast, the pattern for the lower WM conditions showed that performance was independent of the concurrent PM task. Basso et al. (2010) concluded that even if the processes underlying WM and PM tasks are not fully based on the same system, the execution of the intention in PM tasks with high demands requires WM resources. In adolescents, Altgassen, Vetter, Phillips, Akgün and Kliegel (2014) reported data indicating that the theory of mind and switching tasks predicted PM performance in a task in which participants were presented with noun pairs and were required to count the number of vowels in both words and to press the left or right arrow key depending on which of the two members of the pair had more vowels (OT). In addition, they were asked to press the space bar as quickly as possible whenever one of the two words (PM cues) was a verb (e.g., dancing, cleaning, crying) and then to continue responding to the number of vowels.

In children, however, there is no consensus concerning the specific EFs underlying PM development. On one hand, a study by Shum, Cross, Ford and Ownsworth (2008), in which 8- to 12-year-old children read stories out loud and replaced a cue word with another word (PM task), showed that verbal fluency, WM, inhibition and cognitive flexibility could predict PM performance. In addition, Wang et al. (2008) showed that age differences among three-, four- and five-year-old children only appeared in the condition in which the children had to name pictures (OT) and stop naming pictures (i.e., inhibit responding to the OT) when the PM cue appeared and they had to complete the intention. By contrast, age differences were not found for the condition in which the PM cue appeared at the end of the OT, meaning that no inhibition was involved and suggesting that the inhibition processes involved in PM performance might be responsible for developmental effects. Similarly, Ford et al. (2012) concluded that inhibition was the best predictor of PM performance in four- to six-year-old children, whereas the verbal ability and WM tests were not related to PM. In contrast, Mahy and Moses (2011) assessed WM capacity through a digit span task and measured inhibitory control with a night/day task, in which four- to six-year-old children were required to say “day” when pictures related to night appeared and “night” when pictures related to day appeared. In the PM task, children were first introduced to Morris the Mole, a stuffed animal, who had poor daytime vision, and asked to help Morris learn what was on the cards by naming the pictured objects. In addition, they were told that Morris was afraid of animals and that if they saw an animal card, they should hide it from Morris by placing it in a box approximately four feet (1.22 metres) behind them (PM task). The results indicated that WM predicted PM performance, but inhibitory control did not. Similarly, Cheie et al.

(2017) discovered that increasing the difficulty of an OT involving solving arithmetic problems (e.g., "For her birthday, Ana received three shirts, a ball, and two sweaters. The number of clothes she received is…") and recalling the results from two to four previous arithmetic calculations (WM manipulation) decreased the number of times 10-year-old children remembered the intention of pressing the *enter* key whenever they saw the word *ball.* In a similar vein, Kretschmer, Voigt, Friedrich, Pfeiffer and Kliegel (2014) also concluded that WM, but not inhibitory control, was responsible for children's recovery of intentions using a PM task with temporal PM cues (TBPM). Finally, Spiess, Meier and Roebers (2015) reported the results of a confirmatory factor analysis providing evidence that EFs and metacognition share cognitive processes in second grade children's (seven to eight years old) PM performance.

In general, these findings suggest that PM is related to a variety of executive processes, which might underlie the prospective PM components' improvement with age. However, there is no clear agreement concerning which EFs could be involved in PM development, likely due to different studies' use of different methods and conditions for PM assessment. For this reason, many other developmental studies have begun to study focality and other task conditions in children of different ages.

2.2. Focality and other cue effects

Studies manipulating the focality of PM cues and comparing adult and adolescent PM performance have reported age differences, but only in more demanding non-focal tasks (Wang et al., 2011), with the adult group outperforming the adolescents. Wang et al. (2011) used ongoing spatial WM tasks in which participants were asked to press a target key whenever a specific embedded target appeared (focal condition) or whenever the background colour of the WM trials changed to a specific colour (non-focal condition). The response times for the ongoing WM task showed group differences only when the PM task involved non-focal intentions, suggesting that age differences might arise more often in conditions involving more difficult monitoring and cue detection processes. Kliegel et al. (2013) also compared 6- and 7-year-old and 9- and 10-year-old children's PM performance in a videogame task requiring them to drive a vehicle. In the non-focal condition, the PM cue was a yellow flowerpot located outside the road, and in the focal condition, the cue was a yellow car also in the road. Performance in the PM task was lower in the 6- and 7-year-old children than in the 9- and 10-year-old children in both conditions, suggesting that both focal and non-focal cues require attentional resources. However, when performance on the OT was included as a covariate, age differences appeared when the cue was outside of the centre of attention. This is an important methodological detail (difference in OT performance) that we will address in one of our studies. In any case, although the studies investigating the role of focality in children are scarce, they seem to indicate that developmental differences are more evident in more demanding attentional conditions, suggesting that executing intentions in non-focal conditions requires WM and executive control and that these process continuously develop from early childhood until adolescence (Davidson, Amso, Anderson, & Diamond, 2006; López-Vicente et al., 2016; Schleepen & Jonkman, 2009).

Other cue-related features, such as cue salience, have also been shown to have an effect in children. Mahy et al. (2014) found that salient PM cues (surrounded by a red border) resulted in better PM performance than non-salient cues in four- and five-year-old children. Similarly, Walsh, Martin and Courage (2014) also found effects of event vs. activity cues related to salience in preschool children. Walsh et al. (2014) reported results showing age differences when the PM tasks were activity-based; however, these differences were not evident when the task was event-based. In their study, they asked children to “catch Elmo” when it appeared in the corner of the screen while they were playing a computer game (event-based task) or to ask for a sticker at the end of the game (activity-based task). Whereas performance was lower in three- and four-year-old children than five-year-old children in the activity-based task, the children performed at the same level when the task was event-based. Therefore, whether a PM cue is activity- or event-based seems to be relevant during development.

2.3. PM–intention association

Sheppard, Kretschmer, Knispel, Vollert and Altgassen (2015) showed that, unlike adult participants, five- and seven-year-old children did not show an effect on PM performance of the degree of association between the PM cue and intention. In their experiment, children were asked to name pictures for a toy mole, while remembering to respond differently to certain target pictures (target cues). Whenever the children saw a picture of a certain category (an animal in the low-association condition; a fruit in the high-association condition), they were to name the picture, but then to also say the word ‘juice’. The results showed that the level of cue-intention association did not affect the children’s PM performance, suggesting that they were not able to take advantage of this association to facilitate retrieval. However, it is possible that the lack of a cue-intention association effect was produced by certain features of the design, since they included a delay-execute procedure that might have neutralized the positive effect of a high cue-intention association. To our knowledge, no other studies have assessed the effects of PM cue and intention association in children.

2.4. Delay between PM cue and executing the intention

Rendell, Vella, Kliegel and Terrett (2009) explored the effect of delaying the execution of an intention in 5- to 10-year-old children. They investigated the ability to carry out a delayed intention either immediately after a target cue appeared or after an additional delay. In the retrieve–execute condition, most children performed close to the ceiling, particularly the older children. In the delay-execute condition, the pre-schoolers and younger children showed impaired performance with significant variability in the number of correct prospective trials. In a similar vein, Kliegel, Mackinlay and Jäger (2008) manipulated whether participants (first-grade children, fourth-grade children, younger adults and older adults) had to actively interrupt attention to the current OT in order to switch to the execution of the next intended task. In the interruption condition, the next item of the currently attended subtask appeared automatically after a response was made, such that switching to another subtask required actively interrupting the currently selected subtask. In the no-interruption condition, the single items remained after a response was made. Age differences in intention execution were substantially greater when active task interruption was necessary. These results suggested that the degree of inhibitory control needed to succeed in the task may be one factor underlying development. This pattern is in line with the results obtained by Kvavilashvili, Messer and Ebdon (2001), who found that the PM performance of four-, five-, and seven-year-old children was significantly better than their performance in conditions in which they had to interrupt the OT to carry out the PM task. Similar effects of task interruption were found by Ślusarczyk and Niedźwieńska (2013) in a naturalistic study in which the need to interrupt the OT decreased performance in three-, four-, and five-year-old children.

In sum, most studies manipulating the attentional demands of the PM task have shown larger age differences when the task conditions require more attentional or WM demands. However, these results are not always clear or systematically manipulated; therefore, they deserve more investigation. Some studies have attempted to explore developmental differences and identify the sources of this difference by looking at brain activity during PM performance. In the following section, we review some of these studies, particularly those using EEG recording, as this is the type of recording we use in some of our studies.

3. Neural correlates of prospective memory and its development

The neural mechanisms underlying PM have been investigated in adults by looking at changes in brain activation with FMRI techniques while performing PM tasks. The results of some of these studies have shown changes in activation in the anterior prefrontal cortex (BA10) related to cue detection and retrieval of the intention, suggesting the involvement of attentional control (Beck, Ruge, Walser, & Goschke, 2014; Burgess, Gonen-Yaacovi, & Volle, 2011; Simons, Schölvinck, Gilbert, Frith, & Burgess, 2006). However, different patterns of sustained activation have been found in focal and non-focal PM tasks, suggesting that PM processes might differ depending on the task conditions. Neural activation patterns in non-focal PM tasks are located in regions associated with attentional control, such as the anterior frontal cortex (aPFC). Activation is especially evident in the rostrolateral PFC (BA10), the dorsolateral-prefrontal cortex (DLPFC; BA46), the parietal cortex (BA7) and the precuneus (Beck et al., 2014; Burgess et al., 2011; Cona, Scarpazza, Sartori, Moscovitch, & Bisiacchi, 2015; McDaniel et al., 2015). This pattern of higher sustained activation for non-focal than focal tasks in areas related to executive control is expected, since non-focal tasks are assumed to involve more costly monitoring process that rely directly on attentional control. In addition, Kalpouzos, Eriksson, Sjölie, Molin and Nyberg (2010) have found evidence of hippocampal involvement in naturalistic focal PM, in line with previous work suggesting that the hippocampus also plays a role in spontaneous retrieval of information when a cue is encountered and fully processed (Eichenbaum & Cohen, 2004; Konkel & Cohen, 2009).

Numerous studies have also used event-related potential (ERP) waveforms to understand the neurocognitive mechanisms that underlie PM and to dissociate specific prospective and retrospective PM components. For example, N300 and frontal positivity have been associated with the prospective component. N300 is a negative deflection over the occipital and parietal regions that occurs between 300 and 500 ms after a stimulus onset (West, 2011; West, McNerney, & Travers, 2007). The amplitude of N300 is usually greater for PM hits than for PM misses and for OTs (West, 2011; West & Ross-Munroe, 2002), suggesting that N300 reflects the detection of a PM cue in the environment et al., 2002; Zöllig et al., 2007). With respect to the frontal positivity component (FN400), the results of several studies have revealed greater amplitudes for PM cues than for OTs (West, 2011; West et al., 2007). Thus, like N300, this ERP component seems to dissociate between PM trials and ongoing and PM miss-trials. Specifically, frontal positivity has been related to switching from an OT to a PM task (Bisiacchi, Schiff, Ciccola, & Kliegel, 2009; Mattlly et al., 2011), although some authors (Cona, Bissiacchi, & Moscovitch, 2014) have also linked it to retrospective recognition of the cue.

The parietal positivity and the frontal slow wave have been associated with the retrospective components of PM. The parietal positivity represents sustained positivity over the parietal region, which is greater for the PM cues than for the OT. The parietal positivity reflects three components with distinct functionalities: P3b, the parietal old-new effect and prospective positivity. P3b is a sustained positivity from the P300 family and reflects the detection of low-probability PM cues (West, 2011). The parietal old–new effect is associated with recognition from the PM cue (West, 2011). Finally, prospective positivity appears after P300b and the old-new parietal effect, and it is associated with the task set configuration for the retrieval and execution of a prospective intention (Bisiacchi et al., 2009; West, 2011). The frontal slow wave, on the other hand, is a positive activity over the frontal and parietal regions that begins around 400 ms after stimulus onset and has been associated with monitoring the retrieval of the intention (West, 2007).

Several PM developmental studies have tried to identify processing differences between children and adults by looking at the prospective (N300, FN400) and retrospective (parietal positivity and frontal slow wave) ERP components associated with PM. However, the results are still mixed, and not all ERPs associated with PM performance have been investigated among children. For example, Mattli et al. (2011) reported differences between PM hits and PM misses during the N300 time frame in adults. However, for children (10 to 11 years old), the differences in amplitude between PM hits and PM misses were not significant, suggesting that, although children might have been detecting the cue (as there were differences between PM hits and OTs), this process did not necessarily lead them to execute the intention (as there were no differences between PM hits and misses). In contrast, Hering et al. (2016; see also Bowman, Cutmore, & Shum, 2015) did not observe differences in N300 amplitudes between hits and OTs in adults, though a difference in amplitudes between PM and OTs was present in adolescents. The reasons for the discrepancies between the two studies are not clear, although the N300 component seems to be able to capture developmental differences regarding cue detection. Regarding the second prospective component, Mattli et al. (2011) also looked for possible age differences in the FN400, but they observed that both children and adults showed similar patterns, with PM hits differing from both PM misses and OT trials. This finding is intriguing, since it differs from that observed for the N300, in which differences between PM hits and PM misses were only present in adults and differences between PM hits and OTs were present for both children and adults. Mattli et al. (2011) suggested that poorer PM performance in children relative to adults might stem from difficulties with task switching. Hence, looking at the two components together could facilitate interpretation of the developmental pattern. However, before reaching any conclusion, and since very few studies have examined these components in children, it is important to replicate the pattern and extend the results to younger children and to conditions in which the attentional demands of the task are manipulated (e.g., focality).

Regarding the retrospective components (parietal positivity and frontal slow wave), age differences in PM trials (relative to OTs) have also been explored (Hearing et al., 2016; Zollig et al., 2007). Zollig et al. compared adolescents and younger and older adults and reported age-related differences in the amplitudes of the parietal positivity component (greater amplitudes in the adolescents than in the younger and older adults) that they interpreted as less efficient recruitment of the cognitive resources to retrieve the intention. Similar results were reported by Bowman et al. (2015) who found greater mean amplitudes for the parietal positivity component for their younger group (12- to 13-year-olds) than for their older group (18- to 19-year-olds). In line with these results, Hearing et al. (2016) also reported larger amplitudes for parietal positivity for adolescent than for adult participants. In addition, in their study, they included PM, frequent OTs, and OTs that were equated to the PM trials in their frequency of appearance (as PM trials are typically less frequent than OTs). In this case adult participants showed larger amplitude for PM than ongoing trials independently of their frequency, whereas the adolescent group showed larger mean amplitudes for PM targets than for frequent ongoing trials that showed, in turn, greater amplitude than low frequency ongoing trials. This pattern was interpreted as a post-retrieval evaluation process that worked less efficiently in adolescent than in adults since they paid attention to features that were irrelevant to the task. In general, these studies have also found greater PM-OT amplitude differences for younger (adolescents and 12-13 years old children) than older participants (Else, Bowman et al., 2015; Hearing at al., 2016; Mattli et al. 2011; Zolling et al., 2007), suggesting less efficient recognition of the cue and retrieval and monitoring of the intention in children than in adults.

Regarding the Frontal slow wave, the existing developmental studies have only compared younger and older adults (West & Covell, 2001; West, Herndon, & Covell, 2003) and they have reported differences in mean amplitude between PM trials in which the intention was performed and trials in which the intention was forgotten, but only for younger adults, since these differences were not reliable in older adults. This suggests that some difficulties in remembering intentions in older adults might be related to this retrospective component, and to their difficulties in remembering the intentions. To our knowledge, the frontal slow wave has not been previously examined in children or adolescents, and therefore three is not available information on how this retrospective component and the processes associated to it develop with age.

In sum, studies comparing adult participants and adolescent suggest that both prospective and retrospective PM components seem to differ with younger participants showing less efficient processing. Although results are sometimes mixed, they seem to suggest that adolescent are able to detect the cues, but they show less efficient processing when moving from the ongoing to the PM task. In addition, they also seem to allocate their resources less efficiently than older adults since they show greater parietal positivity amplitudes, and they react to irrelevant-salient features of the task. However, these developmental studies are still limited since ages younger than 10 years old have not been explored, and variables that can facilitate interpretation of developmental pattern have not been manipulated. For example, with adult participants, Cona et al. (2014) manipulated the focality of the PM cue to explore which and to what extend PM processes involved attentional control. Whereas they fail to show focality effects in the N300 component, they observe clear differences between focal and non-focal tasks in the frontal positivity, parietal positivity and frontal slow wave. The Frontal positivity component has been shown to be the only ERP component with larger amplitudes in focal than non-focal conditions, lending support to the idea of greater involvement of switching processes under focal conditions. Therefore, the manipulation of cue focality and the recording of EEG in children of younger ages might help to dissociate the PM processes that play a large role during development.

4. Methodological concerns when studying prospective memory in children

As mentioned, very few PM studies have included school children of different ages, and most developmental studies have focus on comparison between adolescent, younger and older adults. One reason for the small number of studies looking at developmental trajectories at young ages is the number of methodological difficulties associated to the way that PM tasks are conducted. Age effects have been shown very labile and dependent on factors such as the difficulty of the ongoing tasks, the nature of the task including context, cue salience or modality (Ceci & Bronfenbrenner, 1985, McGann et al., 2005, Passolunghi et al., 1995), that in turn, has been also shown to interact with motivation and task engagement (see- Kvavilashvili, KyLe, & Messer, 2008 for a discussion of these methodological difficulties). In the following paragraphs we will discuss some of these factors since they might be critical in the research that we are reporting later. Thus we will discuss the studies showing effects of the difficulty, and the nature of the task, to then turn to motivation as a modulating factor. We will always discuss first studies with adult participants to then look at the effects of these variables with children.

4.1. Difficulty on the PM task

Obviously, some ongoing activities are more demanding or engaging than others and this might affect PM performance and be the cause of many PM failures. For example, Kvavilashvili (1987) manipulated the presence and interest of the ongoing task and found that more-engaging ongoing tasks led participants to dedicate fewer thoughts to the PM task during the retention period. Thus, as the ongoing task become more engaging participants reported thinking about the PM task 42% (when they did not have ongoing task during the retention interval), 20% (when they has to perform a low-engaging task) and 8% (when the ongoing task was very engaging). Marsh and Hicks (1988) also found that increasing the cognitive demands of the OT had an effect in PM performance. In their experiment, they introduced a concurrent task that engaged central executive resources and compared PM performance when the concurrent task involved the articulatory rehearsal loop or the visual-spatial sketchpad. Their results showed that only the executive concurrent task affected PM performance (see also Marsh, 2002 for manipulation of the task demands). In general results show that complex, demanding ongoing task produced worse PM performance, and therefore if one want to compare performance in the PM task, it is necessary to equate differences in the difficulty of the OT. Obviously this is important when studying developmental effects (or other factors related to individual differences), since fair age comparisons of PM performance require adapting the ongoing task to achieve similar difficulty levels.

With children, the effect of task difficulty has also being demonstrated. For example, Kliegel et al. (2013) assessed PM performance of two groups of children (9-and 10 and 6-an7- year old children) through a video game in which the ongoing task consisted of driving a vehicle and maintaining it in the road without crashing with other cars (15 cars per minute in the less demanding condition, and 35 cars per minute in the more demanding condition). For the PM the children were required to remember to refuel the car when one-fourth or less fuel was left in the tank. The results showed poorer PM performance for children in the more demanding condition. Mahy et al. (2014) demonstrated that the effect of cue salience in children interacted with the difficulty of the ongoing task. In their study, they manipulated the difficulty of the ongoing activity by requiring 4- and 5-year-old children to sort cards according to the size of pictured items (easy) or by having the opposite size (difficult). In addition they were asked to ring a bell whenever they detected an animal in the card (PM task). They found that more difficult ongoing task impaired PM performance when the PM cue was not salient (the PM card did not have a red border), but this effect was not evident when the PM card had a red border (high salience).

In general, the important conclusion here is that different elements of the ongoing task may interact with other factors related to PM performance, and because children of different ages may experience different levels of difficulty, it is important to consider if these factors and interactions are responsible for age differences when studying PM development (Mahy et al., 2014; Rendell, McDaniel, Forbes, & Einstein, 2007).

