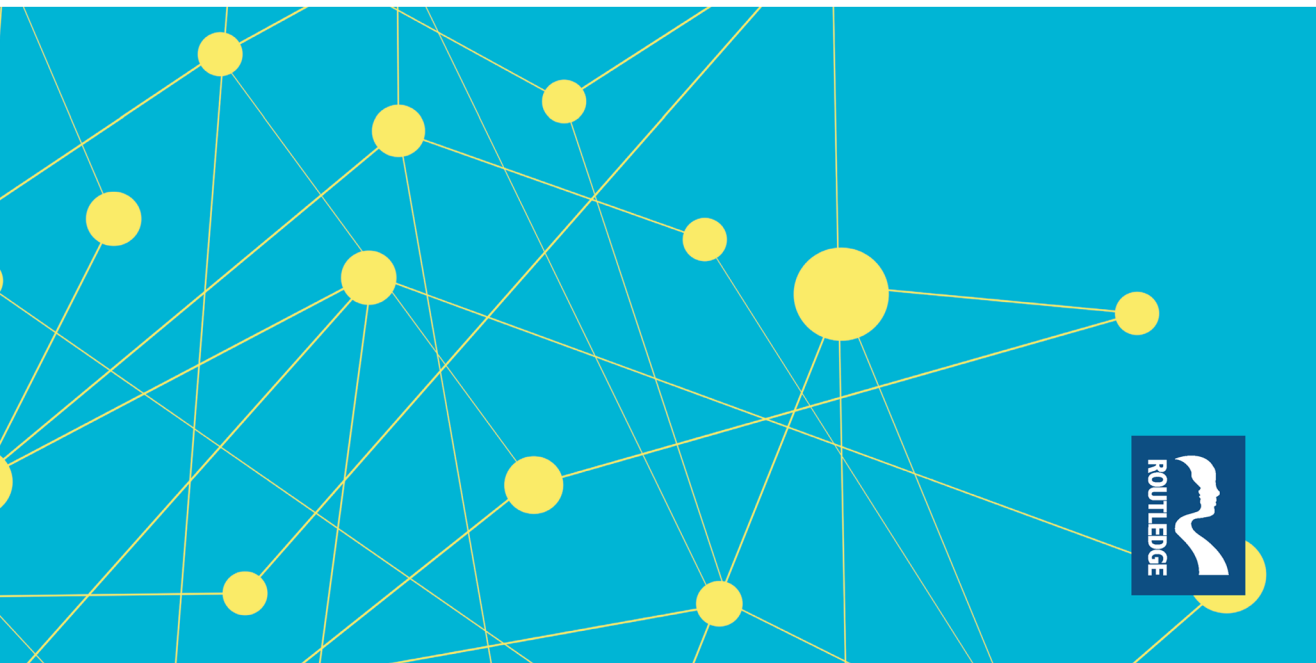
PROSPECTIVE MEMORY IN CLINICAL POPULATIONS

Edited by
Sarah A. Raskin



Prospective Memory in Clinical Populations

Prospective memory has emerged as an important aspect of episodic memory. Prospective memory involves remembering to complete a previously formed intention. Successful prospective memory performance is important in daily life tasks such as taking medications or paying bills and has been related to compliance with treatment.

Prospective memory has now been studied in many clinical populations as well as across the lifespan. Although prospective memory is recognized as an important aspect of daily life, there has been only limited crossover from the research literature to clinical practice. The wealth of research findings needs to be translated to evidence-based clinical approaches that are uniquely tailored to individual populations. Each chapter of *Prospective Memory in Clinical Populations* covers current knowledge of prospective memory deficits in a population; approaches to clinical assessment; any published evidence-based approaches to treatment; and suggestions for management.