4.2. Nature of the PM task

A second methodological factor that has been the cause of concern is the nature of the PM task. Some studies have provided evidence that same age related differences in PM are due to the nature of the PM task. Thus, age differences in laboratory tasks are smaller or not evident when more naturalistic tasks are involved (Kvavilashvili & Fisher, 2007; Rendell & Craik, 2000). In this vein, Henry et al. (2004) performed a meta-analysis comparing age related deficits in lab-based and naturalistic-based task and concluded that age-related deficits in lab-based PM tasks are equivalent in magnitude to the age-related benefits observed in naturalistic PM task. That is, that lab-based PM tasks are better performed by young adults, whereas naturalistic PM task are better performed by older adults. In Maylor's (1998) study participants were assessed with a laboratory event-based PM task (EBPM) in which slides of famous people were shown in a screen and participants were asked to name each face (ongoing task). In addition they were asked to mark the trial number if the person shown in the picture was wearing glasses (PM task). The proportion of prospective memory responses to target events declined monotonically with increasing age (0.77, 0.62, and 0.26, for the young, middle-aged, and elderly, respectively). Similarly, other laboratory TBPM tasks are consistent with the view that there is an age-related decline for PM with impaired performance for older adults (Mioni & Stablum, 2014; Vanneste, Baudouin, Bouazzaoui, & Taconnat, 2016). In contrast, older adults perform as well or better than younger adults in semi naturalistic studies involving time-based and event-based PM task (Kvavilashvili & Fisher, 2007; Rendell & Craik, 2000). In their Experiment 2, Rendell and Craik (2000) assessed young, young - old and old-old participants with 10 PM tasks that they had perform during 7 days. There were four regular (routine, recurring) tasks, four irregular (one-off, nonrecurring) tasks and two time-check tasks. Participants received full instructions about the time-check and the regular tasks in a session before the experiment began. Instructions for the four irregular tasks were provided on a daily task sheet at the beginning of each day. The four regular tasks involved to "take medication"; two of them were time-based (at 11 a.m. and 9 p.m.) and two were event-based (at breakfast and dinner). The four tasks introduced each day also comprised two time-based tasks and two event-based tasks (e.g., "at 12 noon, phone the insurance company to arrange an appointment "and "when you first open the fridge in the afternoon or evening, check if there is enough butter"). The two time-check tasks required participants to do a time-check in relation to the two daily event-based irregular PM tasks; 60 minutes after first and 30 minutes after the second. The pattern of results showed that the older adults mostly outperformed the younger adults in all the tasks. In particular, the younger group had lower performance than both young-old and old-old groups on regular and irregular tasks, and the young-old group had a superior performance on the time-check task. Similarly, Kvavilashvili and Fisher, (2007) provide instructions to younger and older adults to try to remember to call the experimenter the next Sunday at an appointed time (they received instruction on a Monday). In addition, they were asked to make an entry in a diary whenever the intended action came to mind. Results showed that old participants were as good as young participants in remembering to call at the appointed time (time-based task). In addition, the entries in the diary suggested that good performance in older people in more naturalistic tasks might be due to the fact that outside the laboratory there are more probabilities of encountering cues that stimulate retrieval of the intentions during the interval between the formation of the intention and the time to perform the intention. In addition, although the older adults did not report thinking about the task more frequently than the younger adults, age effects were obtained in self-rated levels of motivation and the type of ongoing activities people were engaged in at the time of rehearsal. Older adults reported to have higher levels of (intrinsic) motivation before and after the completion of the PM task than younger adults. In addition, although older participants were more likely to be engaged in seemingly automatic activities at the time of reported rehearsals, they were also more likely to be concentrating on these activities since they were more attentionally demanding for them. In this line, McDaniel and Einstein (2007) have also suggested that better or similar performance for older relative to younger adults in natural time-based PM tasks is that in semi-naturalistic settings older adults have more control over the ongoing activities, and they also have more resources available for internally initiated reminders or monitoring. In any case, these results provide some insights into possible reasons for obtaining contradictory findings in PM and aging studies regarding significant age effects in the laboratory with no age effects (or superior performance of older adults) outside the laboratory.

There is also some evidence that the nature of the task can also modulate PM performance in children. Ceci and Bronfenbrenner (1985) examined time-based PM for 10- and 14-years-old who were asked to remember to take cookies out of the oven in 30 minutes or to remove the battery charger in 30 minutes, and during the 30-minutes interval, the children were encouraged to play a video game in another room. Children showed varied strategies depending on the context in which PM task was presented. When the baking and the battery charging task were presented in the laboratory, many children increased the frequency of their monitoring as the target time approached to support good performance. In contrast, when the baking and the battery-charging tasks were performed at home, the children adopted a strategy that allowed them to maintain similar PM performance but also freed up maximal time for playing the video game. Contrasting results regarding cue focality in children can also be related to nature of the task. Thus Kliegel et al., (2013) found differences between 6-7 year-old and 10-11 year-old children in a non-focal PM involving a driving computer game, whereas there were no age differences in the focal condition of the PM computer game (Kliegel et al., 2013). In a more naturalistic procedure, however, Walsh et al. (2014) reported age differences in 5- to 7- years old children in a focal PM task in which they had to remember to buy items in a shopping task. In particular, children were asked to do a virtual shopping trip in which they had to remember to buy an item whenever the target store appeared (focal cue). Similarly, Krasny-Pacini, Servant, Alzieu and Chevignard (2015) in a natural environment also found differences in children from 8- to 11- year-old in a focal task involving cooking a chocolate cake and a fruit cocktail (OT) and remembering a PM intention related with their cooking activity (e.g., putting the rubbish in the bin). Hence, the nature of the OT is a relevant factor to be considered when evaluating developmental PM performance. What it is important here is that in order to reach conclusion on the effects of some variable during development, it is necessary to consider the type of tasks and the environment in which the PM tasks has been performed.

4.3. Motivation of the PM task

Motivation is also a factor to consider when designing a developmental PM study. Many studies have shown higher PM performance under conditions in which successful performance in the PM task has been emphasized (Kliegel, Martin, McDaniel, & Einstein, 2001; Brandimonte & Ferrante, 2015; Cook, Rummel, & Dummel, 2015). For example, Cook et al. (2015) examined the effect of value-added intentions by manipulating the cognitive frame (loss-frame, gain-frame and no-frame control conditions) associated with monetary contingencies for detecting prospective memory (PM) cues. The loss-frame condition was associated with a monetary punishment for failing to respond to cues, whereas the gain-frame condition was associated with a monetary reward for remembering to respond to cues. Both conditions were compared to a no-frame control condition with no contingency linked to performance. Cook et al. (2015) found increased PM performance for participants in the loss-frame and in the gain-frame conditions relative to the no-frame condition. However, other studies have shown that incentives do not always produce increments in PM performance and that their effects might depend on the type of PM task. For instance: Kliegel et al., (2001) reported two experiments that manipulate task importance in a time-based and an event-based prospective memory paradigm. As ongoing task, participants were told that they would receive a series of trials in which they had to rate a word in a given dimension. Thus, each ongoing trial consisted of a word, the rating dimension, and the rating scale. In addition, in Experiment 1, participants were told that they should press the red key every 2 minutes once they started the experiment (in experiment 2 the PM task was to press the red key whenever a particular word appeared). They were told that they could monitor the time by pressing the yellow key, in this case a time counter would appear for 2 seconds. Half of the participants were told that the prospective memory task was more important than the word-rating task, whereas the other half was told that the word-rating task was the more important task. Interestingly, their results showed that importance had an effect on the time-based but not on the event-based task. In addition, analyses of the time- course for monitoring indicated that participants monitored the clock more frequently in the high-importance group.

Brandimonte and Ferrante (2015), in two experiments, also explored the effects of different types of rewards on pro-social PM performance. In Experiment 1, participants received no reward, a low-value reward (1 euro), or a high-value reward (20 euros) for their pro-social PM action. In experiment 2, the reward condition consisted in disclosure of their altruistic behaviour once they performed it. Results revealed that introducing a small-value reward or non-material reward (experiment 2) impaired performance in the pro-social PM relative to the high-value reward condition. In a recent review, Walter and Meier (2014) concluded that intrinsic and extrinsic motivation are directly related to some specific PM processes. Thus while extrinsic motivation seem to induce strategic monitoring, intrinsic motivation enhances the activation of intention representation and leads to a performance advantage due to automatic retrieval. In this line, the effect of some factors seem to depend on the degree of motivation. For example, Nigro and Cicogna (2000) showed that the effect of the delay between formation of the intention and its execution depended on the participants motivation. In their experiment, at the end of a first experimental session, they asked their participants to deliver a message to the experimenter responsible of the second experimental session. The length of the time interval varied (10 minutes, 2 days, 2 weeks), however it did not affect performance when participants received instructions emphasizing the importance of delivering the message (the intended action).

The interaction of motivation with other characteristic of the PM task has been shown in children. For example, Han et al. (2017, Experiment 1) required children to place the correct colour ball that previously had been associated with one specific animal below the corresponding animal. Additionally, they had to give a bone model to the dog (PM task) if they found the target dog in the OT. In their Experiment 3, they manipulated OT difficulty by including three or five possible animal-colour pairs. In addition, Han et al. also manipulated (by offering a prize to half of the children because of their well OT performance) the children's motivation. Results showed that the difficulty of the OT had an effect over the PM performance only when 3-, 4- and 5- year- old children were motivated to complete the OT. On the other hand, Sheppard, Kretschmer, Knispel, Vollert and Altgassen (2015) showed that in 5- and 7- years-old children the degree of association between the PM cue and the intention did not have an effect in PM performance in a non-motivated conditions. However, children´s performance increased when they received an extrinsic incentive (taking a surprise prize from a box). Similarly, Causey and Bjorklund (2014) found that pre-schoolers´ performance was higher in a high motivation condition where they were asked to remember to take a sticker when the finish the task, relative to a low motivation condition, in which children were asked to remember to change the sign on the door before leaving their classroom. Agency was also manipulated so that in both conditions children either have to remind the experimenter to perform the action or to do it themselves. While agency did not have an effect over PM performance and children remembered the prospective intention independently of who had to do the intention (the experimenter or themselves), the degree of motivation had an effect on performance.

Somerville, Wellman and Cultice (1983) also showed that age effects can be reduced or eliminated when motivation is included. Thus, 2-year-olds were as good as 4-year-olds, with 80% success in remembering high reward PM tasks. Moreover, high relative to low monetary incentives have been found to benefit PM retrieval in children with orthopaedic injury and moderate traumatic brain injury (McCauley et al., 2011). In this study, 7- to -16- years -old children were asked to remember to respond with the sentence “ Please give me three points” each time the experimenter told them “Let´s go to try something different” while children were completing a neuropsychological evaluation. Children included in the high motivation group could exchange their points for dollars while children in the low motivation condition could exchange their points for pennies. McCauley et al.’s study results showed children with orthopaedic injury and moderate traumatic brain injury performed significantly better when they were in the high-incentive condition than when they were in the low-incentive group. Sheppard, Kvavilashvili and Ryder (2016) also found differences between severely autistic and typical development children when they were asked to remind the experimenter of a low motivation intention (e.g., remembering to clap in response to hearing music), whereas in a motivated PM task in which they had to remember to ask for a reward, differences between these group of children were not found. These results clearly show the importance of motivational factors when remembering a delayed intention during childhood. In addition, Penningroth, Bartsch and Mcmahan (2012) in a naturalistic study in which parents described their children´s performance (6-and 10-years-old) in everyday prospective memory tasks, reported better PM performance in the tasks regarded as more important by the children. Older children outperformed younger children when the tasks were less motivating, however, these age differences were not evident when the tasks were evaluated by the parents as highly important for their kids. In conclusion, motivation is a factor to take into account when children´s PM is assessed.

4. Organization and goals of the experimental series

The general aim of the studies we present in this dissertation was to better understand the development of PM by looking at conditions in which attentional demands of the PM task were manipulated (focal vs non-focal and event- vs activity-based PM task) and explore the effects of these manipulations in school children´s PM performance. The study of PM in children is important for theoretical and applied reasons. Theoretically, both PAM and dual process PM theories assume that younger children will have more difficulties than older children and adults when confronting many PM situations. As we have discussed, PM involves maintaining the intention in working memory, monitoring the environment for cues, detecting the cue and switching the task goal, retrieving the intention and executing it. Obviously, these processes will be difficult to perform for a brain that it is still in development. Despite PAM and dual processes theories agree on the basic component processes involved in PM, they differ in assuming whether or not attentional control is mandatory. Thus, whereas PAM theory proposes that preparatory attention and memory processes are necessary for successful prospective retrieval, the dual process framework assumes that some situations may facilitate these processes, making them more automatic and autonomous. Thus, focal cues are assumed to facilitate cue detection diminishing the need to for strategic monitoring. Similarly, strong cue-intention relation facilitates spontaneous retrieval of the intention, and other variables can also act to facilitate or make more difficult PM performance. Therefore, according to the latest framework, effortful attentional processes are not always needed, as it is assumed by PAM theory. From this view, dual process framework will also predict that age differences will be smaller or not present in situations where perspective remembering can be more automatic and spontaneous. From this, developmental research can be used to test some of the predictions of the theories. From a developmental point of view, understanding how PM works and develops in children of different ages is also of great interest since PM involves many memory and executive processes and it provides a context in which monitoring, goal maintenance, switching and retrieval can be observed at work. Finally, understanding the difficulties that children confront when trying to remember future actions has also many implications for applied setting. Although pre-school children are not assumed to take responsibilities over future plans or to remember things that they need to do, this situation changes when they turn 6 years old and they start going to regular school. At this point, parents and teachers start giving the children more responsibilities, and start assuming that they can follow instructions to bring materials to school the following day, to deliver messages to their parent, to do the homework, and remember many other small things that are important for the children's life. Knowledge of the children's difficulties and the conditions that can facilitate them to remember their tasks can be helpful to design conditions that progressively help the children to take responsibilities over plans and intentions plans and intentions.

In the three experimental series described in the next chapter, we explored the role of cue focality, activity-event base cues, and motivation in laboratory and natural tasks performed by children of 6-7 to 10-11 years old. In the first section of the chapter, we looked at the effect of cue focality over monitoring process by looking at the consequences of performing PM over the ongoing tasks (PM cost) in 6-7 and 10-11 years old children. According to PAM theory (Smith, 2003), monitoring the environment for PM cues generates a cost in ongoing activity. From this, the lower performance of children in OTs can be due to less developed cognitive abilities for processing PM cues and retrieving the intention, (resulting in lesser PM performance; Kliegel et al., 2013), but also to deficient strategies related to allocating resources to the PM task; Leigh & Marcovitch, 2014). In order to explore what process are underlaying OT costs in school children, in our first experiment[1] we assessed children´s PM performance with two type of task (focal and non-focal) that have been shown to require different strategic allocation of resources for monitoring the environment for the PM cues and retrieving the intention (Kliegel et al., 2013). Because detection of focal PM tasks involve the same type of processing than the ongoing task (the OT forces processing of the PM target), effortful monitoring processes are not required and spontaneous cue detection and PM retrieval is probable to occur. In contrast, in non-focal PM tasks, monitoring for external cues is necessary because there is no overlap between the processes involve in OT and PM performance (McDaniel et al., 2015). Performance on the ongoing task will allow us to pinpoint if our groups of 6 and 11 year old children, were able to strategically allocate their resources depending on the requirement of the task. Thus, OT performance was evaluated by comparing the performance of a single condition with an ongoing activity condition involving a focal on non-focal prospective tasks. In line with Kliegel et al.'s (2013) findings, we expected to obtain better PM performance in the older group than in the younger group in the non-focal condition, but no age differences in the focal condition. Second, based on the findings of Smith et al. (2010) that observed a PM cost in 6- and 11-year-old children when a single (OT) condition was compared to a condition that included non-focal PM task, we expected that the non-focal PM task to would produce worse OT performance in both age groups relative to the focal condition. In general we would expect that younger children will have more difficulties adjusting their monitoring strategies to the tasks requirements and that their performance will be similar in the two cue conditions.

In the second section of the chapter, we aimed to dissociate the specific prospective and retrospective PM components that are more susceptible to developmental effects. Hence, in our second study[2], we recorded EEG while 6, 8 and 10 year-old children performed focal and non-focal PM tasks. Particularly, we were aimed to explore age differences in the N300 component (related to detection of the cue: West, 2011), the frontal positivity (associated to the ability to switching from the OT to the PM; Bisiacchi et al., 2009), parietal positivity (related with the recognition of PM task; West, 2011) and the frontal slow wave (associated with monitoring the retrieval of the intention; West, 2011). Based on a previous study by Cona et al. (2014), we expected focality effects in the frontal positivity (reflecting switching) being more sensitive to the focal condition and more pronounced amplitudes in non-focal compare to focal PM task in parietal positivity and frontal slow wave components. However, the exact pattern of results were not predictable since previous studies had not included children as young as 6 year-old and there is no developmental study comparing ERPs variations in focal and non-focal conditions in children of different ages. As mentioned, this is important because, ERPs associated to PM allowed us to identify specific PM processes susceptible of changes with age.

In the third experiment[2], we wanted to extend our finding to more natural situations and explore event and activity based PM tasks that are also assumed to require different cue monitoring and processing. In addition, we took care of an important methodological concern in PM developmental studies and adjusted the difficulty of the ongoing task to the age of the participants. Previous studies have shown that some controversial findings might be due to difference in difficulty with age (Krasny-Pacini et al., 2015; Kvavilashvili & Fisher, 2007). In addition, we wanted to explore and additional modulating factor and report whether younger children can reach similar level of accuracy than older children if rewarding, motivation conditions are introduced (Penningroth & Bartsch, 2012). Hence in our third study, 6 and 11 year-old children were evaluated by using school- related activities as OT (working with puzzles, reading, find differences between two pictures and solving math problems), half of them involving event cues (the PM cue appeared during OT; e.g., remember mark in the paper the more difficult difference to detect); and half of them involving activity cues (the PM cue was the end of the OT task; e.g., remind me to put the paper in the enveloped when you finish finding the differences between the pictures). Additionally, half of the participants were assigned to a reward condition in which they receive a small or large prize depending on their performance and whereas the other half was assigned to a non-reward condition. Based on the assumption that more resources are needed to remember an intention when the PM cue does not appear during the OT (Walsh et al., 2014), we expected better performance in the event PM task compare to the activity based PM. Similarly our expectation were that age difference will be larger in the more difficult activity-based, although these differences may be reduced in the motivation condition.

Finally, in the last chapter of this dissertation we tried to summarise the main findings and conclusions, and discuss the theoretical and practical implications in a more general way.

[1] This study is published in the journal "Frontiers in Psychology".
[2] This study is under revision.

CHAPER II: EXPERIMENTAL SECTION

Experiment I

Prospective memory (PM) is the ability to remember to complete a future intention (Brandimonte et al., 1996). This ability is essential to success in daily life activities, such as remembering to make an important call or take a pill after breakfast. In children, low PM performance could disrupt school life; for example, a child may forget to give his/her parents a permission slip or bring his/her homework to class (Kvavilashvili et al., 2001). In a typical PM task, participants are asked to carry out an ongoing task (OT) while also remembering to perform a prospective task, either when they encounter a specific cue embedded within the OT or when a specific time has elapsed (Kvavilashvili et al., 2001). Prospective recall is a time-based PM task that requires the person to remember to perform an action at a specific time or time interval, and event-based PM tasks involve remembering to perform an intention upon the occurrence of a specific event (McDaniel & Einstein, 2000). The present study focuses on the latter type of PM task and tries to identify age differences in the possible costs associated with maintaining a prospective intention while performing an ongoing task.

Previous research has suggested that successfully remembering an intention involves four main processes: forming an intention, maintaining the intention until the appropriate cue or time is present, initiating the intended action when the cue is detected (event or time) and, finally, executing the intention (Kliegel et al., 2002). According to the preparatory attentional and memory processes (PAM) theory, these processes consume attention and generate a cost in the OT (Smith, 2003; Smith et al., 2010). Thus, to monitor the environment for cues that signal retrieval of the intention, participants should maintain a state of readiness during the OT. Although these processes may be outside of conscious awareness, they consume resources, impairing OT performance. This claim has been supported by various experiments reporting slower performance and lower accuracy for the OT while trying to remember an intention, relative to a control condition in which the OT is performed by itself (Anderson et al, 1998; Craik et al., 1996; Park et al., 1997; Smith, 2003; Smith et al., 2007). For example, Smith (2003) reported that participants were 300 milliseconds (ms) slower in performing a lexical-decision task (deciding whether or not a string of letters formed a word) when they were also instructed to prospectively remember a particular word (PM intention) than when they were not asked to remember a word. Similarly, Smith et al. (2010) reported lower performance in a color-matching task when participants were required to press another key when a particular image appeared on the screen (PM task). In general, results comparing OTs with and without concurrent prospective intentions suggest that participants strategically allocate resources to monitor PM cues, imposing a cost on the OT.

Strategic allocation of resources to a PM task has also been related to working memory (WM) capacity. WM is needed to keep an intention in mind and to update the task goal when a cue is encountered (Einstein et al., 2000). Several studies have reported a relationship between WM and prospective recall performance (Mahy & Moses, 2011; Smith & Bayen, 2005; Wang et al., 2008). For example, Smith and Bayen (2005) found that WM capacity predicted the extent to which participants engaged in preparatory attentional processes to perform a PM task. Participants with higher span scores showed greater costs than participants with lower span scores in the OT, indicating that high-span participants were more prone to engage in preparatory attentional processes. Similarly, Cheie et al. (2017) showed that increasing processing demands on the OT or imposing an additional WM span on children compromised their performance.

However, the PAM theory assumption that prospective remembering always requires preparatory attentional processes has been questioned. According to the dual process framework, PM retrieval could be spontaneous or effortful, depending on the task demands (Einstein et al., 1997; McDaniel et al., 2015). For example, Basso et al. (2010) manipulated the cognitive demands of WM and PM dimensions on an event-based prospective task. The ongoing activity was either a WM-updating task involving higher or lower demands or a lexical decision task (low WM demands). The prospective task required the participants to respond whenever a previously presented word appeared. The results pattern was complex because PM only affected performance on the WM task at higher loads. By contrast, the pattern for the lower WM conditions showed that performance was independent of the concurrent PM task. Similarly, a number of studies have shown no cost to the OT with successful PM performance (Harrison & Einstein, 2010; Knight et al., 2011; Scullin et al., 2011; Scullin et al., 2010), suggesting that, in some cases, cue monitoring might not be attentionally costly.