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The Clinical Neuropsychologist (TCN) serves as the premier forum for (1) state-of-the-art clinically-relevant scientific research, (2) in-depth professional discussions of matters germane to evidence-based practice, and (3) clinical case studies in neuropsychology. Of particular interest are papers that can make *definitive statements* about a given topic (thereby having implications for the standards of clinical practice) and those with the potential to *expand today's clinical frontiers* (e.g., introduction of a disorder that is typically not under the purview of clinical neuropsychology, yet presents with neurocognitive sequelae; introduction of new assessment or intervention tools). Research on all age groups, and on both clinical and normal populations, is considered.

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INTRODUCTION

Prospective memory in clinical populations

Sarah A. Raskin

ABSTRACT

Objective: Prospective memory (PM) has emerged as a form of episodic memory that is frequently impaired in a variety of clinical populations. Neuropsychologists who routinely evaluate these populations are often unaware of the possibility of PM deficits or the impact these deficits may have on everyday functioning. The objective of this special issue is to provide an overview of the nature of prospective deficits in a range of clinical populations, to discuss neuropsychological assessment techniques, and to critically evaluate management strategies. **Method**: We solicited papers from established researchers and issued a general call for papers for the special issue on PM in clinical populations. **Results**: We received submissions from the nine authors that we solicited. These submissions range from developmental disorders, including autism, attention deficit hyperactivity disorder, and dyslexia; to disorders of adulthood, such as schizophrenia, HIV, brain injury, and multiple sclerosis; and finally disorders that tend to occur at older ages, such as Parkinson's disease and mild cognitive impairment. In addition, we have included four original research articles that provide novel data on other populations. These are children and adolescents with 22q11.2 deletion syndrome, first-degree relatives of people with schizophrenia, individuals with mild brain injury, and individuals with idiopathic REM sleep behavioral disorder. **Conclusions**: The issue highlights the need for clinical neuropsychologists to be aware of the possible existence of deficits in PM in a variety of clinical populations and the importance of both assessment and management strategies to reduce the impact on daily life.

Prospective memory (PM), i.e. the ability to remember to execute a previously formed intention (e.g. Kvavilashvili, 1992), has emerged as an important aspect of episodic memory. The cognitive functions required for successful PM performance include attention, retrospective memory recall, and planning. Prospective remembering itself involves forming the intention, monitoring time or recognizing a cue in the environment, and acting upon the intention at the appropriate time, and performance evaluation once the task is completed. Two particular types of prospective remembering have been identified – time based and event based. Time-based intentions are those that must be completed at a particular time (e.g. please

call your doctor at 2:00 pm); event-based intentions, on the other hand, require completion of the intention in response to a cue in the environment (e.g. when you see your therapist, please remind her to give you a copy of your medical records). Successful PM performance is critical in daily life tasks such as taking medications or paying bills. Deficits in PM can be mistaken for lack of initiation or poor compliance with treatment, making an accurate assessment of PM worthwhile.

With increasing recognition of the importance of PM for daily functioning, there has been an increased interest in PM research. With this growing interest, there have been special issues published on this topic in *Applied Cognitive Psychology* (2000), *The International Journal of Psychology* (2003), and the *Canadian Journal of Experimental Psychology* (2011). However, the previously published special issues have primarily focused on theoretical issues in cognitive psychology. Furthermore, seven years have passed since the publications of the most recent special issues. Thus, it has become clear that the field would benefit from an updated overview of the current state of the PM research, as well as from a review of both the theoretical perspectives on PM construct and the practical clinical information on the assessment and treatment of individuals with PM deficits. These then are the goals of the present special issue.

The issue begins with a series of review articles that all follow a similar structure: current knowledge of PM deficits in that population, including neurological etiology if known; approaches to clinical assessment of PM for individuals with that disorder; the types of errors most often seen in that population in daily life; any published evidence-based approaches to treatment; and suggestions for management of PM deficits for individuals with the disorder. Four original research articles then follow that highlight newer research questions in populations that have not been previously studied as extensively.

The first three articles cover neurodevelopmental disorders. The article by Sheppard, Bruineberg, Kretschmer-Trendowicz, and Altgassen (2018) provides an overview of PM in individual with autism. These authors provide an analysis of the deficits of PM within an embodied predictive-coding account. In other words, they postulate that people with autism have their attention drawn to stimuli in the environment that are not relevant to the PM cue. The reduction in the relevance and salience of the PM cue, in combination with poor prediction, lead to failures to complete PM tasks. This theoretical account leads the authors to suggest embodied interventions such as providing clear and consistent structures and expectations. The next article, by Talbot, Muller, and Kerns (2017), synthesizes the small number of studies that have investigated PM in children with attention deficit/hyperactivity disorder. These children have demonstrated greater deficits in time-based, as compared to event-based, PM tasks, which the authors relate to underdeveloped executive functions. They highlight the need for a clinical measure of PM for children and recommendations are made for multicomponent psychosocial strategies, including compensatory approaches, to mitigate any deficits. The review of PM in individuals with dyslexia by Smith-Spark (2017) mentions effects in children but the main focus is on adults with dyslexia. The authors report that these individuals have greater difficulty with time-based than event-based tasks; nevertheless, deficits on episodic event-based tasks and on tasks that have a longer delay have been found. The authors relate this difficulty to potential deficits in accessing episodic retrospective memories as well as executive function deficits in shifting away from the ongoing task. Specific compensatory recommendations are made, including the use of mobile reminding devices.

The special issue then turns to disorders of adulthood including schizophrenia, HIV, adults with brain injury, and multiple sclerosis. The review by Wang, Chan, and Shum (2017) focuses on individuals with schizophrenia, providing an analysis of the components of PM that have been found to be impaired in a sometimes conflicting literature. Overall, the authors find that people with schizophrenia are more likely to make errors due to a lack of awareness of the need to make a response suggesting that this is a primary deficit in prospective remembering itself. There is some evidence that time-based PM is more impaired than event-based PM, and that people with schizophrenia are more greatly affected by increases in time delays. Perhaps of greatest importance is the consistent findings that PM performance is related to negative symptoms as well as to functioning in daily life, including medication adherence. Lastly, the authors offer a number of intervention suggestions, including increasing awareness.

Individuals with HIV represent one of the more extensively studied clinical populations with respect of PM. This relatively extensive literature is reviewed by Avci et al. The authors suggest that PM deficits in this population are evident primarily when strategic, rather than automatic, cognitive processes are involved. Thus, they suggest that findings of greater time-based than event-based impairments are due to failures in strategic monitoring. With this model, the authors incorporate the findings of greater deficits with longer time delays and a relationship between both executive functions and time perception with PM performance. They also review potential biomarkers for PM and common comorbidities. Importantly, they highlight the research demonstrating the interaction of age and performance within those who have HIV. The authors provide ample evidence for the effect of PM on daily life, including medication management and medication adherence, which are critical in this population. In terms of management of deficits, the authors suggest approaches that focus on improving strategic monitoring as well as behavioral techniques for daily living skills.

In the review of the relatively large number of studies of individuals with brain injury by myself and my colleagues (Raskin, Williams, & Aiken), we also find that the current research supports the multi-process theory. That is, individuals with brain injury show greater deficits in time-based than event-based tasks and show an increased effect of longer time delays. In general, deficits are increased in conditions that require greater attention, working memory, or strategic monitoring. Within this framework, a number of other potential areas of investigation are discussed, including the effects of cue focality and the relationship between the cue and the intention. The relationships among laboratory-based tasks, clinical measures, and self-report questionnaires are discussed, with the suggestion that each of these assessment approaches may be tapping into different aspects of PM functioning. Turning to remediation suggestions, the greatest number of studies has focused on compensatory devices such as pagers, smart phones, programmable watches, and planners. However, there is some evidence for both rote repetition and visual imagery training as rehabilitation techniques may show more promise in terms of generalizability. We suggest that the heterogeneity of brain injury lends itself to the need for individualized treatment techniques that could include compensation as well as training focused on attention, time perception, recognition of the cue, reinforcement of the memory for the intention itself, enactment, etc., depending on the deficit observed in the individual. Finally, we suggest that the literature on episodic future thinking may provide insights for training techniques that generalize to daily life.