More direct evidence for the dual process framework (McDaniel et al., 2015) comes from studies manipulating the focality of the prospective cue. Focality is manipulated under the assumption that the degree to which attentional resources are demanded for cue monitoring depends on whether the PM task involves focal or non-focal cues. Focal PM tasks are those in which the OT involves processing the defining features of the PM cues (e.g., categorizing strings of letters as words/non-words and pressing another key whenever a predetermined target word appears as a PM task; Einstein & McDaniel, 2005). By contrast, non-focal tasks involve PM cues that are not part of the information extracted from the OT for accurate performance (e.g., deciding whether the word on the left is a member of the category on the right as an OT and pressing another key whenever the word includes the syllable “tor”; Einstein & McDaniel, 2005). In focal PM tasks, the OT forces processing of the PM target, potentially requiring spontaneous non-attentional retrieval. By contrast, in non-focal PM tasks, monitoring for external cues is necessary because there is no overlap between the information needed for the OT and that needed for PM performance. In this case, effortful monitoring should be invested to detect the PM cue and to switch from the OT to the PM. According to this proposal, cue focality should have clear effects on monitoring and cue detection, since the ability to strategically monitor for environmental cues may depend on whether the OT orients attention to the relevant contextual PM cue. For example, in Ball and Bugg’s (2018, Experiment 1) study, participants were asked to perform a lexical decision task (OT) and to detect a syllable embedded in some words. They were specifically told that the syllable occurred in words, but not in non-word trials (focal context cue condition). By contrast, in the non-focal condition, they were told that the syllable appeared only in items starting with consonants (non-focal context cue condition). Strategic monitoring (resulting in an OT cost for the PM condition relative to the single-OT control condition) was only evident during the focal condition, in which the type of OT processing automatically oriented attention to the relevant features of the contextual cue. These findings suggest that strategic monitoring is dependent on limited-capacity processing resources and may be relatively limited when the attentional demands of context identification are sufficiently high.

Because these processes require efficient WM and executive control capacity, another important factor in PM performance is age. In general, research has shown that the development of PM across the lifespan follows an inverted U path, with PM increasing from preschool to adolescence and decreasing from late adulthood

(Zimmermann & Meier, 2006; Zöllig et al., 2007). OT costs have been found in adult populations, but also in children. For example, Leigh and Marcovitch (2014) reported PM costs in young children (4, 5 and 6 years old) categorizing images (as animals/non-animals or food/non-food) when they were also asked to press a smiley face button whenever they saw a particular image. However, although some studies have included OT performance as a covariate (Kliegel & Jäger, 2007; Kvavilashvili et al., 2008), few studies have focused on PM costs during OT performance by themselves, and these effects are not completely understood (Leigh & Marcovitch, 2014). In addition, the lower performance of children in OTs might be due to less efficient cognitive processing (resulting in more costly PM), but also to deficient strategies related to allocating resources to the PM task.

One way to approach this problem is to manipulate the attentional demands of the PM task (e.g., by manipulating cue focality) and explore the effects of this manipulation in children of different ages. This approach has been followed with younger and older adults (see Henry et al., 2004, for a review). For example, Rendell et al. (2007) manipulated the presence of focal and non-focal PM cues in younger and older adults and found that age-related differences on PM performance were more pronounced when the cue was non-focal.

Age differences in more demanding non-focal tasks have also been shown in studies comparing adolescents and young adults (Wang et al., 2011). Wang et al. (2011) manipulated the focality of the cue and found that the adult group outperformed the adolescent group in the non-focal PM condition. They used ongoing spatial WM tasks in which participants were asked to press a target key whenever a specific embedded target appeared (focal condition) or whenever the background color of the WM trials changed to a specific color (non-focal). Response times for the ongoing WM task showed group differences only when the PM task involved non-focal intentions, suggesting that age differences might specially arise in cases involving more difficult monitoring and cue detection. Finally, Kliegel et al. (2013) compared 6- and 7-year-old and 9- and 10-year-old children who played a videogame requiring them to drive a vehicle. In the non-focal condition, the PM cue was a yellow flowerpot located outside the road, and in the focal condition, the cue was a yellow car also in the road. Performance in the PM task was lower in the 6- and 7-years children than the 9- and 10-year-old children in both conditions, suggesting that both focal and non-focal cues require attentional resources. However, when performance on the OT was included as a covariate, age differences appeared when the cue was outside of the center of attention.

However, Kliegel et al. (2013) found mixed results and did not report direct comparisons of the children's performance on the OT. Thus, the main aim of the present study was to address the role of cue focality in children of different ages by examining PM performance and ongoing cost. We directly compared children's (6 and 11 years old) performance in the OT in conditions in which they performed the OT by itself (single-task condition) and in conjunction with a focal or a non-focal PM task. We chose 6-year-olds and 11-year-olds for our groups because previous research has shown differences in PM between these two age groups (Kliegel et al., 2013; Smith et al., 2010) and there is evidence that WM capacity, goal maintenance, inhibition and other related cognitive abilities increase from the age of 6 (Henry, 2011; López-Vicente et al., 2016; Marcovitch, Boseovski, & Knapp, 2007; Marcovitch, Boseovski, Knapp, & Kane, 2010; Towse, Lewis, & Knowles, 2007). First, in line Kliegel et al.'s (2013) findings, we expected to observe better PM performance in the older group than in the younger group in the non-focal condition, but no age differences in the focal condition. Second, based on the findings of Smith et al. (2010), we expected the non-focal PM task to produce worse OT performance in both age groups relative to the focal condition. Smith et al. (2010) observed a PM cost in 6- and 10-year-old children when a single-task condition was compared to another condition including a non-focal PM task. Regarding the focal condition, and based on Leigh and Marcovitch's (2014) results, we expected to observe a PM cost in our younger (6-year-old) group. Our expectations for the 10-year-old group were less clear, since no study has yet reported data on focal PM costs in late childhood. However, because overall age-related differences are usually more pronounced under non-focal cues (e.g. Kliegel, Jäger, & Phillips, 2008; Rendell et al., 2007; Scullin et al., 2010; Wang et al., 2011), one could predict a lesser cost (or even no cost at all) in 11-year-old children (relative to 6-year-old children).

1. Materials and Methods

1.1. Participants

We recruited 95 children from a local primary school in Granada (Spain). The younger group consisted of 45 children (23 boys and 22 girls) who were 6 years old (M = 6.88, SD = 0.29), and the older group consisted of 50 children (26 boys and 24 girls) who were 11 years old (M = 11, SD = 0.39). The number of participants per group (approximately 50) was decided in advance based on the sample sizes considered in previous studies with children (e.g., Mahy et al., 2014; Smith et al., 2010). All participants were born in Spain and spoke Spanish as their mother language. The children were recruited through an informative talk for their parents in the school. The study was approved and carried out in accordance with the recommendations of the Research Ethics

Committee of the University of Granada. All parents of participants were provided with information about the study and gave written informed consent in accordance with the Declaration of Helsinki. The participants belonged to families with medium socioeconomic status, as measured through their income index. To minimize the error variance, all participants performed all three experimental conditions: single-task, focal and non-focal. Hence, the study comprised a mixed design with age (6 vs. 11) and experimental condition as variables (between and within participants, respectively).

1.3. Procedure

The experimental tasks used here were adapted from standard PM tasks used in previous studies with children (Cottini, Basso, & Palladino, 2018; Mahy et al., 2014). Before conducting the present experiment, a pilot study with ten 6-year-old children and ten 11-year-old children was carried out to ensure that children of these ages were able to successfully perform the focal and non-focal conditions and that we were able to obtain levels of performance similar to those of previous experiments. In the preliminary study, children were asked to perform the focal and non-focal tasks in random order. As the ongoing activity in both conditions, they had to categorize images that appeared on the screen as animals or not animals. In the focal condition, along with the categorization activity, children were asked not to categorize the ball or kite images but to press particular keys. In the non-focal condition, they had to stop the ongoing activity and press particular keys whenever the border of the screen changed to magenta or grey. The results of the pilot study showed that all the children were able to perform the PM task with levels of performance similar to previous studies (see Kliegel et al., 2013). In the focal condition, there was no difference between 6-year-old (M = 0.91, SD = 0.13) and 11-

year-old (*M* = 0.92, *SD* = 0.06) children, $t(18) < 1$. In contrast, the analyses revealed statistically significant differences between the younger (*M* = 0.44, *SD* = 0.13) and the older (*M* = 0.71, *SD* = 0.09) children in the non-focal condition, $t(18) = 5.23$, $p < 0.01$, $d = 2.41$. Since these results are in line with those obtained by Kliegel et al. (2013), we conducted the proper experiment with a focus on the cost of focal and non-focal PM cues over the ongoing activity.

As in the preliminary study, testing was conducted individually in the school and lasted approximately 20 minutes. The testing session took place during school hours, and the children were taken out of their classroom during the testing. Each session consisted of three parts corresponding to each of the experimental conditions (single-task, focal and non-focal), whose order of administration was randomized.

In all three conditions, children were asked to perform a single task (OT) that consisted of categorizing pictures as animal or non-animal. We used 65 images taken from the work of Rossion and Pourtois (2004). Each was repeated twice during the three parts of the experiment. Half of the images referred to animals, and the other half did not. The stimuli appeared in the center of the screen surrounded by a 15 by 15 pixel color border, which was randomly changed for each presentation of the stimuli (red, blue, green or yellow). The children were asked to press the key 'yes' (placed on the 'a' in the keyboard) whenever an animal item appeared and the key 'no' (placed on the 's') whenever a non-animal item appeared. In the focal condition, the prospective focal task was included in the OT. Children were asked to remember to press a different key whenever a target picture (a kite or a ball) appeared. Whenever the kite appeared, they had to press the key 'start' (placed on the 'k'), and whenever the ball appeared, they had to press the key 'square' (placed on the 'l'). In the non-focal condition, the children performed the OT and were also asked to press a different key when the picture frame had a particular color (magenta or grey). Specifically, whenever the screen border was magenta, they were asked to press the key ‘start’ (placed on the ‘k’), and whenever the border was grey, they were to press the key ‘square’ (place on the ‘l’).

In each condition, the experiment had the following structure: First, the participants received the instructions for the single-task condition and practiced the task on nine trials. Then, after being informed that the tests had started, they moved to the experimental trials. The order in which the three conditions were presented to each participant was random. In the single-task condition, the participants faced 50 trials. In the focal condition, they were told about the prospective intention and practiced the OT task, which included four PM targets. When they correctly performed two of these four targets, they started the test that included 50 ongoing trials with five PM trials. We chose this PM trial frequency based on previous studies with children of similar ages (Ford et al., 2012; Kliegel & Jäger, 2007). The non-focal condition used the same structure, but involved instructing the participants about the non-focal cues. There was a short break (about 2 min.) between conditions, during which the children were given the instructions to perform the next block: “Now, I am going to explain the next game to you. Are you ready for this?” After all participants had been assessed, they received a gift for their participation.

The PM trials appeared in the focal condition in the 10th, 23rd, 32nd, 42nd and 54th positions. In the non-focal condition, the PM trials were in the 8th, 19th, 32nd, 45th and 54th positions. In the focal condition, two of the PM trials showed a kite, two showed a ball, and the fifth cue varied randomly across participants. In the non-focal condition, half of the target's frames were magenta, and the rest were grey. The dependent measures were the proportion of correct responses and the reaction time.

Stimuli presentation during the OT and PM trials was set to a minimum of 1600 ms and a maximum of 2800 ms. When participants responded after 1600 ms, the next trials occurred after an inter-stimulus interval (ISI) of 250 ms. A response latency shorter than 1600 ms was filled with a black screen until 1600 ms, followed by the inter stimulus interval. If the participant did not respond within 2800 ms, the inter-stimulus interval appeared.

3. Results

While the focus of the present experiment is on the performance of an ongoing task, we also report analyses of PM performance for the sake of completeness. As expected from the pilot study (and also the study by Kliegel et al., 2013), focality had a reliable effect for the 6-year-old group ($F(1, 44) = 16.18$, $MSe = 0.01$, $p < 0.01$, $\eta_p^2 = 0.27$), indicating better performance when the cue was focal (M = 0.74, SD = 0.32) relative to the condition in which the cue was non-focal (M = 0.50, SD = 0.32). The same pattern was observed in the 11-year-old group (M = 0.92, SD = 0.16 vs. M = 0.82, SD = 0.21; $F(1, 49) = 52.07$, $MSe = 0.00$, $p < 0.01$, $\eta_p^2 = 0.51$).

Table 1. *Performance of OT*

	6 years (n=45)		11 years (n=50)		Mean	
	ACC	*RT*	*ACC*	*RT*	*ACC*	*RT*
single	0.93(0.07)	1213(178)	0.97(0.04)	939(135)	0.95(0.06)	1076(156)
focal	0.89(0.12)	1322(150)	0.97(0.04)	1018(133)	0.93(0.08)	1170(141)
non-focal	0.81(0.14)	1498(207)	0.91(0.07)	1331(135)	0.86(0.11)	1414(171)
Mean	0.88(0.11)	1344(178)	0.95(0.05)	5096(134)		

Note: Means of the proportions of correct OT responses and reaction times (in ms). Standard deviations are reported in brackets.

Performance in the ongoing task was analysed first by conducting a 3 (condition) by 2 (age) ANOVA on the proportion of correct responses (Table 1). For each participant, correct responses were averaged across conditions and introduced into the analysis. Errors were evenly distributed across stimuli and participants with no outliers. The analysis of accuracy showed an effect of age ($F(1, 93) = 26.24$, $MSe = 0.01$, $p < 0.01$, $\eta_p^2 = 0.22$), such that the older group performed the OT better than the younger group. In addition, there was a reliable effect of condition ($F(2, 92) = 41.42$, $MSe = 0.01$, $p < 0.01$, $\eta_p^2 = 0.31$). Post-hoc analyses using Bonferroni tests indicated that performance was reliably lower in the non-focal condition than in the focal and single-task conditions.

More relevant, there was a reliable interaction between age and task condition (see Figure 1; $F(2, 92) = 4.59$ $MSe = 0.01$, $p = 0.01$, $\eta_p^2 = 0.05$), which was followed up by analyzing the effects of condition on each age group. The analysis revealed a statistically significant effect in the 6-year-old group ($F(2, 43) = 20.18$, $MSe = 0.01$, $p< 0.01$ $\eta_p^2 = 0.31$). Further analyses indicated that performance was reliably worse in the non-focal condition than in the focal ($t(44) = 3.30$, $p < 0.01$, $d = 0.53$) and single-task ($t(44) = 6.57$, $p < 0.01$, $d = 1.05$) conditions. The difference between the focal and single-task conditions also reached statistical significance ($t(44) = 2.89$, $p < 0.01$, $d = 0.47$).

There was also a reliable effect of condition in the older group of children ($F(2, 48) = 27.85$, $MSe = 0.00$, $p < 0.01$, $\eta_p^2 = 0.36$). Performance in the non-focal condition differed from performance in the focal ($t(49) = 5.69$, $p < 0.01$, $d = 0.91$) and single-task conditions ($t(49) = 6.33$, $p < 0.01$, $d = 0.95$). In this group of children, however, the performance difference between the single and focal conditions was not reliable ($t(49) < 1$, $d = -0.10$).

We also performed a 3 (condition) by 2 (age) ANOVA for reaction times on the ongoing task. Results of this analysis revealed a reliable effect of condition (F (2, 92) = 263.37, MSe = 11555.34, $p < 0.01$, $\eta_p^2 = 0.74$). Bonferroni tests indicated that responses were slower in the non-focal condition than the focal and single-task conditions. Reaction times in the single-task condition also differed from those in focal condition. The age effect was also reliable ($F(1, 93) = 82.97$, MSe = 52787.49, $p < 0.01$, $\eta_p^2 = 0.47$). The younger group took longer to respond than the older group (M = 1096.53, SD = 134.86). More importantly, there was a reliable interaction ($F(2, 92) = 11.29$, MSe = 11555.34, $p < 0.01$, $\eta_p^2 = 0.11$; see Figure 1). The one-way ANOVA in the 6-year-old group showed the effect of condition to be reliable ($F(2, 43) = 64.11$, MSe = 16512.18, $p < 0.01$, $\eta_p^2 = 0.59$). Reaction times were longer for non-focal trials than for focal (t(44) = 7.37, p < 0.01, d = 0.97) and single (t(44) = 9.59, p < 0.01, d = 1.57) trials. These children were also slower at responding in the focal than the single-task condition (t(44) = 4.97, p < 0.01, d = 0.66). A similar pattern of results emerged in the 11-year-old group ($F(2,48) = 24.92$, MSe = 7824.79, $p < 0.01$, $\eta_p^2 = 0.85$). This group was slower when responding to the OT in the non-focal condition than in the focal (t(49) = 17.29, p < 0.01, d = 2.33) and single-task (t(49) = 22.3, p < 0.01, d = 2.88) conditions. Reaction times for the single trials were faster than reaction times for the focal trials (t(49) = 4.52, p < 0.01, d = 0.58).

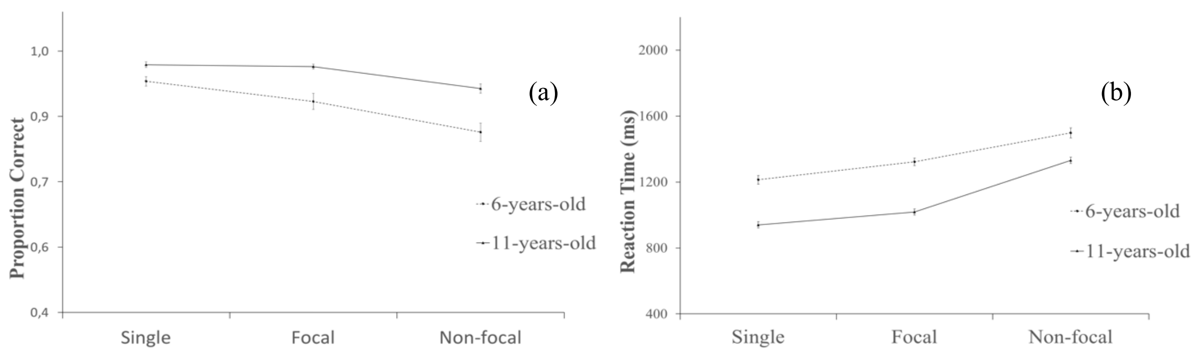

Figure 1. Ongoing performance. Proportion of correct responses as a function of age and condition (a). Reaction time as a function of age and condition (b). Error bars represent standard desviations.

4. Discussion

The purpose of the present experiment was twofold: First, we aimed to test some of the predictions of the dual process framework (McDaniel et al., 2015) by comparing young children's performance on the OT when cue focality was varied. The idea was that performance on the OT would provide an index of the cognitive costs associated with holding a prospective intention and monitoring for appropriate cues. Our second aim was to assess early developmental changes in the effect of the intention over the OT. Previous research with adult participants (Smith, 2003) has shown a PM cost over the OT when a PM intention is included. This cost has also been observed in 4-, 5- and 6-year-old children (Leigh & Marcovitch, 2014). To estimate this cost, we compared performance in a single-task condition (in which children only performed the OT) with performance in two prospective memory conditions varying in cue focality (focal vs. non-focal).

The results for the OT show an interesting pattern. On one hand, the reaction time findings are partly in line with the predictions of the PAM theory: For both younger and older children, holding a PM intention produced an OT cost such that they were faster in the single-task condition than in the focal and non-focal conditions. According to the PAM theory, to retrieve an intention and perform the action, an individual must maintain a state of readiness and monitor the elements of both the OT and the environment for PM cues (Smith, 2003). Interestingly, the cost varied across conditions, such that non-focal cues produced longer reaction times, which suggests that different cue conditions require different degrees of attention. Similarly, the reaction time findings showed that holding the intention was more costly for younger than for older children and that the difference between focal and non-focal cues was also more pronounced for younger children. On the other hand, the accuracy during the OT showed a very similar pattern so that younger and older children exhibited different degrees of impairment depending on the focality of the cue. Thus, although both had a similar cost when the cues were non-focal, older children were more efficient in the focal condition. Despite the focal and single-task conditions not showing differences in accuracy, the differences in reaction time between these two conditions suggest that both focal and non-focal PM tasks produce a cost over the OT, even though this cost is less pronounced in the focal task and in older children. These findings agree, in part, with the dual process framework (McDaniel et al., 2015) and suggest that when there is an overlap between the processing required to perform the OT and the prospective task, remembering the intention is less effortful and that different degrees of attention are involved in processing focal and non-focal cues.

Our pattern of results was similar to that observed by Wang et al. (2011), who found that adolescents and adults exhibited greater cost over the OT when the cue was non-focal than when it was focal. Hence, our older children behaved as adolescents and young adults usually do. While our study did not include any measure of executive functioning, previous studies have related some executive control processes, such as flexibility (Mahy & Munakata, 2015), inhibitory control (Wang et al., 2008) and monitoring abilities (Nigro, Brandimonte, Cicogna, & Cosenza, 2014), to PM performance. Thus, our finding that the older children outperformed the younger ones could be related to the development of their executive functioning. Future studies exploring the present experimental paradigm should include measures of executive function.

From a developmental perspective, our findings suggest that there are relevant changes from 6 to 11 years of age that make older children more efficient than their younger counterparts in dealing with PM tasks. Older children committed fewer errors and had shorter reaction times than younger children when they performed the OT while trying to remember a PM intention. Interestingly, the interaction between focality and age for OT response times showed that the older children were better able to reallocate their attention depending on the difficulty of the task. Thus, the magnitude of the difference between the focal and non-focal conditions was larger (Cohen's $d = 2.33$) for the older group than the younger group (Cohen's $d = 0.97$). Although both increased their times when the PM cue was non-focal (the difference between focal and non-focal conditions was significant for both groups), this increment was larger for the older children. Hence, the older children seemed better able to detect the difficulty of the non-focal task and allocate more resources (relative to the younger children) to cue monitoring. In line with this finding, previous studies have shown that metacognition affects PM performance. Kvavilashvili and Ford (2014), for example, found that PM performance was more accurate in children who better predicted their own performance. More recently, Cottini et al. (2018) found better performance in a categorical PM task in children with high declarative metamemory (relative to children with low metamemory). Importantly, metamemory was found to have no effect on the specific PM task, which is thought to be less demanding than the categorical task. These findings support the theory that children who are good at predicting how well they will do on PM tasks are also better able to choose the most appropriate strategy to deal with the task at hand. Hence, performance from our older children could have stemmed from better predictions of their PM performance, which, in turn, allowed for better adjustment to the requirements of the focal and non-focal tasks. While this interpretation fits well with our results, it should be corroborated in future studies involving more direct measures.

However, the fact that both 6- and 11-year-old children performed better on focal than non-focal PM tasks suggests that, though less efficiently, younger children are also able to monitor for cues and be sensitive to their focality. These developmental findings are consistent with those of Smith et al. (2010), who showed a PM cost for 7- and 10-year-old children and adults, and those of Leigh and Marcovitch (2014), who found that this cost is also present in 4-year-old children. These findings suggest that even at a very young age, children can engage in preparatory attentional processes and monitoring strategies for a PM cue, thus reducing their performance on the OT.

Although the pattern of results is clear and consistent with previous findings, the study is not without limitations. First, although our sample size was large enough to detect the interaction between focality and age, a larger sample might have shown more pronounced age differences. Second, we only used one type of focal and non-focal cue, and it could be possible that other cues might have produced different results. For example, PM tasks involving less salient cues might produce greater cost in the children's performance, with younger children showing more difficulties relocating the resources needed for remembering the intention. Hence, to be able to generalize our findings, further studies should include more than one type of PM task with different relations between the PM and the OT (e.g. a PM focal task in which the PM cue is not part of the materials used in the OT or a non-focal task involving other than perceptual information). Despite these limitations, our results are important and possess clear implications. Parents and teachers occasionally assume that when children start school they are prepared to effectively fulfil the responsibilities that are required at school, such as giving their parents a permission slip or remembering to bring course materials. However, our results suggest that these tasks can be highly demanding for them and that younger children might need to learn simple strategies that help them efficiently allocate their resources to be able to recall their intentions.

In sum, the results of the present study show that, under some conditions (focal cues and older children), holding a PM intention produces lower costs during OT performance and that, therefore, cue monitoring and intentional retrieval might not always play a main role in PM. This evidence is partially in line with the dual process framework (McDaniel et al., 2015), since the fact that reaction times were slower for both the focal and the non-focal conditions relative to the single-task conditions for both younger and older children suggests that the involvement of attentional processes is a question of degree, such that either more or less resources are necessary depending on task focality. While focal PM tasks affect RT but not accuracy, non-focal tasks hamper both accuracy and response times. This pattern advances an interesting problem, given that the role of cue focality is not completely clear; while some studies have failed to reveal differences between focal and non-focal cues (Kliegel et al., 2013), others have shown the opposite pattern: namely, a greater cost for focal than non-focal cues (Ball & Bugg, 2018). Most likely, cue focality interacts with the type of OT, such that effective resource allocation to the PM task depends on the amount of demands of both the PM and the OT. Further studies should explore this interaction and how it modulates children's ability to strategically remember performing actions in the future.

Experiment II

Prospective memory (PM), the ability to carry out planned activities in the future (Einstein & McDaniel, 1990), is critical for everyday activities during adulthood and childhood (e.g. remembering to bring materials to school). Performance in PM tasks involves both remembering an intention to do something (the prospective component) and retrieving what the intended action is (the retrospective component) (Smith et al., 2010). PM might be especially difficult during childhood because it requires many demanding processes, namely, maintaining the intention while performing other activities (ongoing activities), detecting the appropriate moment to perform the intention and stopping the ongoing task (OT) to retrieve and perform that intention (Kliegel, 2002). In fact, some research suggests continuous development of the processes underpinning PM across childhood and adolescence (see Mattli et al., 2011; Smith et al. 2010; Zimmermann & Meier, 2006; Zöllig et al., 2007), although the relative role of these processes has not been systematically investigated in young children.

ERPs have been used to dissociate the neurocognitive mechanisms that underlie PM. For example, both N300 and Frontal Positivity have been associated with prospective components. N300 is a negative deflection over the occipital and parietal regions that occurs between 300 and 500 ms after the stimulus onset (West, 2011; West et al., 2007). The amplitude of N300 is greater for PM hits than for PM misses and ongoing trials (West, 2011; West et al., 2002), and it has been suggested that N300 reflects the detection of a PM cue (West, 2011; West et al., 2002; Zöllig et al., 2007). Interestingly, Mattli et al. (2011) reported developmental differences in this component, with adults showing differences between PM hits and PM misses, whereas in children

(10-to-11 years old), these differences were not significant. In contrast, Hering et al.(2016) (see also Bowman et al., 2015) observed no differences in N300 amplitudes between the hits and the ongoing trials in adults, even though a difference in amplitudes between PM and the ongoing trials was present in adolescents. The reasons for the discrepancies between the two studies are not evident, although the N300 component seems able to capture developmental differences regarding cue detection.

Similarly, Frontal Positivity (FN400), a positive deflection occurring between 300 and 500 ms after the stimulus, dissociates between PM trials and ongoing and PM miss trials (Bisiacchi et al., 2009; Mattlly et al., 2011; West, 2011), and has been linked to retrieval processes related to cue recognition (Cona et al., 2014), but also to switching from the OT to the PM task. The latter interpretation is based on a study by Bisiacchi et al. (2009) in which modulation of this component was observed only in a task-switch version of the PM task (participants were asked to stop responding to the OT when they detected the PM cue), in contrast to a dual-task version in which participants were asked first to respond to the OT when the PM cue was detected and then to perform the PM intention. In a developmental study, Mattli et al. (2011) observed that for both children and adults, PM hits differed from both PM misses and OT trials in the FN400 component, whereas N300 differences between PM hits and PM misses were present only in adults. These authors suggested that the poorer PM performance of children might stem from difficulties with task switching. While developmental studies have examined age differences in N300 and FN400, no previous studies have addressed age differences in children younger than 10 years old. Therefore, it is worth examining whether and how these components vary at younger ages.

Age differences in PM trials (relative to ongoing trials) have also been reported in two retrospective components: the Parietal Positivity (a sustained positivity over the parietal region that begins at about 400 ms) and the Frontal Slow Wave (a positive activity over the frontal and parietal regions that begins at about 400 ms after the stimulus onset). In PM tasks, these two components have been associated with retrieval and monitoring of the intention, with the Frontal Slow Wave varying with the number of intentions (West et al., 2003). Developmental studies have found age-related differences in the Parietal Positivity component, with differences in PM-OT amplitude in younger (adolescents and 12-to-13 year-old) participants than for older ones (Else, Bowman et al., 2015; Hering et al., 2016; Mattli et al., 2011; Zöllig et al., 2007). Studies on the Frontal Slow Wave that have compared younger and older adults have found reliable differences between the PM trials in which the intention was remembered and those in which it was forgotten only in younger adults, which suggests difficulties in the retrospective PM component in older people (West & Covell, 2001; West et al., 2003). To our knowledge, the Frontal Slow Wave has not previously been examined in children or adolescents.

In sum, although some ERP components have been shown to capture age differences, the results do not always show clear developmental patterns, and very few studies have included children younger than 8-to-10 years old. In the present study, three groups of children (6-to-7, 8-to-9 and 10-to-11 years old) performed a PM task and an OT while electroencephalogram (EEG) was registered. In addition, the focality of the PM cues was manipulated (see Cejudo, Gómez-Ariza, & Bajo, 2019). Focal PM tasks are those in which the PM cue is part of the ongoing task (e.g., if the OT is a lexical-decision task, the focal cue could be a specific word, such as tortoise), whereas non-focal PM tasks involve cues that are not part of the OT (e.g. a change in colour of the screen frame while words are being categorised). Non-focal tasks are thought to be more difficult and attentionally demanding than focal tasks (Rose et al., 2010). According to the dual-process framework (McDaniel et al., 2015), PM performance might be supported by either automatic or strategic/attentional processes, with a higher probability that focal rather than non-focal tasks automatically trigger prospective intentions (McDaniel & Einstein, 2007). Therefore, these processing differences between the types of PM tasks are relevant to exploring age differences in PM. For example, in an EEG study with adult participants, Cona et al. (2014) observed larger amplitudes in focal than non-focal conditions in the Frontal Positivity component and no differences in N300, thus suggesting automatic recognition of the cue in both conditions but more involvement of the switching processes in the focal than in the non-focal condition. In addition, more negative Frontal Slow Wave in the non-focal than in the focal PM condition suggested more effortful retrospective retrieval and monitoring processes for the non-focal than the focal tasks. Therefore, in young children, manipulating cue focality and recording EEGs are suitable to dissociate the PM processes that might play a larger developmental role.

Based on previous findings, we expected age differences in PM performance, especially in the non-focal condition, with older children performing better than younger ones. Similarly, we expected focality effects in the Frontal Positivity and the Frontal Slow Wave components, with Frontal Positivity (reflecting switching) being more evident in the focal condition. We also expected developmental differences in the retrieval and monitoring of the intention (Parietal Positivity and Frontal Slow Wave). However, we recognise that the exact pattern of the effects is difficult to predict because no previous study has involved children as young as 6 years old, and no previous ERP developmental study has directly compared the focal and the non-focal conditions.

1. Materials and Methods

1.1. Participants

In total, 91 children participated in the experiment. Children were recruited from a public primary school in Granada (Spain). The younger group included twenty-nine 6- to 7-year-old children (*M* = 6.96, *SD* = 0.32; 16 girls), the middle age group consisted of thirty-one 8- to 9-year-old children (*M* = 8.98 *SD* = 0.387; 12 girls) and the older group included thirty-one 10- to 11-year-old children (*M* = 10.67, *SD* = 0.43; 16 girls). 16 children (5 in the younger group, 6 in the middle group and 5 in the older group) were excluded from the analyses due to poor overall EEG quality. A power analysis (80% power) using GPower 3 (Faul, Erdfelder, Lang, & Buchner, 2007) indicated that a sample of 30 participants (per group) was large enough to detect focality effect (focal vs. non-focal) based on the effect size (partial eta-square = 0.65) obtained by Cona et al. (2014). Caregivers of all the children gave written informed consent in accordance with the Declaration of Helsinki to participate in the study after being informed of its general aim (the procedure had the approval of the Ethics committee of University of Granada). All participants were Spanish and belonged to families with a medium socioeconomic status.

1.2. Procedure

Testing was conducted in one session (lasting approximately 50 minutes) in an individual room of the Memory and Language Lab at the Centre for Brain, Mind and Behaviour (University of Granada). The session contained two blocks corresponding to the focal and non-focal conditions. The order of the blocks was counterbalanced so that the same number of participants received each condition first. To prevent children from becoming tired during testing, there were three 3 min. breaks: one in the middle of each condition and one between conditions.

1.2.1. PM tasks

The OT consisted of categorising pictures as animal or non-animal. We included 90 images taken from (Rossion & Pourtois, 2004). Each image was repeated three times in each condition, so that across conditions images were presented six times. In addition, we used 63 images for OT assessment and practice (see Cejudo et al., 2019 for details). The stimuli appeared in the centre of the screen surrounded by a 15 by 15 pixels colour border, which was randomly changed for each presentation of the stimuli (see Figure 1). The children were asked to press the key ‘no’ on the keyboard if an animal stimulus appeared and the key ‘yes’ if a non-animal stimulus appeared. In the prospective focal task, in addition to the OT, the children were asked to remember to press a different key if a target picture (ball or kite) appeared. If a ball appeared, they were to press the key ‘square’, and if a ball appeared, they were to press the key ‘star’. For the non-focal task, the children were asked to press a different key when the picture frame had a particular colour (magenta or grey). If the screen border changed to magenta, they were asked to press the key ‘star’, and if the border was grey, they were asked to press the key ‘square’. Note that the number of intentions to retrieve was kept to a minimum while most studies with adults include more than two intentions and these intentions change across blocks of trials. This was done because a pilot study with children suggested that increments in number of intentions made the task too difficult for the younger children.

The experiment had the following structure: The children received instructions regarding the OT and practiced it for 9 trials, followed by 26 experimental OT trials. Once they finished the single OT block, the children received instructions regarding one of the PM tasks (focal or non-focal), which they practiced by performing the OT task that included four PM targets. If they correctly responded to two of the four PM targets, they started the PM task; otherwise, they started another practice cycle. In each PM condition we used 30 prospective targets inserted into a series of 300 OT trials (see Figure 1). We selected this frequency of PM trials based on previous studies with children of similar ages (Ford et al., 2012; Kliegel & Jäger, 2007). The PM trials randomly appeared after 6, 8 or 10 OT trials. The PM targets differed for the focal and non-focal conditions. Thus, for the focal condition half of the PM trials were a kite, and the rest were a ball. For the non-focal condition half of the PM target's frames were purple, and the rest were grey. Half of the children did the focal condition first while the other half did the non-focal condition first.

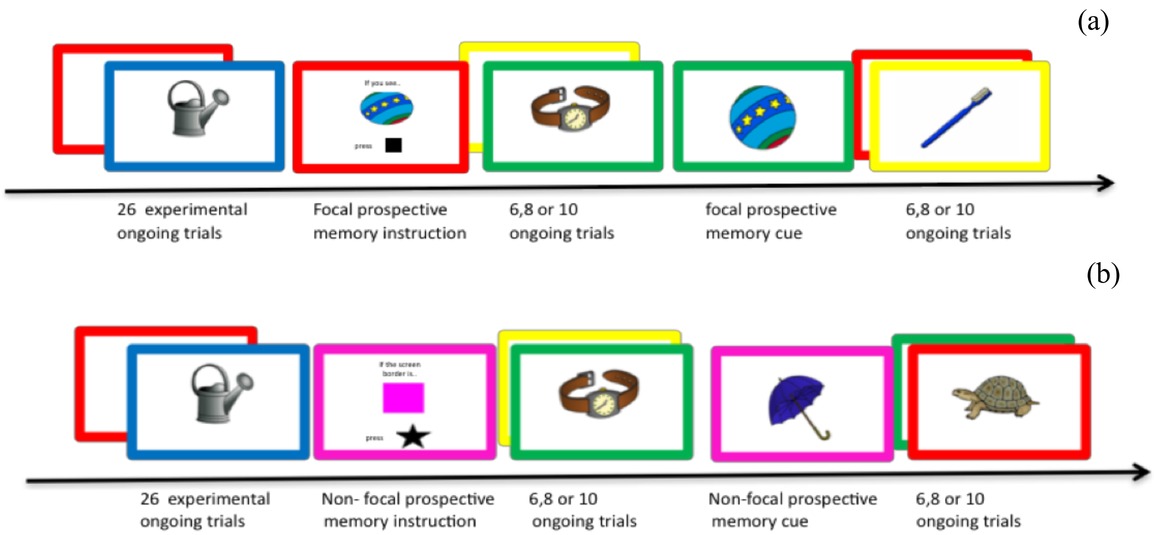

Figure 1. Illustration of the prospective memory task used in the present study. Sequence of the focal prospective memory task (a). Sequence of the non-focal prospective memory task (b).

The duration of the stimulus presentation for the OT and PM cue trials was set to a minimum time of 1600 ms and a maximum of 2800 ms. When participants responded in 1600 ms or longer, the next trial occurred after a white screen was presented for 250 ms (inter-stimulus interval, ISI). When participants responded in less than 1600 ms, their response was filled with a white screen until 1600 ms and then an ISI. When a participant did not respond within 2800 ms, the ISI appeared.

1.2.2. Recording process

The EEG signal was recorded continuously while the children were performing the PM task. The acquisition was done using a 40-channel Nuamp system at a sampling rate of 1000 Hz. All the electrodes were referenced to the average, and only electrodes with impedances below 15 kΩ were considered. We used Scan 4.5 to process the data, which were bandpass-filtered (0.5 Hz to 30 Hz, 24 db/oc; Bakos, Landerl, Bartling, Schulte-Körne, & Moll, 2017, 2018). ERP analysis epoch included 100 ms of pre-stimulus baseline and 1000 ms post-stimulus activity. Ocular artefacts were corrected using a regression analysis in combination with artefact averaging, and the results of this correction were visually inspected. Following visual inspection participants with 10% or more rejected channels or with 25% or more epochs rejected were excluded (see participants' section).

ERPs were then averaged by considering four types of trials: 1) Ongoing trials that immediately preceded a focal PM cue (6-year-old children: M = 30, SD = 2.06; 8-year-old children: M = 30, SD = 0; 10-year-old children: M = 30, SD = 0); 2) Focal PM hits (6-year-old children: M = 28.72, SD = 3.52; 8-year-old children: M = 27.90, SD = 2.41; 10-year-old children: M = 27.72, SD = 2.53); 3) Ongoing trials immediately preceding a non-focal PM cue (6-year-old children: *M* = 29, *SD* = 3.74; 8-year-old children: *M* = 30, *SD* = 0; 10-year-old children: *M* = 29.79, *SD* = 0.94); and 4) Non-focal PM hits (6-year-old children: *M* = 12.24, *SD* = 4.73; 8-year-old children: *M* = 15.74, *SD* = 4.55; 10-year-old children: *M* = 20, *SD* = 4.68). The ERP epoch included the time frame from 100 ms pre-stimulus activity to 1200 ms post-stimulus activity.

3. Results

3.1. Behavioural results

3.1.1. Performance on the OT

Performance was analysed by conducting 2 (condition: focal vs. non-focal) by 3 (age: 6- to 7-, 8- to 9- and 10- to 11-year-old) ANOVAs on the proportion of correct responses and mean reaction times, which comprised cue focality as the within-participant factor and age as the between-participant factor. For the sake of simplicity we only include here the higher order interactions and the simple effect analyses of each condition (see Supplementary Material for full report of the effects).

There was a reliable interaction between age and condition (Table 1; $F(2, 88) = 12.18$, $MSe = 0.00$, $p < .01$, $\eta_p^2 = .22$), which was followed up by analysing the effect of age in each condition. These analyses only revealed an effect of age in the non-focal condition ($F(2, 88) = 11.54$, MSe: 0.01, $p < .01$, $\eta_p^2 = .21$; focal condition with F < 1). Bonferroni tests only showed reliable differences between the two older groups and the 6- to 7-year-old group.

The ANOVA on reaction times revealed a reliable interaction between condition and age ($F(2, 83) = 4.28$, $MSe = 17284.92$, $p < .01$, $\eta_p^2 = 0.09$). Analyses of simple effects (Table 1) indicated that the effect of age was significant in the focal condition ($F(2, 88) = 18.06$, $MSe = 29907.67$, $p < .01$, $\eta_p^2 = 0.29$). Post-hoc comparisons indicated that the 6- to 7-year-old and 8- to 9-year-old groups took more time to respond than the older group. In the non-focal condition, there was also an effect of age ($F(2, 88) = 11.94$, $MSe = 21691.90$, $p < .01$, $\eta_p^2 = .21$). Post-hoc analyses showed the same pattern as the focal condition (the 6- to 7-year-old and 8- to 9-year-old groups took more time to respond than the older group). The interaction was, however, due to the fact that while the 8- to 9-year-old and 10- to 11-year-old groups exhibited faster responses in the focal condition than in the non-focal condition, the difference between the two focality conditions was not statistically significant in the younger group.

Table 1. *Performance on the OT.*

	6-7 years (n=29)		8-9 years (n=31)		10-11 years (n=31)	
	ACC	*RT*	*ACC*	*RT*	*ACC*	*RT*
focal	0.93(0.07)	1086(161)	0.93(0.07)	1076(123)	0.94(0.06)	851(220)
non-focal	0.75(0.12)	1109(129)	0.84(0.11)	1194(132)	0.87(0.07)	1011(175)

Note: Means of the proportions of correct OT responses and reaction times (in ms). Standard deviation are reported in brackets.

3.1.2. Performance on the PM task

To examine the effect of cue focality on PM performance, we looked at accuracy and reaction time by comparing focal and non-focal trials. Again, we only report here the higher order interaction and the simple effect analyses of each condition (see Supplementary Material for the remaining sources of variability).

Concerning accuracy, the interaction condition by age was reliable ($F(2, 88) = 14.81$, $MSe = 0.01$, $p < .01$, $\eta_p^2 = .25$; Table 2). To qualify the interaction (Table 2), we carried out a simple effect analysis for each condition. While age did not have an effect on the focal condition (F < 1) there were age-related differences in the non-focal condition ($F(2 ,88) = 15.19$, $MSe = 0.02$, $p < .01$, $\eta_p^2 = .26$). Bonferroni tests revealed reliable differences among all age groups. As for reaction times, however, the ANOVA failed to show significant effects [interaction with $F(2,88) = 1.71$, $p = .18$, $\eta_p^2 = .03$].

Table 2. *Performance on the PM.*

	6-7 years (n=29)		8-9 years (n=31)		10-11 years (n=31)	
	ACC	*RT*	*ACC*	*RT*	*ACC*	*RT*
focal	0.91(0.13)	1463(204)	0.92(0.07)	1315(174)	0.93(0.08)	995(321)
non-focal	0.42(0.15)	1748(201)	0.53(0.15)	1669(176)	0.64(0.16)	1388(199)

Note: Means of the proportions of correct PM responses and reaction times (in ms). Standard deviations are reported in brackets.