The review of PM in individuals with multiple sclerosis by Rouleau et al. (2017) also highlights the relationship between PM and functioning in daily life. In a limited number of

studies, individuals with multiple sclerosis were found to have greater deficits on longer time delays and on items that required a verbal response rather than an action response. A strong relationship has been demonstrated between PM performance and executive function measures. PM deficits have also been found to be related to symptoms such as pain, and to be predictive of activities in daily life such as medication adherence. The authors suggest that high cue salience improves performance, and that psychoeducation and increasing awareness represent important interventions, combined with cognitive rehabilitation techniques in individual cases.

The final two review articles turn to disorders of aging, namely Parkinson's disease and mild cognitive impairment. In reviewing the literature on PM in Parkinson's disease, Costa, Caltagirone, and Carlesimo (2017) do not find consistent evidence for a differential effect of time-based vs. event-based cues. Like many of the other disorders reviewed, PM performance has been found to be related to executive functioning and to activities of daily living. There is some evidence to suggest that specific deficits in PM are related to an inability to shift mental set, but that there are separate deficits in the retrospective recall of the item to be remembered. Finally, the authors present some evidence to suggest that PM is not impaired in all individuals with Parkinson's disease, but only in those who are experiencing mild cognitive impairment. Similarly, the review of PM in individuals with mild cognitive impairment by Kinsella, Pike, Cavuoto, and Lee (2018) does not find evidence for a differential deficit in either time- or event-based items. In addition, there is evidence for deficits in habitual items that are routine, such as bringing in the newspaper each morning. This suggests a primary deficit in working memory in addition to PM deficits. The authors provide a description of a novel treatment approach that embeds implementation of intentions and compensatory devices within a group treatment protocol.

The remaining articles are original research articles that provide novel data on PM in clinical populations not covered by the review articles due to the relative recency of findings of deficits. The first paper demonstrates time-based PM deficits in children and adolescents with 22q11.2 deletion syndrome. Souchay et al. (2017) tested children ages 6–14 years on a video driving game that requires the child to remember to add fuel to the car when fuel levels are low. The participants with 22q11.2DS were less likely to remember to add fuel and also checked the fuel gage less often. The authors suggest that this could be due to a reduction in strategic monitoring, lower motivation to complete the task, or deficits in working memory.

The next original research article examines PM in first-degree relatives of individuals with schizophrenia. Saleem, Kumar, and Venkatasubramanian (2017) used a laboratory task modeled after those of Einstein and McDaniel (1990). They report that first-degree relatives show impairments in prospective remembering compared to healthy adults, but that these impairments are less severe than those seen among individuals who have been diagnosed with schizophrenia. The impairment was found to be greater for event-based tasks than for time-based tasks. This finding may be an artifact of the task; however, as all three groups performed better on the time-based task than the event-based task, a finding that is uncommon in the literature.

Next, as part of the Canadian Longitudinal Study on Aging, Bedard, Taler, and Steffener (2017) administered the Miami Prospective Memory Test to a large cohort of individuals with mild traumatic brain injury (TBI). The majority reported less than one minute of loss of consciousness, and all were at least one-year post injury. The Miami Prospective Memory Test

contains one event-based task and two time-based tasks, although only one time-based task was used in this study. The results showed a disproportionate deficit on time-based PM performance for those who experienced a mild TBI. The findings on the event-based task were somewhat more difficult to interpret, as those participants who had experienced a mild brain injury with a loss of consciousness of less than a minute performed better on this task than healthy adults. Further analyses suggested that this finding may have been due to the fact that this group was younger than controls.

The final article by Bezdicek et al. (2017) measures PM performance in individuals with REM sleep behavior disorder. These individuals demonstrated deficits in both retrospective memory on the Rey Auditory Verbal Learning Test and PM on the Memory for Intentions Test (MIST). In addition, event-based PM was impaired but time-based was not. The event-based PM deficit is suggested to be related to the retrospective memory impairment such that the cue to the intention is not successfully retrieved and recognized. Interestingly, the time-based performance was significantly related to dopamine depletion measured by dopamine transporter imaging using SPECT.