To examine age differences when responding to PM cues while performing the OT, we compared the ERPs when the EEG response was time-locked to OT targets (which appeared before each PM cue) for each condition (focal vs. non-focal). In addition, these OT targets were compared to those time-locked to PM hits. This was done to ensure the same number of trials in each condition and to reduce variability due to changes in attention across the experimental session. Thus, for each PM trial, the previous OT trial was considered for comparison. Based on a visual inspection of wave forms and analyses in previous studies (e.g., West et al., 2003), we selected a 180 to 280 ms time window over posterior regions (electrodes P3, PZ, P4,) to locate N300. Similarly, we selected a 180 to 280 ms time window over the anterior region (electrodes F3, FZ, F4) to reflect frontal positivity. In addition, we selected a 400 to 700 ms time window over parietal regions (electrodes P3, PZ, P4) to capture the Parietal Positivity component as well as the same time window over frontal regions (electrodes F3, FZ, F4) to capture the Frontal Slow Wave component. We averaged the mean amplitudes across electrodes and conditions and introduced them into the ANOVAs performed for each component. To examine cue detection, switching and intention retrieval, we looked at differences between PM and OT trials for the time windows for each component (N300, Frontal Positivity, Parietal Positivity and Frontal Slow Wave) as a function of cue focality and age. This was performed with mixed ANOVAs with age (6- to 7-, 8- to 9- and 10- to 11-year- old), trial type (PM and OT), and focality (focal and non-focal) as factors. As we did with the behavioural results, we describe here the higher order interactions and the simple effect analyses of each condition (for further results see Supplementary Material).

3.2.1. N300

The ANOVA to examine N300 showed the interaction focality by type of trial by age reached statistical significance, $F(2 ,88) = 12.57$, $MSe = 5.09$, $p < .01$, $\eta_p^2 = .22$. Hence, we qualified the highest-order interaction by performing analyses for each focality condition.

In the focal condition the ANOVA showed a reliable main effect of type of trial $F(1, 88) = 35.27$, $MSe = 4.53$, $p < .01$, $\eta_p^2 = .29$, with more negative amplitudes for the PM trials ($M = -1.64$, $SD = 3.10$) than for the OT trials ($M = 0.28$, $SD = 2.42$) but it was not significant for age ($F < 1$). The interaction between age and trial was also reliable (Figure 1), $F(2, 88) = 12.20$, $p < .01$, $MSe = 4.53$, $\eta_p^2 = .22$. While there were statistically significant differences in amplitude between PM and OT trials in the 8- to 9-years-old group ($M = -2.39$, $SD = 3.65$; $M = 0.36$, $SD = 2.57$; $t(30) = -4.76$, $p < .01$, $d = -0.87$) and the 10- to 11-years-old group (*M* = -2.21, *SD* = 2.41; *M* = 0.98, *SD* = 2.06; t(31) = -5.28, *p* < .01, *d* = -1,42), the youngest group exhibited comparable amplitude in the PM (*M* = -0.22, *SD* = 2.69) and OT (*M* = -0.56, *SD* = 2.42) trials (t(28) > 1, *p* = 0.43, *d* = 0.13).

The ANOVA in the non-focal condition only revealed a main effect of age (Figure 2), $F(2, 88) = 11.08$, $MSe = 10.13$, $p = .01$, $\eta_p^2 = .20$, which was essentially accounted for by the difference between the youngest and the oldest groups. The effect of type of trial ($F < 1$) and the interaction age by trial were not statistically significant, $F(2, 88) = 2.80$, $p = .07$, $\eta_p^2 = .06$.

3.2.2. Frontal Positivity

The corresponding ANOVA showed a reliable interaction of focality by type of trial by age ($F(2, 88) = 8.93$, $MSe = 3.67$, $p < .01$, $\eta_p^2 = .17$). Thus, we performed separate analyses for each focality condition (Figure 1 and Figure 2).

The analysis in the focal condition showed more positive amplitudes for PM trials (*M* = 2.61, *SD* = 2.02) than for OT trials (*M* = 0.65, *SD* = 1.98; $F(1, 88) = 56.23$, $MSe = 2.98$, $p < .01$, $\eta_p^2 = .39$). The effect of age was not statistically significant ($F(2, 88) = 1.73$, $p = .18$, $\eta_p^2 = .04$) but the interaction was, $F(2, 88) = 13.83$, $MSe = 2.98$, $p < .01$, $\eta_p^2 = .24$. The difference in amplitude between the PM (*M* = 1.61, *SD* = 1.89) and OT (*M* = 1.62, *SD* = 1.98) trials was not significant in the 6- to 7-year-old group (t(28) < 1, *p* = .99, *d* = -0.00). By contrast, this difference was statistically significant in the 8- to 9-year-old group (*M* = 3.45, *SD* = 2.13; *M* = 0.50, *SD* = 1.72; t(30) = 6.36, *p* < .01, *d* = 1.52) and 10- to 11-year-old groups (*M* = 2.70, *SD* = 1.63; *M* = -0.11, *SD* = 1.91; t(31) = 5.64, p < 01, d = 1.58).

As for the non-focal condition, only the effect of age was reliable ($F(2, 88) = 8.95$, *MSe* = 6.25, $p < 0.01$, $\eta_p^2 = .17$) whereas the type of trial and the interaction were not significant (*F*s < 1). Pairwise comparisons showed differences between the 6- to 7-year-old and 10- to 11-year-old groups ($p < 0.01$) and between the 8- to 9-year-old and 10- to 11-year-old groups ($p < 0.01$).

3.2.3. Parietal Positivity

The ANOVA to examine Parietal Positivity showed a reliable interaction of focality by type of trial by age ($F(2, 88) = 10.90$, *MSe* = 4.33, $p < .01$, $\eta_p^2 = .20$). Follow-up analyses in the focal condition (figure 1) showed more positive amplitudes for OT trials (*M* = 0.10, *SD* = 1.98) than for PM trials (*M* = -1.84, *SD* = 3.24; $F(1,88) = 43.46$, *MSe* = 3.76, $p < .01$, $\eta_p^2 = .33$). The effect of age ($F(2, 88) = 17.07$, *MSe* = 6.61, $p < .01$, $\eta_p^2 = .28$) and the interaction was statistically significant ($F(2, 88) = 16.31$, *MSe* = 3.76, $p < .01$, $\eta_p^2 = .27$). The difference in amplitude between the PM (*M* = 0.91, *SD* = 2.28) and OT (*M* = 0.48, *SD* = 1.97) trials did not reach significance in the 6- to 7-year-old group (t(28) < 1, $p = .31$, $d = 0.20$). By contrast, this difference was statistically significant in the 8- to 9-year-old group (*M* = -2.64, *SD* = 2.87; *M* = 0.14, *SD* = 1.94; t(30) = -5.28, $p < .01$, $d = -1.35$) and 10- to 11-year-old groups (*M* = -3.62, *SD* = 2.67; *M* = -0.30, *SD* = 1.66; t(30) = -6.33, p < 01, $d = -1.49$). As for the non-focal condition, neither the simple effects nor the interaction were statistically significant [type of trial: $F(1, 88) = 2.02$, $p = 0.16$, $\eta_p^2 = 0.02$; age $F(1, 88) = 1.13$, $p = 0.33$, $\eta_p^2 = 0.02$; interaction: $F(2, 88) = 1.09$, $p = 0.34$, $\eta_p^2 = 0.02$].

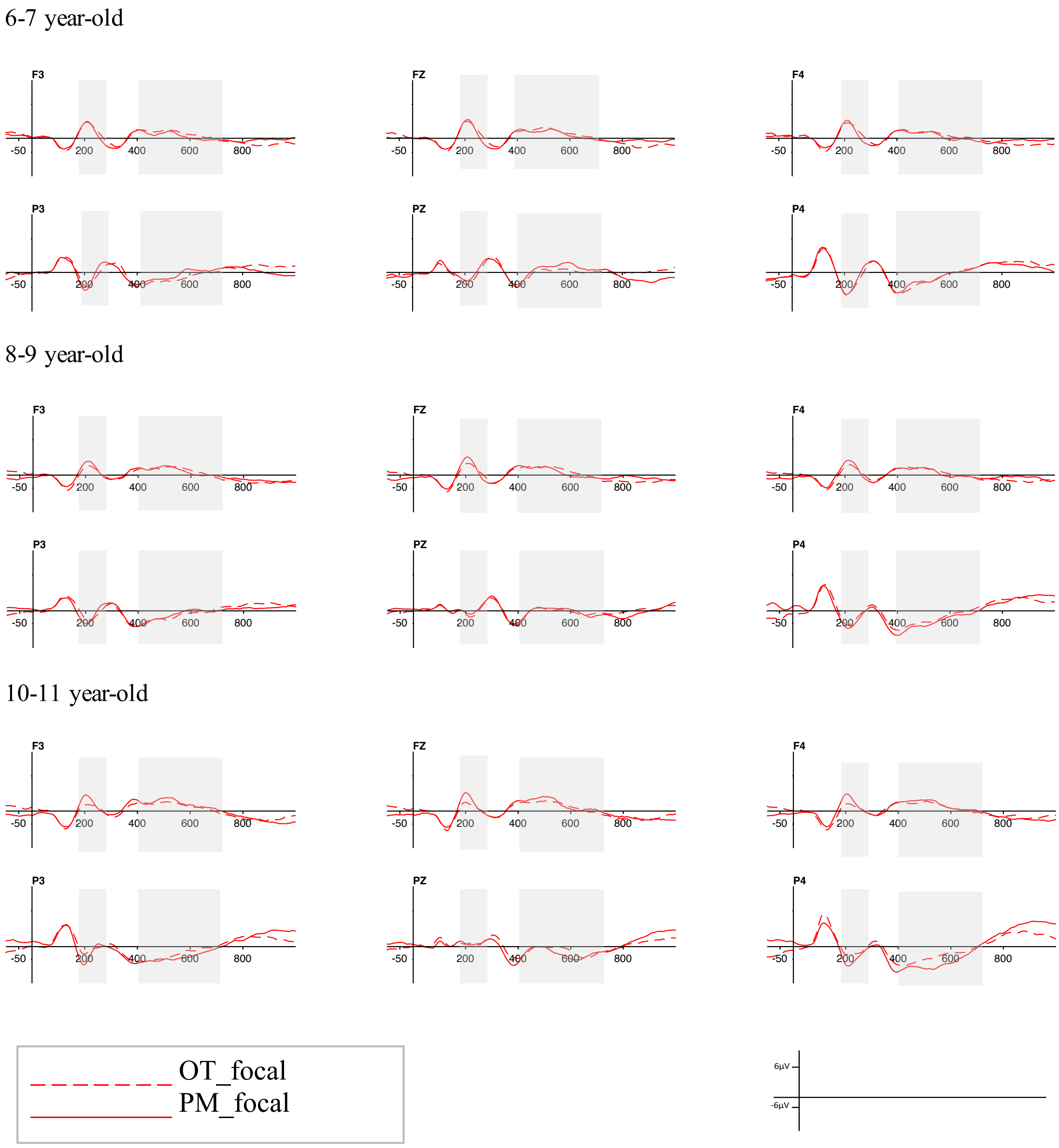

Figure 2. Grand-averaged event-related potentials (ERPs) at selected electrodes demonstrating N300, Frontal Positivity, Parietal Positivity, Frontal Slow Wave for the OT and PM trials in the focal condition for the three age groups.

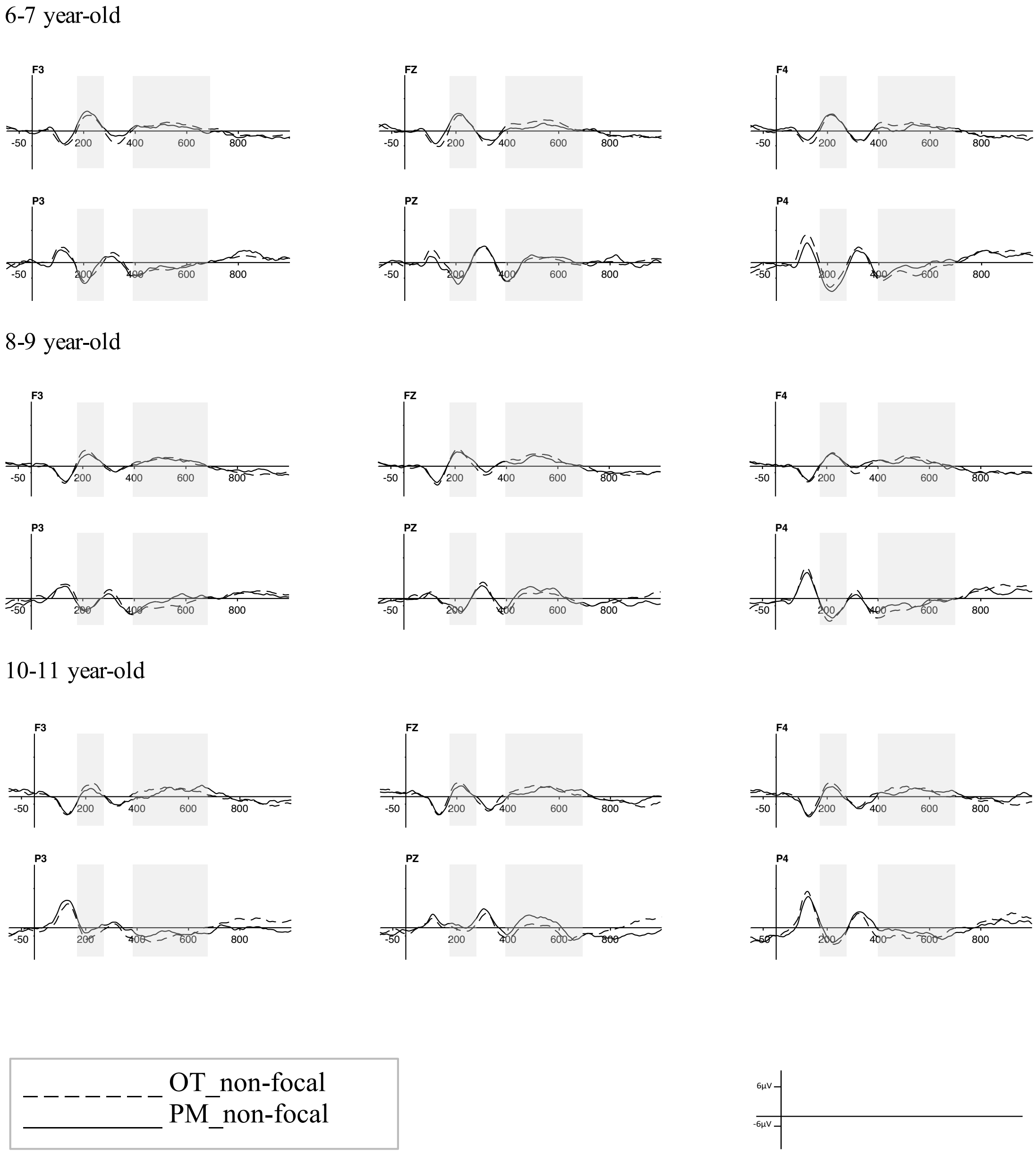

Figure 3. Grand-averaged event-related potentials (ERPs) at selected electrodes demonstrating N300, Frontal Positivity, Parietal Positivity, Frontal Slow Wave for the OT and PM trials in the non-focal condition for the three age groups.

3.2.4. Frontal Slow Wave

The ANOVA to examine the Frontal Slow Wave showed a significant focality by type of trial by age interaction ($F(2, 88) = 3.93$, $MSe = 2.37$, $p < .00$, $\eta_p^2 = .08$), which we followed up by performing separate ANOVAs in each focality condition (Figure 1 and Figure 2).

The analysis in the focal condition showed more positive amplitudes for the PM trials than for the OT trials ($F(1, 88) = 38.43$, $MSe = 2.40$, $p < .01$, $\eta_p^2 = .30$). The effect of age was also significant ($F(2, 88) = 8.53$, $MSe = 2.91$, $p < .01$, $\eta_p^2 = .16$), and the Bonferroni tests only revealed significant differences between the older groups and the 6- to 7-year-old group. The interaction was also reliable ($F(2, 88) = 10.70$, $MSe = 2.40$, $p < .01$, $\eta_p^2 = .20$) and we followed it up by focusing on each age group. Similar to the results for other ERP components, the amplitude differences between the PM and OT trials were reliable only for the 8- to 9-year-old group ($M = 2.20$, $SD = 1.84$; $M = 0.14$, $SD = 1.04$; $t(30) = 5.46$, $p < .01$, $d = 1.38$) and the 10- to 11-year-old group ($M = 2.52$, $SD = 2.00$; $M = 0.23$, $SD = 0.92$, $t(28) = 5.39$, $p < .01$, $d = 1.47$). No significant differences were found between the PM and OT amplitudes in the 6- to 7-year-old group ($M = 0.12$, $SD = 1.82$; $M = 0.21$, $SD = 1.84$; $t(28) < 1$, $p = 0.82$, $d = -0.05$). The ANOVA in the non-focal condition failed to show significant effects. The effects of type of trial $F(1, 88) = 1.42$, $p = .24$, $\eta_p^2 = .02$), age $F(2, 88) = 1.85$, $p = .16$, $\eta_p^2 = .04$) and the interaction ($F < 1$) were not significant.

4. Discussion

This is the first EEG study to investigate the effect of cue focality on event-based prospective memory in children. The manipulation of cue focality together with the EEG recording allowed us to examine developmental changes in the processes underlying performance in focal and non-focal cue conditions.

Following the assumptions of the dual process framework (McDaniel et al., 2015), and in line with previous studies (Cejudo et al., 2019; Kliegel et al., 2013), we expected that age differences would be more prominent for non-focal conditions, since the PM cue was not part of the OT and more resources were needed to detect it. The behavioural results of our study confirmed this prediction: PM performance under the non-focal condition improved from 6 to 11 years old, whereas no age-related changes were observed for PM performance under the focal condition. In general, children's performance in the PM non-focal condition was worse than that in the focal condition in terms of both accuracy and RT. This is in line with previous results for adolescent and adult participants indicating that focal cues produce better PM performance (Kliegel et al., 2008; Rendell, et al., 2007; Scullin et al., 2010; Wang et al., 2011).

Similarly, children's OT performance was better (higher accuracy and faster times) in the focal condition than in the non-focal condition. Poorer OT performance while trying to remember an intention, relative to a control condition in which the OT is performed by itself, has been interpreted as the cost of maintaining the intention in working memory and monitoring the environment for PM cues (Anderson et al., 1998; Craik et al., 1996; Park et al., 1997; Smith, 2003; Smith et al., 2007). Thus, in the present context, the slower RTs and lower accuracy for the OT can be interpreted as indicating that the cost of cue monitoring was higher for non-focal than for focal cues. Again, age had a modulating impact on the monitoring cost; namely, accuracy in the OT was similar for all age groups when the task was focal, but increased with age under non-focal conditions. According to the dual process framework (McDaniel et al., 2015), this is because in the focal condition both the ongoing and PM tasks require semantic categorisation (sorting pictures as animal vs. not animals [OT] or as a PM cue [kite or ball]), such that no additional processes are necessary to detect the cue. However, in the non-focal task additional processing is needed to detect the colour of the frame, such that in addition to semantic processing (of the OT), perceptual and monitoring processes are necessary to detect changes in frame colour (Anderson et al., 2017), making PM performance more demanding. However, the most remarkable finding regarding the OT was that the 6- to 7-years-old group showed comparable response times in the two focality conditions, whereas the 8- to 9-year-old and 10- to 11-year-old children were reliably slower in the non-focal than in the focal condition. This finding could be explained by age-related differences in monitoring strategies, such that older children adjusted their time to monitor for more difficult (non-focal) cues, whereas younger children were not able to do so, which resulted in comparable RTs for the easier (focal) and more difficult (non-focal) conditions. This developmental difference in the allocation of resources might also account for the older children's better performance on the non-focal PM task relative to their younger counterparts, who showed very poor PM performance. In line with this finding, previous work has related age differences in PM performance to the development of executive attention during childhood (Ford et al., 2012; Mahy & Moses, 2011; Shum et al., 2008). Hence, it is possible that the larger differences observed in the non-focal condition might be due to the use of specific monitoring and attentional allocation strategies that are not sufficiently developed at early ages (Davidson et al., 2006; López-Vicente et al., 2016; Schleepen & Jonkman, 2009).

The results of the EEG data were helpful in identifying the specific processes underlying the age differences in PM. The analyses of the N300 component (thought to reflect cue detection) showed that differences between the PM and OT trials in the focal condition were present for the two older groups of children but not for the younger children. However, there were no significant differences between the PM and OT trials for any of the age groups in the non-focal condition. This pattern suggested some differences in the ways that younger and older children attempted to detect PM cues. When the PM cue involved the same type of processing as the OT, the older children seemed to easily detect the PM cues, as reflected by the differences between the PM and OT trials. However, younger children did not seem to discriminate between the PM and OT trials when detecting the cue, as there was no difference between the two types of trials in the amplitude of the N300. In addition, older children seemed to adjust their strategies when a different type of processing was required to perform the task (the non-focal condition). Both the longer RTs in the OT non-focal condition (relative to the focal condition) and the lack of PM-OT differences in the N300 modulation suggested that in these trials, the older children might have adopted a dual-processing strategy in which they processed both the semantic and perceptual information to monitor for possible PM cues, even though this strategy may have been more costly in terms of longer times in the OT. Interestingly, children 6-to-7 years old seemed unable to adjust their strategies to the requirements of the task, because they showed similar times in the OT in both the focal and non-focal conditions and no modulation of the N300 component between the two conditions. It is also possible that these younger children adopted a dual-task strategy in both types of trials. However, their decreased performance in the non-focal condition indicates that either this strategy did not help them to detect the cue or that they did not use specific strategies to adjust to the requirements of the task. As mentioned, previous research has suggested that attentional control develops across childhood/adolescence, and it is possible that the differences between the children 6-to-7 years old and those 10-to-11 years old reflect this developmental trend (Davidson et al., 2006; López-Vicente et al., 2016; Schleepen & Jonkman, 2009).

The Frontal Positivity component (which is thought to reflect switching) showed a similar developmental pattern. The difference between the PM and OT trials was present only for focal cues and only in the two older groups of children. These differences were not evident for any group in the non-focal condition. The fact that children 8-to-9 years old and those 10-to-11 years old were able to recognise the focal-PM cue and switch from the OT to the PM task, whereas the younger children were not, is in line with the results of previous studies (Cuevas & Bell, 2014; Davidson et al., 2006; Jacques & Zelazo, 2005) and suggests that switching is an executive function that develops from early childhood to adolescence. It is also remarkable that there were no PM-OT differences in the non-focal condition for either the younger or the older children. In line with our interpretation, the children may have been using a dual-task monitoring strategy in which every trial involved processing the semantic and perceptual features of all the elements of the display. If so, they would have been switching the focus of their attention to different elements of the display in every trial. This strategy would then result in no obvious differences between the OT and the PM, because cue monitoring and switching were performed equally in both types of trials. Again, note that although this more costly strategy might also have been used by the younger children for the focal and non-focal cues (because no changes in N300 and Frontal Positivity were observed), the differential performance in the two PM conditions suggests that these younger children may have been unable to adapt and use specific strategies, thus producing worse performances overall in the more difficult attentionally demanding tasks.

The overall pattern of results regarding the two PM prospective ERPS components is in line with the assumptions of the dual-process framework (McDaniel et al., 2015) and supports the idea that PM conditions modulate the type of processing involved in PM performance. Thus, PM focal tasks involving less attentionally demanding processes recruit different monitoring and detection processes to non-focal tasks. The findings of the present study agree with those of Cona et al. (2014), which included greater frontal amplitudes (Frontal Positivity) for focal than non-focal conditions in adult participants. In addition, the present results suggest that focality-related changes in attentional allocation develop during childhood; the children who were 6-to-7 years old did not show the focal–non-focal difference that usually appears in adult participants and that was also present for the older children.

Similarly, the Parietal Positivity and the Frontal Slow Wave, which have been associated with monitoring and evaluating retrieval intention, also showed interesting developmental changes that suggest different processing requirements for the focal and non-focal PM conditions. Thus, for the focal condition, the older children (8-9 and 10-11 years old) showed differences between the PM and the OT trials, whereas the younger children (6-7 years old) did not. Interestingly, the Parietal Positivity indicated more positive amplitude for the OT than the PM trials, while the Frontal Slow Wave showed the usual pattern of more positive amplitudes for the PM than the OT trials. The more positive amplitude for the OT trials might be due to the requirement in those trials to retrieve and discriminate between two possible responses. When the OT required discrimination between two responses depending on the nature of the target (animal vs. non-animal), the PM cues were associated with only one response. Therefore, it would seem that once the children detected the cue, they had no difficulties remembering the intention. This is consistent with results showing increments in parietal activation in children performing more difficult semantic discriminations (Chou et al., 2006). In contrast, post-retrieval monitoring processes (related to the Frontal Slow Wave) seem to be more costly in the less frequent PM trials (Cona et al., 2014). However, again, the critical pattern is that while the older children adjusted their retrieval strategies according to the demands of the tasks and showed differences between the focal and non-focal conditions in the Parietal Positivity ERP and the Frontal Slow Waves, the younger children seemed unable to do so and showed no differences between the two PM conditions.

To conclude, the present results showed developmental differences in PM. Although the PM performance showed age effects only under non-focal conditions, the electrophysiological data showed amplitude differences between children 6-7 years old and those 8-9 years old regarding the ERP components associated with cue detection, switching from the ongoing to the PM task, intention retrieval and the monitoring process of the intention recovery (N300, Frontal Positivity, Parietal Positivity and Frontal Slow Wave, respectively). In addition, the focal and non-focal differences in these components were present only in the older children, suggesting that only those children were able to adjust their monitoring and attentional-allocation strategies to the demands of the tasks. This finding suggests that, as other developmental studies have found, the ability to adjust attentional strategies, monitoring, switching and retrieval develop across childhood and affect PM performance in attentionally demanding conditions.

5. Supplementary material

Table 3. *OT performance*

	OT accuracy				OT reaction time			
	MSe	F	*p*	η_p^2	*MSe*	F	*p*	η_p^2
Focality	0.00	116.90	< .01	.57	17284	26.55	< .01	.23
Age	0.01	6.38	< .01	.13	34314	21.13	< .01	.32
Focality by Age	0.00	12.18	< .01	.22	17284	4.28	< .01	.22

Note: ANOVAs on the proportion of correct responses and mean reaction times (in ms) of OT trials. reported in brackets.

Table 4. *PM performance*

	PM accuracy				PM reaction time			
	MSe	F	*p*	η_p^2	*MSe*	F	*p*	η_p^2
Focality	0.01	656.29	< .01	.88	26085	206.10	< .01	.70
Age	0.02	8.77	< .01	.16	69769	39.85	< .01	.47
Focality by Age	0.01	14.81	< .01	.25	26085	1.71	0.18	.03

Note: ANOVAs on the proportion of correct responses and mean reaction times (in ms) of PM trials.

Table 5. *N300 and Frontal Positivity.*

	N300				Frontal positivity			
	MSe	F	*p*	η_p^2	*MSe*	F	*p*	η_p^2
Focality	5.61	0.45	0.50	.00	3.44	8.01	< .01	.08
Type of trial	4.82	17.34	< .01	.16	3.58	24.04	< .01	.21
Age	3.70	6.71	0.03	.08	6.93	6.57	< .01	.13
Focality by Age	5.61	11.57	< .01	.21	3.44	5.12	< .01	.10
Focality by Type of trial	5.09	14.94	< .01	.14	3.67	22.26	< .01	.20
Type of trial by Age	4.82	1.31	0.28	.03	3.58	3.43	< .01	.07
Focality by Type of trial by Age	5.09	12.57	< .01	.22	3.67	8.93	< .01	.17

Note: Two (Focality: focal vs. non-focal) by 2 (Type of trial: PM vs. OT) by 3 (age: 6 to 7, 8 to 9 and 10 to 11 years old) ANOVAs to examine N300 and Frontal Positivity.

Table 6. *Parietal positivity and Frontal Slow Wave.*

	Parietal Positivity				Frontal Slow wave			
	MSe	F	*p*	η_p^2	*MSe*	F	*p*	η_p^2
Focality	5.22	24.31	< .01	.22	2.49	17.18	<.01	.16
Type of trial	3.69	13.16	< .01	.13	2.01	14.82	< .01	.14
Age	8.09	3.87	0.02	.08	3.62	2.87	0.06	.06
Focality by Age	5.22	17.06	< .01	.28	2.49	8.16	< .01	.16
Focality by Type of trial	4.33	28.55	< .01	.24	2.37	27.02	< .01	.23
Type of trial by Age	3.69	5.11	< .01	.10	2.10	8.06	< .01	.15
Focality by Type of trial by Age	4.33	10.90	< .01	.20	2.37	3.93	< .01	.08

Note: Two (Focality: focal vs. non-focal) by 2 (Type of trial: PM vs. OT) by 3 (age: 6 to 7, 8 to 9 and 10 to 11 years old) ANOVAs to examine Parietal positivity and Frontal Slow Wave.

Experiment III

Prospective memory (PM) is the ability to remember a delayed intention. Forgetting to complete intentions could affect school-age children's academic performance (e.g., forgetting to bring their homework to school) and social relationships (e.g., forgetting to give back a friend's book). In PM, delayed intentions have to be remembered in response to particular contextual situations (Kvavilashvili & Ellis, 1996). In event-based PM tasks, retrieval of an intention requires a trigger of an associated memory from some external cue (e.g., remembering to buy bread when passing the grocery store on the way home). In contrast, in time-based PM tasks, the person intends to perform a task at a specific time, within a specific time period or when a period of time has elapsed (e.g., remembering to buy bread before 8 p.m., when the grocery store closes). Finally, activity-based tasks require that intentions be retrieved and executed upon completing other tasks (e.g., remembering to buy bread after buying vegetables from the fruit stall). Successful completion of a PM task requires remembering an intention (e.g., press a key when red words appear on a screen) while performing another ongoing task (OT; e.g., answering general knowledge questions). In addition, at the appropriate moment or when the prospective cue appears, the person must stop performing the OT to instead perform the intention (Kvavilashvili et al., 2001; McDaniel & Einstein, 2007).

Several studies have shown developmental increments in PM performance using event-based PM tasks (see Mattli et al., 2011; Zimmermann & Meier, 2006; Zöllig et al., 2007). Age differences in PM tasks appear when cues are not part of the OT (non-focal cues), but not when cues are part of the OT (focal cues). Focality effects in event-based tasks have been studied with children of different ages (Kliegel et al., 2013); however, very few developmental studies have focused on activity-based tasks (Causey et al., 2014;

Walsh et al., 2014), even though results with adult participants indicate that these are more difficult to remember than event-based tasks (Brewer et al., 2011). For example, in two experiments with adult participants, Brewer et al. (2011) reported differences in PM performance depending on the nature of the PM. When the PM cue was event-based (e.g., saying “now” when the OT involved numbers), participants correctly responded 60% of the time, while their performance dropped to 23% when the PM cue was activity- based (e.g., saying “now” when the activity involving numbers came to an end). The greater difficulty associated with activity-based tasks seems to reflect the low salience of activity-based cues. In their second experiment, Brewer et al. (2011) also manipulated cue saliency. They asked participants to generate exemplars for specific categories as an OT and to remember to place a checkmark next to the category label when they encountered fruits and insects (event-based condition) or when the time to generate exemplars for these categories was called out (activity-based condition). Additionally, in the salient conditions, participants were instructed to draw a line underneath the last member of the category and to write the number of generated exemplars next to the line when the experimenter said “stop”. The results showed that salience had no effect on the event-based PM task, whereas making the end of category generation salient greatly improved performance in the activity-based task, suggesting that, at least in part, activity based tasks are more difficult because of the low salience of the activity cues. Similarly, the studies conducted with children have shown low performance in activity based tasks with age differences being more evident in activity than event based tasks. For example, Wash et al. (2014) did not find age difference in pre-schooler when they completed an event-based task in which children were asked to catch the explicit visual cue “Elmo” when its image appeared on the screen while they were playing a computer game, but the probabilities of asking for a sticker after finishing the game were quite low for 3-and 4-

compare to 5-year-old children. However, activity based performance can improve if children are motivated (Causey et al., 2014).Thus, in a study focusing on motivation and agency, Causey et al. (2014) found that retrieval of the intention was higher in a high motivation condition where pre-schooler were asked to remember to take a sticker when finishing the task relative to a low motivation condition, in which children were asked to remember to change the sign on the door. Therefore, activity-based and event-based PM effects seem to be relevant during development, and motivation seems to be a modulating factor.

In general, motivation seems to affect the probability that children remember the PM intention (Han et al., 2017; Penningroth et al., 2012; Sheppard et al., 2015; Ślusarczyk & Niedźwieńska, 2013). For example, Han et al. (2017) required children to correctly place coloured balls (previously associated with a specific animal) below the corresponding animals. In addition, they had to give a model bone to a dog (PM task) whenever they encountered the target dog in the OT. In their experiment 3, Han et al. (2017) manipulated the difficulty of the OT by including three or five possible animal–colour pairs. They also manipulated the children's motivation by offering a prize to half of the children if they performed well on the OT. The results showed that the difficulty of the OT affected the PM performance only when 3-, 4- and 5-year-old children were highly motivated to complete the task. In addition, in a naturalistic study in which parents described their children's (6- and 10-year-olds) performance in everyday PM tasks, Penningroth et al. (2012) reported better PM performance in the tasks the children considered more important. Further, older children outperformed younger children when the task was less motivating; however, these age differences disappeared for tasks that parents evaluated as highly important for their children. Hence, these studies suggests that children's motivation might modulate PM performance by elevating performance when children are highly motivated, and reducing the effects of age, and type of tasks.

Finally, other factors that seem to affect PM performance is the difficulty and natures of the OT task. In particular, there is some evidence that the difficulty and nature of the OT might modulate some PM effects. For example, Rendell et al. (2007) found differences in PM performance between younger and older adults in a non-focal event task (experiment 1), but found that these age differences disappeared when the OT was more complex (experiment 2). Similarly, some observed interactions between age and focality in event-based PM tasks (Kliegel et al., 2013) have been interpreted as being due to the greater difficulty of non-focal tasks for younger children, since the OT is usually not adapted to children's ages (e.g. Kvavilashvili et al., 2008; Kvavilashvili et al., 2001). The nature of the task (artificial vs. natural) might also explain some of the contradictory results. For example, Kliegel et al. (2013) found no age differences in a focal event-based condition consisting of a driving computer game (artificial setting), while Krasny-Pacini et al. (2015) reported age differences in 8- to 11-year-old children who performed a focal event task in a more natural environment (in which the OT consisted of baking a chocolate cake). Therefore, the nature of the task might also be an important factor to consider when exploring PM effects. However, very few studies have explored natural tasks (Krasny-Pacini et al., 2015; Walsh et al., 2014), and their use has not been extended to the types of prospective situations that children usually confront during school (e.g., writing their name on a test or asking for a letter for their parents).

In sum, since previous studies have shown that motivation (e.g. Causey et al., 2014; Han et al., 2017; Sheppard et al., 2015) and type of PM task (activity- vs. event-based) influence children's performance in PM tasks (Walsh et al., 2014), we sought to explore whether motivation and type of PM task influenced the prospective performance of school-age children and whether these variables interacted with each other and modulated their possible effects. In addition, since the nature of the task seems to also influence PM performance, we explored these effects by using natural tasks that were close to the types of activities that children usually perform at school and by adapting the difficulty of the tasks to the participants' ages. Thus, in our study, children were evaluated using school-related OT activities (e.g., working with puzzles, completing math problems, reading, finding differences between pictures, etc.) that they performed in their school context. Since we were interested in developmental effects, we assessed the 6-7 and 10-11-year-olds with the adjusted event- and activity-based PM tasks. In addition, half of our participants were included in the motivation group, while half were assigned to the non-motivation group. Overall, we expected better performance in the event-based PM task than in the activity-based PM task, and that these differences were more evident in the non-motivated condition. In addition, we expected that age differences would be larger in the more demanding activity-based conditions. These predictions were based on the assumption that more demanding conditions should produce larger developmental effects, and that motivation might modulate these effects.

1. Materials and Method

1.1. Participants

A total of 115 children were recruited from a local primary school in Granada, Spain. The younger group consisted of 63 children (35 boys and 28 girls) aged 6 to 7 years (M = 6.89, SD = 0.38), and the older group consisted of 52 children (27 boys and 25 girls) aged 10 to 11 years (M = 10.99, SD = 0.39). Sample size was decided in advance based on the number of participants in previous studies in which motivation was manipulated in children PM procedures (Sheppard et al., 2015; Ślusarczyk & Niedźwieńska, 2013)The Ethics Committee of the University of Granada approved the procedure.The caregivers of all the children were provided information on the study and gave written informed consent in accordance with the Declaration of Helsinki.

1.2. Procedure

Our study assessed two groups of participants: 6- to 7-year-olds and 10- to 11-year-olds. Testing included individual sessions conducted in a quiet room at the school. Half of the participants (32 participants of the 6- to 7-year-old group and 24 of the 10-year-old group) were randomly assigned to the reward condition, while the other half were assigned to the no reward condition. The session lasted 20 minutes and included event and activity PM tests.

Both groups (reward and no reward) received the same initial instructions: “We are going to play some games in which you have to remember to do things. You should try to perform the tasks and to remember all the things I ask you to do, but you do not have to try to do them quickly. The time is not as important as your performance. Before starting each game, I will explain to you what you have to do and what you have to remember. When you finish one game, I will give you the instructions for the next game.

After receiving the initial instructions, children in the reward group were told that they were going to receive points for good performance and that they would be able to exchange their points for a reward at the end of the session: “For each task you perform right and for remembering the things I am going to ask you to remember, I will give you points. There are a total of four points. So, at the end of the game, if you have three or more points, I will give you a larger present [showing the children the larger of two bags], and if you have two or fewer points, I will give you the smaller present [showing the children the smaller bag]". After these instructions were delivered, the bags were hidden to avoid distracting the children. In the instructions, we emphasized that accuracy in both PM and OT tasks was equally important.

PM was assessed in all children using four PM tasks. Each task had two versions: an event version and an activity version. Each version of the task included the same OT, but children were asked to remember different prospective intentions depending on whether they completed the event or the activity version of the task. In total, therefore, children were asked to remember a total of four intentions: two for the event versions of the tasks and the other two for activity versions of the tasks. Thus, PM performance could range from 0-2 for each type of task (event and activity-based), for a similar approach see (Krasny-Pacini et al., 2015). Every child performed 2 event- based tasks (e.g. one was the event version of "the puzzle" and the other was the event version of "math problems") and two activity-based tasks (one was the activity version of the "reading task" and the other was the activity version of "the find the differences task"). The order of presentation of the tasks was kept constant (puzzle, reading, find the differences and math problems tasks) but we counterbalanced the task versions across participants. Hence there were 6 possible versions and children were randomly assigned to one version. The OTs consisted of doing a puzzle, reading, finding differences between pictures and doing math problems. From the results of a pilot study of twelve 6-7 and 10-11-year-olds children, the OTs for all activities were adapted for the younger and older groups (a puzzle with more pieces, more complex sentences and math problems and more complex pictures, for which finding the differences was more difficult). The prospective tasks were the same for both age groups. All the children completed the OT, so that performance on the OT was only evaluated according to completion speed.

In the event version of the *puzzle task*, the children were asked to complete a puzzle and remember to put all the pieces back inside the box, except for the two pieces they did not have to use. These instructions were given as follows: “The last children who did the puzzle included pieces from another puzzle. Could you put all the puzzle pieces back inside the box, except for the pieces that will not be used?” Hence, the children could see the other-puzzle pieces (event cues) while putting all the other pieces, and they had to remember to leave them out of the box. In the activity version, the children were asked to remind the experimenter to write the time down on the paper when they finished the puzzle: “I would like to know what time it is when you finish the first game. Could you remind me to write the time down on the paper before I explain to you the instructions for the new game?” To adapt the task difficulty to each age group, younger children did a 25-piece puzzle, and the older children did a 50-piece puzzle.

During the *reading task*, the children read sentences from a 15-page notebook. Each page included three sentences. To ensure they paid attention while they were reading, the children were asked to underline the words referring to animals. Additionally, in the event version, they were asked to circle the words referring to numbers. These instructions were given as follows: “Some of the sentences are too long. I would like to shorten them. Could you please help me and circle the words referring to numbers so that, later, I can change these words to digits?” To make it similar to the activity-based task only one PM cue appeared during the reading task. In the activity version, the children were asked to write their names on the right corner of the first page of the test once they finished the practice trials (the first three pages of the notebook, with one sentence per page): “We are now going to practice the task. Once you finish practicing, please do not forget to write your name in the right corner of the first page of the actual task. I need you to write your name there at the beginning of the test because the practice is the same for all children, and I need to know which test is yours”. To adapt the difficulty of the OT, the sentences presented to the older group were longer and more complex than the sentences presented to the younger group.

After the reading activity, children were given a task in which they had to *find the differences* between two pictures. In the event version of the task, they were asked to indicate the last difference they found with an arrow: “I would like you to find the differences between the two pictures; however, sometimes, one of the differences is very difficult to find. I would like to know which one was the most difficult for you. Would you please tell me what difference did you find the most difficult (i.e., the last difference you found)? Please mark it with an arrow”. In the activity version, the children were asked to remember to put the page used for the task inside an envelope, as follows: “I don’t want to lose your picture’s page. Could you put it inside this envelope when you finish the task?” The older group was presented with more complex pictures than the younger group.

Finally, the children completed *math problems* from a 10-page notebook with four arithmetic operations per page. We included two practice pages with two math problems per page. After practicing, the children were given the intention instruction. In the event version, they were asked to remember to circle the number three any time it appeared in operations (it appeared only once), as follows: “There is a math problem which is more difficult than the rest, and this problem contains a three. Could you find this problem for me so that I can eliminate it from the game?" In the activity version, children were told to remember to ask for a letter for their parents after they had finished the practice part of the task, as follows: "I have a letter for your parents [showing the children the letter] that says we have finished the experimental session. Could you ask me for the letter after you finish practicing?" For the children in the reward group, the instructions changed to: "I have a letter for your parents saying that you have done a good job and that you finished the experimental session. Could you ask me for the letter after you finish practicing?" In order to adapt the task difficulty, the 10-11-year-old children were given math problems with three-digit numbers and the younger children were given math problems with one-digit numbers. For all the PM task children scored a point if they remembered the PM intention before starting the new game, in the last task children got a point if they remember to complete the intention (ask for the letter) before leaving the class.

Before starting each activity and after all the activities were completed, each child was required to repeat the task instructions. The idea was to check whether the children were able to remember what they were required to do in each task. If they could not remember the instructions for a particular task, the instructions were repeated. All children were able to remember the instructions after repetition.

2. Results

To test that the OT difficulty was successfully adjusted to each age group and to explore whether the type of cue (event vs. activity) or motivation influenced the OT completion times (measured in seconds), a 2 (type of task: event vs. activity) x 2 (motivation: reward vs no reward) x 2 (age: 6-7 vs. 10-11) mixed ANOVA was performed on the completion time of OT data. The results of the analysis showed a significant effect of motivation (table 1), $F(1, 111) = 7.08$, $MSe = 15473.51$, $p < 0.01$, $\eta_p^2 = 0.06$, indicating that the children in the reward group performed faster ($M = 384.82$, $SD = 11.88$) than the children in the no reward group ($M = 428.75$, $SD = 11.47$). All other effects and interactions were not significant: type of task x motivation, $F(1, 111) = 1.14$, $p = 0.29$, age, type of task x age, age x motivation, and type of task x age x motivation (Fs < 1). These results show that, although children of the reward group performed the OT faster than children of the no reward group, the type of cue did not influence OT reaction time performance. More relevant, no age differences were found in the completion times for OT performance, indicating that the OT was properly adapted to each age.

2.1. PM performance

PM scores were analysed by comparing event and activity conditions between the reward and no reward groups and the two age groups (6-7 and 10-11-year-olds), PM correct responses for each condition were calculated and submitted to a 2 (type of task: event vs. activity) x 2 (motivation: reward vs no reward) x 2 (age: 6-7 vs. 10-11) mixed ANOVA. The results of this analysis revealed a statistically significant effect of type of cue (table 2), $F(1, 111) = 18.08$, $MSe = 0.11$, $p < 0.01$, $\eta_p^2 = 0.14$, with better performance in the event ($M = 0.67$, $SD = 0.35$) than in the activity ($M = 0.48$, $SD = 0.38$) condition. The effect of age was also reliable: The older group was more accurate than the younger one ($M = 0.69$, $SD = 0.31$ vs. $M = 0.48$, $SD = 0.37$), $F(1, 111) = 18.77$, $MSe = 0.13$, $p < 0.01$, $\eta_p^2 = 0.14$. The motivation effect was very close to statistical significance, $F(1, 111) = 3.78$, $MSe = 0.13$, $p = 0.054$, $\eta_p^2 = 0.03$. None of the interactions were significant: type of task by age, $F(1, 111) = 2.00$, $p = 0.16$; type of task by motivation, $F(1, 111) = 1.26$, $p = 0.26$; age by motivation, $F(1, 111) = 0.53$, $p = 0.47$; type of cue x age x motivation, F

(1, 111) = 0.14, $p = 0.71$. Because score distribution of PM performance was not normal, we performed supplementary non- parametric analyses (see Ślusarczyk & Niedźwieńska, 2013 for a similar approach). A Kruskal-Wallis ANOVA confirmed that the main effects of type of task H(1)= 14.00, $p < 0.01$ and age H(1)= 16.47, $p < 0.01$ were significant.

Although motivation did not interact with the other variables, since previous studies results have showed motivation decreased the age differences in PM, we compare children performance in both motivation groups (reward and non-reward). There were significant differences between our young (*M* = 0.42, *SD* = 0.36) and older (*M* = 0.66, *SD* = 0.31) groups in the non-reward condition (t (116) = 3.63, p <0.01, d = 0.71) and also age significant differences were found in the reward condition (t (110) = 2. 55, p <0.05, d = 0.51; *M* = 0.54, *SD* = 0.38 and *M* = 0.72, *SD* = 0.32). Since we were expecting motivation to have larger effects in the activity-based than in the event-based condition, we conducted post-hoc analyses to examine the effects of motivation on each type of cue condition. These analyses revealed no differences between the reward (*M* = 0.70, *SD* = 0.32) and no reward (*M* = 0.66, *SD* = 0.30) conditions when the cue was event-based (t (113) = 0.53, p=0.05, d = 0.13), whereas motivation had a significant benefit (t (113) = 1.97, p=0.05, d = 0.37) when the cue was activity-based (*M* = 0.56, *SD* = 0.38; *M* = 0.42, *SD* = 0.38).

Table 1. Prospective memory performance.

		Event-based	Activity-based	Mean
		ACC	*ACC*	*ACC*
6 to 7 years	No Reward	0.50(0.36)	0.34(0.35)	0.34(0.35)
	Reward	0.59(0.39)	0.50(0.38)	0.50(0.38)
10 to 11 years	No Reward	0.82(0.24)	0.50(0.38)	0.50(0.38)
	Reward	0.81(0.25)	0.62(0.38)	0.62(0.38)
	Mean	0.68(0.31)	0.49(0.37)	0.49(0.37)

Note: Means and standard deviations of the proportions of correct response as a function of age, type of task and reward conditions. Standard deviations are reported in brackets.

3. Discussion

We explored whether age differences in remembering an intention were modulated by the type of PM task (activity- vs. event-based) and by children's motivation. The idea was that children would perform event -based PM tasks better than activity-based tasks as previous studies with pre-school children and adults have shown (Brewer et al., 2011; Walsh et al., 2014). We also expected that motivation would increase performance and that age differences would be more evident in more difficult conditions (activity-based tasks) and when the children were not motivated. The results only partially supported our expectations.

First, performance was higher for event-based than activity-based tasks, indicating that activity-based intentions are more difficult to recall than event-based tasks. This effect could be attributed to the high salience of the event-based cues since they provide more explicit visual cues than the activity-based tasks (Walsh et al., 2014). As mentioned, Brewer et al. (2011) showed that when activity-cues were made salient by asking participants to underline the last generated word (OT) and write the number of words generated, participants improved their performance in the activity based tasks. Therefore, our results are in line with previous data indicating that the salience of the cue (represented by event vs activity based tasks) is an important factor determining PM performance (Kliegel et al., 2013). This result was obtained despite the adjustment of OT task difficulty to the children's ages. This is important because it suggests that the effect of cue salience (event-based) generalises to different tasks and that this effect cannot be attributed to the nature of the task or to differences in difficulty, since all the children were able to perform the tasks in similar time frames. Importantly, the OTs and the context in which they were performed were chosen to be similar to the activities and contexts the children usually experienced at school or at home. To our knowledge, this is the first study directly comparing activity- and event-based tasks that adjusts the OT to the children's age and uses natural tasks and school contexts.

Intriguingly, the performance of the older children was higher than that of the younger children, independent of the type of PM task and motivation. Age effects are easily explained by the fact that, within the studied age range, attentional processes and executive functions are still developing (e.g. Davidson et al., 2006), and PM performance during childhood is likely related to the development of executive functions (Ford et al., 2012; Mahy & Moses, 2011). However, we expected smaller or even null effects in the easier event-based condition, since event-based tasks are assumed to involve more spontaneous, less demanding processes than non-focal or activity-based tasks (McDaniel et al., 2015). Previous studies have shown contradictory results, with some studies showing age differences in focal event tasks (Krasny-Pacini et al., 2015; Walsh et al., 2014) and others showing no differences (Kliegel et al., 2013). These contrasting results could be explained by differences in the tasks used. For example, Kliegel et al. (2013) used a computer game as the OT, while Walsh et al. (2014) and Krasny-Pacini et al. (2015) used more natural tasks, such as purchasing items while shopping. It is likely that computer games in which children focus only on the computer screen—are more absorbing (i.e., more focal) than natural tasks, in which the children move more freely and information is more dispersed. However, this needs to be tested, since the effects of different type of cues on children have rarely been investigated.

We also sought to test the role of motivation in the performance of activity- and event-based tasks, as several studies have found motivation to have positive effects on PM performance during childhood (e.g. Causey et al., 2014; Han et al., 2017; Penningroth et al., 2012; Sheppard et al., 2015). Our hypothesis was that, if children were motivated, their PM performance would increase and age differences would decrease (Penningroth et al., 2012). However, our results show only marginal motivation effects. The fact that our motivation effects were smaller than those obtained in previous studies might be due to several factors. First, the procedures were very different, since Penningroth et al. (2012) based their results on parents' recordings of their children's activities, while our study was based directly on children's performance on PM tasks. Second, it is possible that the children were not differentially motivated by our motivation conditions. Although a previous study with adults has shown that participants' pro-social PM performance is improved when they obtain a large reward (e.g., 20 euros) relative to a small reward (e.g., 1 euro) or no reward , in our study, the children might have perceived neither reward to be sufficiently stimulating because they were presented inside a bag (big or small) and were unknown (Brandimonte & Ferrante, 2015). Despite these factors, the reward instructions provoked faster responses in the OT and showed a tendency to increase PM performance in the activity-based task, but not in the event-based task. Note that it is possible, that children under the faster OT times in the reward condition might have produced lower performance in the PM task (speed/accuracy trade-off) so that if they had remained at the slower pace than children in the non-reward condition, the differences in PM performance might have been larger. In any case, it is clear that motivation had an effect on OT performance by reducing response times and that it seemed to increase PM performance in activity based tasks. This pattern of results would suggest that motivation might only benefit the effortful monitoring processes required to perform PM tasks when less salient PM cues are involved (activity-based tasks) and not the performance of tasks involving explicit visual cues (event-based PM tasks), in which retrieval would be driven by cues with less involvement of attentional control (McDaniel et al., 2015). Interestingly, our results also suggest that even younger children could strategically deploy these resources when motivated to improve their performance.

In conclusion, the results show that PM during child development is affected by task type. PM tasks in which cues appeared as part of the OT produced better performance than PM tasks in which the intention was signalled by the end of the OT and required more cognitive resources for detection. In addition, PM performance was better in 10-11year-olds than in 6-to 7-year-olds in both the event and activity conditions, this results are in line with that have suggested that cognitive resources (e.g., working memory, inhibition and task-switching) are related with good PM performance in children (Ford et al., 2012; Mahy & Moses, 2011) . Finally, our motivation condition had a small effect that was more evident in the activity-based tasks.

CHAPTER III: GENERAL DISCUSSION

PM, or the ability to remember to execute intentions in the future (e.g. remembering to take medication or to go to an appointment), is essential in our daily lives. This ability develops during childhood and into adolescence and adulthood (see Mattli et al., 2011; Zimmermann & Meier, 2006; Zöllig et al., 2007). Failures to remember intentions among both children and adults could affect school/work activities and social lives (e.g. forgetting to give a toy back to a classmate).

Completing a PM task involves encoding and intention, keeping the intention active in one's mind while another activity (the OT) is being performed and stopping the OT to complete the intention when the PM cue appears. Studies assessing PM in adults have shown that features of the PM cue and the OT could affect retrieval of the intention. Some of these features have been shown to also affect children. Particularly, age differences between younger and older children have been found when the PM cue was not part of the process needed to complete the OT (i.e. non-focal PM task) or when the PM cue did not physically appear in the OT (i.e. activity-based PM task).

Following chapter one, which reviewed the theoretical PM models and discussed studies examining changes in PM processing depending on the type of PM task, the main studies exploring PM development and the methodological concerns regarding comparing children of different ages in PM tasks, we designed and carried out three experiments assessing 6- to 11-year-old children's performance in PM tasks with the aim of identifying the mechanisms underlying PM development. To accomplish this, we manipulated the focality of the PM cue, which has been shown to affect PM performance in previous studies. First, we explored whether the ability to strategically monitor for PM cues develops with age by looking at the cost of PM for the OT (Experiment 1). Our results showed that, while the older group of children (11-year-olds) had similar OT performance when the OT was performed singly or concurrently with a focal PM condition, these conditions (singe vs. concurrent PM) were different when the concurrent PM condition was non-focal. Interestingly, this pattern of results was different for the younger group, which exhibited differences among all the conditions (single, focal and non-focal). These findings seem to support the idea that older children adapt their monitoring strategies to the difficulties imposed by the nature of PM cues, while younger children (6-year-olds) are unable to adapt their strategies to meet the requirements of the task (since focal and non-focal PM had similar costs for the OT).

Second, we went further and identified specific prospective and retrospective PM processes developing with age. Specifically, we assessed the PM performance of 6- to 7-year-old, 8- to 9-year-old and 10- to 11-year-old children and registered their brain activity (EEG recordings) while performing focal and non-focal tasks. The EEG recordings allowed us to investigate the ERP components related to the children's detection of cues (N300), switching ability (FN400), retrieval of intentions and monitoring (parietal positivity and frontal slow wave) in focal and non-focal conditions. The results showed different brain reactions to focal and non-focal conditions in the two older groups of children, but these differences were not evident in the younger children (6-year-olds). This finding could indicate that, from the age of eight onward, children are able to use different strategies to detect PM cues, switch from the OT to the PM task and retrieve the intention. Younger children, however, do not seem to have developed the ability to adapt these processes to the requirements of the PM task.

Finally, we sought to explore whether the ability to adapt strategies to task requirements extended to a comparison between event- and activity-based tasks. In addition, in our Experiment 3, we wanted to make sure that the obtained effects were not due to the OTs' differential difficulty with age or to the artificial nature of laboratory-designed PM tasks. Again, we compared the performance of 6- to 7-year-old and 10- to 11-year-old children in event- and activity-based tasks similar to the types of activities performed in schools. Our results showed that, unlike Experiment 2, which showed age effects only in the most resource-demanding tasks (the non-focal condition), this experiment, in which the OT was adapted to the children's age and took place in a natural environment, found age effects in both event and activity PM conditions. This could be because the focal event cues in lab-related tasks are more salient than those used in natural environments, and more salient cues are better detected and processed by younger children. In addition, in Experiment 3, we explored whether motivation modulated other PM effects related to task difficulty or cue salience. For this purpose, we included a group of children who were informed that they would receive a reward (large or small) depending on their PM performance. Our results indicated that motivation had only a marginal effect that was only evident for the more difficult activity-based condition, supporting the idea that motivation during childhood might only facilitate the attention-demanding monitoring processes needed to retrieve and execute intentions in tasks presenting low-salience PM cues (activity-based). By contrast, motivation plays a smaller role for conditions in which retrieval of the intention involves less attentional control because it is driven by salient or easier-to-detect cues.

In the following sections, we summarise the empirical findings obtained in the three experiments and discuss the contribution of the results to understanding changes in PM development. This chapter will be organised around three topics. First, we will examine the cost of PM for the OT during childhood. Second, we will address the effect of manipulating the PM cue and discuss neural and behavioural results. Third, we will discuss whether the nature of the PM task or motivation will affect children's PM performance.

1. Monitoring PM cost during childhood

One way to assess PM and to understand the strategies underlying completing intentions is to focus on the cost of the PM task for the OT. Previous studies (Smith, 2003; Smith et al., 2010) have shown that participants who are asked to remember an intention should stay in a state of readiness to maintain the intention until the appropriate cue (or time) is present (PAM: preparatory attentional and memory processes theory). In this line, various experiments have reported slower performance and lower accuracy for the OT while trying to remember an intention, relative to a control condition in which the OT is performed by itself (Anderson et al., 1998; Smith, 2003; Smith et al., 2007). Only two studies have reported a PM cost for the OT during childhood. Smith et al. (2010) reported impaired performance in a colour-matching task (OT) performed by 7- and 10-year-old children who had to maintain a PM intention. Similarly, Leigh and Marcovitch (2014) reported costs in young children (four, five and six years old) when they categorised images (OT) in addition to remember an intention.

In our first study, we tested and replicated the effect of the cost of the PM for the OT during childhood. When our 6-year-old and 11-year-old children were asked to prospectively remember to press another key whenever a PM cue appeared on the screen (focal: kite, ball; non-focal: magenta, grey border), their reaction times in the OT slowed down relative to the condition in which they only had to perform the OT (i.e. to decide whether the picture on the screen was an animal or not). Here, it is relevant to highlight that both younger and older children showed longer OT reaction times for the conditions in which the PM was included than for the single OT condition. This result is in line with previous studies showing that children are able to use various strategies to remember intentions when they are asked to do so (Leigh & Marcovitch, 2014). On the other hand, OT reaction times were slower for our younger group of children than the older group; therefore, when the PM intention was added, the cost was also higher for the younger group. The later results for OT accuracy also indicated that younger children might have more difficulties adjusting to the requirements of PM.

This finding is also in line with studies that have associated good PM performance with WM ability. For instance, Basso et al. (2010) manipulated WM demands by introducing two types of OT tasks: a lexical decision task and a WM-updating task that varied in terms of the WM demands imposed (low and high). In addition, for the PM, participants had to press an alternative key on the keyboard when a particular word was presented. The results indicated that the PM cost for the OT was only evident in high-WM load conditions. By contrast, performance was not affected by the concurrent PM task in the low-WM load condition. Basso et al. (2010) concluded that PM performance, at least in high-demand tasks, requires WM resources. Mahy and Moses (2011) also reported that WM capacity, assessed by a digit task, was related to event-based PM performance in four- to six-year-old children. In general, since WM and executive control are required for monitoring and successful prospective remembering, and these process continue to develop until adolescence (Davidson et al. 2006), it is possible that the larger costs for the OT in younger children found in our experiment and reported by others might be related to their less efficient WM abilities.

In addition to exploring monitoring cost in relation to children's ages, Experiments 1 and 2 also showed that monitoring cost depends on certain features of the PM task. In our experiments, we manipulated the focality of the PM cue (Experiments 1 and 2) and whether PM is signalled by an event cue or by the end of an activity (Experiment 3). In the next section, we discuss these two effects and how children of different ages manage the extra difficulty imposed by some of these cue conditions. We first discuss the behavioural effects; then, we turn to the evidence provided by the recorded brain activity.

2. Effortful and spontaneous processes in PM performance

2.1. Behavioural effects of PM cue manipulation

An important prediction of the dual process framework (McDaniel et al., 2015) is that some features of the PM task may change the nature of the processes involved in the retrieval of the intention. Thus, the focality of the cue and whether the cue is event- or activity-based may induce effortful monitoring and retrieval processes or more automatic and spontaneous retrieval.

Our three experiments provide evidence supporting this assumption. Experiments 1 and 2 showed better PM performance in focal compared to non-focal conditions in 6- and 11-year-old children (Experiment 1) and in 6- to 7-, 8- to 9- and 10- to 11-year-old children (Experiment 2). In addition, whereas age differences were evident in the non-focal condition, children's performance was similar across ages for the focal condition. This pattern is interesting because, in line with the predictions of the dual process framework, it indicates that non-focal cues induce more effortful monitoring and retrieval process than focal cues, suggesting that not all PM conditions require the same type of effortful processing (per PAM theory). These results also suggest that very young children (6 years old) are able to adequately perform PM tasks when retrieval of the intention is signalled by easier-to-detect focal cues, although they have more difficulties when confronted with a non-focal task.

This pattern extends to the results of Experiment 3 and to the manipulation of event- and activity-based PM tasks, although the nature of the task and adjustment of the task difficulty seemed to change the pattern of age-related differences. Thus, PM tasks in which cues appeared as part of the OT (event-based PM tasks) produced better performance than PM tasks in which more cognitive resources were needed to complete the intention because the PM cue did not physically appear in the OT (activity-based PM tasks). In addition, PM performance was better in 10-year-olds than 6-year-olds (as in the results of Experiment 1), suggesting that the specific executive control processes involved in PM performance might not be sufficiently developed to support efficient PM performance at early ages (Davidson et al., 2006; López-Vicente et al., 2016; Schleepen & Jonkman, 2009). However, there was no interaction between age and type of cue, indicating that, to some extent, when the difficulty of the OT is adjusted to the age of the children, younger children seem to be susceptible to the features of the PM task and also seem to take advantage of the easier detection processes supported by the more salient features of event-based tasks.

Previous PM studies have provided evidence along these lines by showing that events that are distinctive or salient produce very high levels of PM performance relative to their non-distinctive counterparts (Brandimonte & Passolunghi, 1994; Uttl, 2005).

Mahy et al. (2014) also reported that the PM performance of four- and five-year-old children was better when salient cues signalled prospective remembering than when non-salient cues were included. Age differences have also been found in more demanding non-focal tasks when comparing adolescents with young adults (Wang et al., 2011). Kliegel et al. (2013) reported age differences between 6- and 7-year-old and 9- and 10-year-old children when non-focal cues were presented and OT difficulty was introduced as a covariate, whereas age differences were not evident when the PM cue was focal. Similarly, compared to tasks in which the PM appears at the end of the OT (activity-based tasks; Brandimonte et al., 1996), tasks in which the salience of the cue has been manipulated using PM activities and the cue appears in the OT (event-based tasks) showed better performance for event- than activity-based tasks in adults (Brewer et al., 2011) and children (Walsh et al., 2014).

Overall, then, our results and the results of others examining PM performance in different cue conditions and with people of different ages provide support for the predictions of the dual process framework, indicating better performance when the cue can be more easily detected and retrieval of the intention occurs in a more spontaneous way. In addition, our results seem to suggest that older children can more easily take advantage of task features that allow them to more efficiently adjust their performance.

Experiment 1 and 2 also indicated that younger and older children differ in the ways they confront the more difficult conditions imposed by non-focal cues. Accuracy on the OT in younger children showed an incremental pattern of performance, with higher accuracy in the single than in the focal PM condition, which, in turn, was higher than performance in the non-focal condition. In contrast, OT accuracy in the 11-year-old children was similar for the single and focal conditions, and both produced higher accuracy than the OT non-focal condition. This suggests that older children were able to adjust their strategy to the difficulty of the task, such that, in the easier focal condition, they did not have a PM cost. Reaction times to the OT showed differences among the three conditions (single, focal and non-focal) in both age groups, although the differences between the focal and non-focal conditions were higher in the older group than the younger group. Thus, although the OT reaction time showed that the PM had an overall cost effect on the OT (in line with PAM theory), taking accuracy and response times together suggests that the focality manipulation produces differential cost effects in the OT and that these also differ between younger and older children. First, the non-significant difference between single and focal OT accuracy in the 10-year-olds' focal PM task revealed a lower PM cost in this age group. These results are in line with the dual process framework (McDaniel et al., 2015), as they suggest that the retrieval of an intention signalled by a focal cue can be performed in a more spontaneous, less effortful way by older children. Thus, relative to younger children, older children seem better able to detect the difficulty of the non-focal task and to allocate more resources to cue monitoring. In line with these findings, Kvavilashvili and Ford (2014) showed that metacognition affected PM performance such that PM performance increased in children who better predicted their own performance. In addition, Cottini et al. (2018) found that metamemory especially affected more difficult tasks, such that children with better metamemory abilities exhibited better PM performance than children with lower meta-memory abilities, but only in more difficult PM conditions. Our older children seemed able to predict the difficulty of non-focal cues (the difficult condition) and adjust their OT performance to compensate. These findings support the idea that children who are good at predicting their performance on PM tasks can also select the best strategy to deal with the difficulties of the task. While we did not assess individual differences in metamemory abilities, we can assume that older children have developed this ability (Fritz, Howie, & Kleitman, 2010; Schneider, 2015) and are better at predicting their PM performance and adjusting their strategies to the requirements of the focal and non-focal tasks.

2.2. The neural activity of PM development

To better understand the processes underlying PM during childhood, in our second experiment, we recorded EEGs while children were completing focal and non-focal tasks. Numerous studies have used ERP waveforms to understand the neurocognitive mechanisms that underlie PM and to dissociate specific prospective and retrospective PM components. On one hand, N300 and frontal positivity have been associated with the prospective component. N300 reflects the detection of a PM cue in the environment (West, 2011; West et al., 2002; Zöllig et al., 2007), and the frontal positivity component (FN400) has been related to switching from the OT to the PM task (Bisiacchi et al., 2009, Mattlly et al., 2011). On the other hand, the parietal positivity and frontal slow wave components have been related to the retrospective aspects of the PM task. Parietal positivity is associated with the recognition of the PM cue (West, 2011) and the configuration of the prospective task set (Bisiacchi et al., 2009; West, 2011), whereas the frontal slow wave component has been associated with monitoring the retrieval of the intention (West et al., 2007). Age differences have been found in all these components (Bowman et al., 2015; Hearing at al., 2016; Mattli et al., 2011; West & Covell, 2001; West et al., 2003; Zolling et al., 2007), but no previous study had addressed age differences in children younger than 10 to 11 years old or explored differences in components between focal and non-focal conditions during childhood.

In line with the behavioural results of our Experiments 1 and 2, the pattern of ERPs also showed differences between focal and non-focal processing and between younger and older children. Thus, we found a difference between the OT and focal PM in the N300, frontal positivity, parietal positivity and frontal slow wave components in the 8- to 9- and 10- to 11-year-old groups, with no differences between the PM task and the OT for any of the ERP components in the younger group of children. Therefore, in the focal condition, older and younger children differed in how they performed both the prospective and retrospective processes reflected in the ERP components. In the non-focal condition, however, differences between the PM and OT trials were not evident in any of the components for either the older (8- to 9- and 10- to 11-year-old) or the younger (6-year-old) children. We interpreted the lack of PM and OT differences in the non-focal task in the older children as reflecting a change in strategy. Thus, when the prospective intention was signalled by a change in the colour of the screen frame, children used a dual task strategy and began not only processing the meaning of the presented picture, which was necessary to perform the OT, but also perceptually processing the screen frame to check for the presence of the PM cue. This type of dual task strategy implies that both the PM and OT trials involved perceptual and semantic processing; therefore, no differences between PM and OT in cue processing, switching or retrospective retrieval were expected. This interpretation supports the OT reaction times reported in our Experiments 1 and 2, with longer reaction times for non-focal than focal conditions in 10-year-old children, suggesting that the dual task strategy might be more costly and strenuous than the detection-switching strategy in focal conditions. The pattern of ERPs for the younger group of children with no PM-OT differences in any of the PM components also seemed to indicate that six-year-old children did not change their strategy as a function of the cue condition. The longer RTs, lower accuracy and lack of PM-OT differences in the younger children suggested that they might be using the more costly dual task strategy in both the focal and the non-focal condition. Thus, they might search the environment for PM cues in every focal and non-focal trial, even though, in the focal condition, the cue was embedded in the PM. As we have mentioned, younger children are likely to not have developed sufficient metamemory abilities to assess task difficulties and adjust their strategies accordingly. Further research should directly assess children's metacognitive abilities and observe whether they predict children's PM adjustment to task conditions.

3. The nature and conditions of the PM task

In addition to the characteristics of the PM cue (i.e. its physical presence or absence or its focality with respect to the OT), other characteristics of PM and the OT have also shown significant age differences in PM performance. Particularly, increasing the difficulty of an OT hindered retrieval of the PM intention (Marsh, 2002; Marsh & Hicks, 1988), and this effect has also been found in children (Cheie et al., 2017). Rendell et al. (2007), for example, showed that substantial age differences (between younger and older adults) were eliminated when the OT was more complex. However, Mahy et al.'s (2014) manipulation of OT difficulty did not affect four- and five-year-old children's PM performance.

On the other hand, the nature of the task (artificial vs. natural) has also been identified as an important factor in mixed results regarding age differences in PM. This factor might explain why age differences are found in more natural development studies, in which PM performance is assessed using event-based PM tasks (Krasny-Pacini et al., 2015; Walsh et al., 2014). By contrast, some lab studies with more artificial tasks (Kliegel et al., 2013) have reported no age differences in focal event-based conditions. However, the meta-analysis conducted by Henry et al. (2004) with younger and older adults indicated that that, across published studies on age and PM (older vs. younger adults), age-related deficits in lab-based PM tasks are equivalent in magnitude to the age-related benefits observed in naturalistic PM tasks. Therefore, it is not clear whether the nature and difficulty of the task might change the pattern of developmental results. We considered it important to address this issue.

Since our first and second experiments obtained focality effects that differed with the ages of the participants, but in very artificial laboratory tasks, in Experiment 3, we used natural tasks close to the types of activities children would perform at school and adapted the difficulty of the tasks to the participants' ages to assess PM development. In this way, we sought to rule out the possibility that some of the differences in our two first experiments were due to the nature of the task or to the fact that we did not adjust the OT to the children's ages. Thus, in Experiment 3, children were evaluated using school-related OT activities (e.g. working with puzzles, completing math problems, reading, finding differences between pictures, etc.), and we performed a pilot study to adjust the difficulty of each of these tasks to the children's ages to achieve similar performance across all tasks. In addition, we used two versions of PM tasks (event vs. activity). For this, we used an event-based task that included the PM cue in the OT (focal PM task) and an activity-based task in which the cue was the end of the OT. Importantly, as we mentioned above, age effects and type of cue were present regardless of the nature and difficulty of the task. However, and in contrast to the results of Experiments 1 and 2, which used laboratory tasks, we found an age effect for the two types of cue conditions (both event and activity), suggesting that the two PM tasks were more difficult for younger children than for older children. Since we used activity vs. event manipulation, it is not possible to conclude whether the lack of type of cue x age interaction was due to the naturalness of the environment and adjustments to the OT task or to the type of cue manipulation. Further research should attempt to disentangle these results.

3.1. Effect of motivation on PM performance

In Experiment 3, we also manipulated the children's motivation: One group of participants received a reward depending on their PM accuracy, and the other group did not. Children in the reward group were told that they would receive points for good performance and that they would be able to exchange their points for a reward at the end of the session. Our results showed only marginal motivation effects. However, results from previous studies indicate that motivation affects PM performance during childhood (Causey et al., 2014; Hans et al., 2017; Sheppard et al., 2015; Ślusarczyk & Niedźwieńska, 2013). Similarly, in a naturalistic study in which parents were asked to describe their children's (6- and 10-year-olds) performance in everyday PM tasks, Penningroth et al. (2012) reported that older children outperformed younger children when the task was less motivating, but that these age differences disappeared for tasks the parents evaluated as highly important for their children. The fact that our motivation effects were smaller than those obtained in previous studies might be due to several possible reasons. First, the type of procedure we used to motivate the children, in which the reward was hidden in an opaque bag, might not have motivated the children enough to produce a strong effect. Second, our motivation manipulation affected the time children took to complete the OT, and it is possible that the speed–accuracy trade-off made the motivation effect less evident in the PM task. Despite this, the reward instructions showed a tendency to increase PM performance in the activity-based PM task, but not in the event-based PM task. This pattern of results could suggest that motivation might only benefit PM tasks requiring more monitoring resources (McDaniel et al., 2015). Further research should address these factors. Since motivation could mitigate PM difficulties in younger children, it is critical to know whether and under what conditions motivation can have an effect.

4. Conclusions

In the present work, we have provided evidence that the relation between PM and OT and the presence or absence of a PM cue affect PM performance during childhood. PM performance was higher (and did not show an age effect) when the PM cue was part of the OT (focal PM task) than in the non-focal condition, in which the processes required for the OT were different from those used during PM performance. These differences were also evident in the differential cost for the OT for focal and non-focal PM tasks.

In addition, age differences were evident in several aspects of the results. First, the older children showed similar performance in single-OT and focal conditions and higher reaction times when the cue was non-focal, whereas the younger children exhibited differences among single-OT, focal and non-focal conditions. We interpreted that older children were able to detect the difficulty of harder (non-focal) PM tasks and reallocate their resources and strategies accordingly, whereas these metacognitive and executive abilities were still being developed in the younger group. Changes in strategy as a function of task conditions were also shown for older children in the pattern of brain activity reflected by our EEG recordings, which showed that the components related to the detection of the cue, the ability to switch from the OT and the recovery of the intention showed different patterns in focal and non-focal conditions. Whereas there were OT-PM modulations in the focal task for older children and no OT-PM modulations when the task was non-focal, younger children showed the same OT-PM lack of effect in both the focal and non-focal conditions. This pattern again suggests that older children adjust their PM processes to the features of the task, whereas younger children seem to maintain the same strategy regardless of task conditions. Our results also indicated the presence of cue effects when we changed the type of manipulation and compared event vs. activity tasks, as well as when we used PM school tasks adapted to age difficulty. However, natural tasks may involve more resources than laboratory tasks because age differences were also found in event-based tasks with a focal PM cue (Experiment 3). Finally, the effect of motivation in natural tasks seemed to help children retrieve the intention when PM performance required more resources (activity-based task). These results are important because they provide further support to the dual process framework by showing that PM can be performed either with costly attentional processes, such as monitoring, switching or effortful retrieval, or in a more spontaneous and automatic way, depending on the task features. In addition, our results provide evidence to better understand children's difficulties when asked to efficiently complete intention retrievals. Our results clearly indicate that younger children seem unable to allocate their resources to adjust to more or less demanding tasks. Hence, simple strategies like emphasising or reallocating PM cues should improve children's ability to retrieve intentions.

CHAPTER IV: RESUMEN Y CONCLUSIONES

El recuerdo de llevar a cabo intenciones o memoria prospectiva (MP) es esencial en nuestra vida cotidiana para completar tareas como atender a una cita, recoger un paquete o apagar el horno antes de que la comida se queme. Fallos en este tipo de memoria pueden implicar incluso un riesgo para nuestra salud (olvidar, por ejemplo, tomar una medicación; (Brandimonte et al., 1996). Realizar con éxito una tarea de MP implica por un lado, recordar que tienes que realizar una tarea en el momento adecuado (tarea prospectiva) y por otro, recordar qué era lo que debías de realizar (tarea retrospectiva). Por ejemplo: para recordar que tienes que recoger a comprar pan camino de casa, tienes que recordar que debes hacer algo cuando vas camino de casa (tarea prospectiva) y que lo que tienes que hacer es comprar pan (tarea retrospectiva). Para evaluar la MP en el laboratorio se emplea un procedimiento que implica dos tareas: una tarea que el participante realiza de forma continuada en el tiempo (tarea continua) y dentro de esta aparece la clave prospectiva que le indicará al participante que debe realizar la segunda tarea (tarea prospectiva) o intención (Einstein & McDaniel, 2005). El uso de estos procedimientos ha permitido determinar que la MP se desarrolla durante la infancia hasta la adolescencia (Mattli et al., 2011; Zimmermann & Meier, 2006; Zöllig et al., 2007). Aunque este desarrollo se ha relacionado con la ejecución de ciertas funciones cognitivas como la memoria de trabajo, la inhibición o la flexibilidad cognitiva, no se ha llegado a un acuerdo sobre que procesos están relacionados con su desarrollo (Ford et al., 2012; Mahy & Moses, 2011; Shum et al., 2008)

Los objetivos principales de esta tesis son comprender el desarrollo de la MP explorando las diferencias entre tareas que implican distinta carga cognitiva. Particularmente, comparando aquellas tareas donde la clave prospectiva es focal versus aquellas en que la clave es no focal, y actividades en las que la clave es un evento versus tareas donde la clave es la finalización de la propia tarea continua (tareas basadas en la actividad). Además, exploramos estos efectos no solo en tareas de laboratorio sino empleando actividades que los niños realizan en el ámbito escolar.

El estudio del desarrollo de la MP es importante por razones teóricas y prácticas. Por un lado, la teoría de preparación atencional y de memoria (PAM: Smith, 2003) y la teoría de procesamiento dual (McDaniel et al., 2015) asume que los niños menores tienen más dificultades cuando deben recordar una intención que aquellos niños mayores ya que la MP implica el mantenimiento de la atención, la monitorización del ambiente para detectar las claves y una vez detectadas, la capacidad para inhibir la tarea que se está realizando, recordar la intención y realizarla. Este tipo de habilidades están en pleno desarrollo y por tanto, requieren más recursos en niños de menor edad (Davidson et al., 2006; López-Vicente et al., 2016; Schleepen & Jonkman, 2009). A pesar de que ambas teorías están de acuerdo en que estos procesos están implicados en la MP, difieren en si siempre es necesario el control atencional para completar una intención. Mientras que la teoría PAM cree que el control de recursos atencionales es siempre necesario para el recuerdo eficaz de intenciones, la teoría de procesamiento dual asume que hay situaciones en las que estos procesos se realizarán de forma más automática. De esta manera, aquellas tareas de MP en las que la clave sean más focales, y por tanto faciliten la detección de esta, no implicarán la necesidad de monitorizarla (Loft et al., 2007). De la misma manera, aquellas claves que estén asociadas a la intención facilitarán el recuerdo espontáneo de la intención (Uttl, 2005). Además otras variables relacionadas con la tarea continua o la clave prospectiva pueden facilitar o hacer más difícil la ejecución en MP (Henry et al., 2004; Rendell et al., 2007). Por lo tanto, de acuerdo con la teoría de procesamiento dual, no siempre es necesario que grandes recursos atencionales estén implicados para completar una intención con éxito. Desde este punto de vista, la teoría de procesamiento dual predecirá menores o no diferencias de edad en situaciones donde el recuerdo requerido es más espontáneo y automático. Partiendo de ese supuesto, la investigación sobre el desarrollo de la PM puede utilizarse para analizar estas teorías.

Por otro lado, desde el un punto vista del desarrollo, entender cómo funciona la MP y cómo se de desarrolla en niños de distintas edades es también interesante porque la MP implica procesos ejecutivos y de memoria que nos proporciona un contexto en el que evaluar habilidades como el mantenimiento de intenciones, la habilidad de cambio entre tareas o los procesos de recuperación. Por último, estudiar las dificultades a las que los niños hacen frente cuando están intentando recordar una acción que deben de realizar en el futuro tiene muchas implicaciones en el ámbito aplicado. Normalmente los profesores/as y padres/madres, no responsabilizan a los niños en edad prescolar de que recuerden planes o actividades que necesiten realizar en un futuro, sin embargo esta situación cambia cuando inician la educación primaria. En este momento los padres y profesores comienzan a dar responsabilidades a los niños y niñas y en ocasiones, asumen que deben de recordar llevar materiales a clase al día siguiente o darles a sus padres mensajes de sus profesores, recordar todos las deberes y recordar numerosas cosas que pueden suponer esenciales para su vida social como ir a un cumpleaños o devolver a sus compañeros un libro prestado. El conocimiento de las dificultades que los niños de edades escolares tienen para recordar intenciones y las condiciones que pueden ayudarles a completar dichas responsabilidades podría suponer una mejora para los niños en su ámbito escolar, social o personal.

Con el objetivo de identificar los mecanismos subyacentes al desarrollo de MP, diseñamos y llevamos a cabo tres experimentos en los que evaluamos el desempeño de los niños en tareas de MP (de 6 a 11 años de edad). Con esta finalidad, manipulamos la focalidad de la clave de MP ya que resultados de estudios anteriores han demostrado que afecta al rendimiento en MP (Kliegel et al., 2013; Wang et al., 2011). Primero, exploramos si la capacidad de monitorizar las claves de MP se desarrolla con la edad observando el coste de la tarea prospectiva sobre la tarea continua (Experimento 1). Nuestros resultados mostraron que el grupo de niños mayores (11 años) tuvo un desempeño similar en la condición en la que solo realizaba la tarea continua de forma individual y en la condición en la que además de la tarea continua se le pidió que completara una tarea de MP focal, sin embargo si se encontraron diferencias cuando la condición de tarea continua individual se comparó con la condición en la que también estaba incluida una tarea de MP con claves no focales. Curiosamente, este patrón de resultados fue diferente para el grupo de menor edad (6 y 7 años), en el que se encontraron diferencias entre todas las condiciones (tarea continua individual, focal y no focal). Estos hallazgos respaldan la idea de que los niños mayores adaptan sus estrategias de monitorizar a las dificultades impuestas por la naturaleza de las claves de PM, mientras que los niños más pequeños parecen no poder adaptar sus estrategias en función de los requisitos de la tarea (las tareas de PM focal y no focal causaron costos similares en la tarea continua).

En segundo lugar, profundizamos en el análisis de la MP para identificar cambios evolutivos en los componentes prospectivos y retrospectivos incluidos en el recuerdo de intenciones. Para ello, se evaluó el desempeño en tareas focales y no focales de MP en niños de 6 a 7, de 8 a 9 y de 10 a 11 años al mismo tiempo que se registró su actividad cerebral (a través de electroencefalografía: EEG). Los registros de EEG nos permitieron analizar potenciales evocados relacionados con la detección de la clave (N300; West, 2011), la capacidad de cambio entre la tarea continua y la área prospectiva (FN400; Bisiacchi et al., 2009), la recuperación de la intención y la monitorización (positividad parietal y onda lenta frontal; West, 2011). Los resultados mostraron diferencias entre los distintos potenciales en las condiciones focal y no focal en los dos grupos de niños de mayor edad, mientras que estas diferencias no fueron evidentes en los niños más pequeños (grupo de 6 años). Este hallazgo podría indicar que a partir de los 8 años de edad, los niños podían usar diferentes estrategias para detectar las claves prospectivas, para cambiar de la tarea continua a la prospectiva y para recuperar la intención. Los niños más pequeños, sin embargo, no parecen haber desarrollado la capacidad de adaptar estos procesos a los requisitos de la tarea PM.

Finalmente, queríamos explorar si la capacidad de adaptar las estrategias al a las características la tarea prospectiva se extendía a la comparación entre tareas en las que las claves son la aparición de eventos (basadas en el evento) con aquellas donde la clave prospectiva es la finalización de la propia tarea continua (basada en la actividad; Kvavilashhvili & Ellis, 1996). Además, en nuestro tercer experimento, queríamos asegurarnos de que los efectos obtenidos no se debían a la dificultad de las tarea continua no estuviera adaptadas a la edad del participante o a la naturaleza artificial de las tareas de MP empleadas en el laboratorio. Nuevamente, comparamos el desempeño de niños de 6 a 7 años y de 10 a 11 años en tareas basadas en eventos y actividades que fueron similares al tipo de actividades que los niños y niñas realizan en el colegio. Nuestros resultados mostraron una diferencia con los resultados obtenidos en el experimento 2, los efectos de la edad no solo se produjeron en las tareas que requerían más recursos (la condición no focal), sino que al adaptar la tarea continua a la edad de los participantes y realizarla en un entorno natural, los efectos de la edad fueron evidentes tanto en la tarea basada en el evento (tarea focal) como en aquellas basadas en la actividad. Posiblemente esto se deba al hecho de que en las tareas de laboratorio, las claves de tareas focales son más salientes que las que se utilizan en entornos naturales, y por tanto este tipo de claves son más fáciles de detectar y procesar por los niños más pequeños. Además, en el experimento 3, exploramos si la motivación modulaba los efectos del tipo de tarea de MP o las diferencias en edad. Con este propósito, incluimos un grupo en el que se informó a los niños que recibían una recompensa (grande o pequeña) en función de su desempeño en las tareas de MP. Nuestros resultados indicaron que la motivación solo tuvo un efecto marginal evidente para la condición más difícil (tarea basada en la actividad), apoyando la idea de que la motivación durante la niñez solo puede beneficiar los procesos de monitorización necesarios para realizar las tareas de MP cuando estas incluyan claves de MP menos salientes, mientras que en las condiciones de recuperación de la intención que involucran menor control atencional porque las claves son más fáciles de detectar, la motivación tiene un efecto menor.

En definitiva, el recuerdo de intenciones se desarrolla durante la edad escolar y nuestros tres experimentos concluyen que los niños se benefician del tipo de claves a partir de las cuáles se realiza la intención, siendo las tareas que implican claves más salientes más fáciles de recordar. Además, nuestros resultados concluyen que a partir de los 8 años los niños son capaces de adaptar sus estrategias para recordar en función de la dificultad de la tarea, mientras que en niños de edades más tempranas no se observa esta habilidad. Por último, nuestros resultados muestran indicios de mejora en la ejecución de estas tareas cuando los niños han sido previamente motivados, y en particular, cuando realizaron tareas en la que las claves para recordar no aparecían explícitamente. Estos resultados nos permiten concluir que el uso de localizaciones adecuadas para las claves y la motivación mejorarán el recuerdo de realizar acciones futuras durante la infancia.

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