There are several common themes that emerge across the articles in this special issues: first, studies consistently find at least some deficits of PM across a variety of disorders. This consistency highlights how important it is for clinicians to be aware of the possibility of PM deficits in individual clients. Although assessment of PM can be lengthy, clinicians should be aware that it can be a useful adjunct to their current assessment measures, especially in cases where there is a suspicion of a deficit or where there are problems in daily life that might suggest such a deficit (forgetting to take medications, go to scheduled appointments, purchase needed items, pay bills, etc.). In addition, when these deficits are detected, clinicians may want to make specific recommendations for compensatory strategies or treatment techniques to reduce the impact of these deficits. There are now two standardized clinical measures with normative data, the Cambridge Assessment of PM (CAMPROMPT) (Wilson et al., 2005) and the MIST (Raskin, Buckheit, & Sherrod, 2010). A number of the articles in this issue have utilized one of these two measures. There is no comprehensive clinical measure for children at this time, and this need is mentioned by a few of the articles on developmental disorders (Sheppard et al. 2018, Talbot et al., 2017).

Second, many of the articles in this issue conclude that clinical populations have greater deficits in time-based than event-based tasks, and that this has been related to deficits in strategic monitoring as described by the multi-process theory (Einstein, McDaniel, Richardson, Guynn, & Cunfer, 1995). This theory suggests that some PM tasks can be completed more or less automatically, such as when a cue in the environment is sufficiently salient, while others require more controlled processing resources. It is generally assumed that time-based tasks require greater processing resources in order to monitor time and self-initiate the intention with no external cuing. However, several articles in this special issue (Costa et al., 2017; Kinsella et al., 2018) have found impairments in the event-based PM, in the context of normal time-based PM performance. Interestingly, in all cases, these patterns were observed in older populations. This seems to be related to a loss of retrospective memory functioning as a part of the aging process, which differentially impacts cue encoding needed for event-based tasks.

Third, not surprisingly, past research on PM has demonstrated that PM relies on prefrontal cortical mediation, most often Brodmann's area 10 (Benoit, Gilbert, & Burgess, 2011). The Attention to Delayed Intention (AtoDI) model uses imaging data to explain the brain regions

responsible for intention maintenance and retrieval (Cona, Scarpazza, Sartori, Moscovitch, & Bisiacchi, 2015). Specifically, the model proposes that the dorsal frontoparietal network is involved in maintenance and allocation of top-down attention that is used both to monitor for the occurrence of the PM cue and to maintain the intention in mind. The ventral frontoparietal network, on the other hand, mediates the bottom-up attention automatically captured by the occurrence of the prospective cues and used during retrieval. Consistent with past findings and with the AtoDI model, several of the articles in this issue (Avci et al., 2017; Costa et al., 2017; Raskin et al., 2018; Rouleau et al., 2017; Smith-Spark, 2017; Talbot et al., 2017) point out a relationship between performance on tasks of PM and tests of executive functioning, and make suggestions that it is the prefrontal dysfunction that occurs in each disorder that is mediating the PM deficits.

Fourth, rehabilitation strategies covered by the articles in this issue include compensatory strategies, such as datebooks, smartphones, and other electronic reminders. Environmental modifications are also discussed by several authors. Other strategies that may show promise include the use of visual imagery, implementation of intentions, time awareness training, and goal management training. Several authors make the point that rehabilitation is most successful when it is individually tailored and that PM training must take into consideration social and emotional factors that may impact performance (e.g. Raskin et al., 2018).

Finally, several of the articles highlight some new areas of research that strive to build bridges between related fields of study. For example, the research on episodic future thinking, the ability to imagine specific personal episodes that may occur in the future (Szpunar, 2010), is certainly related to realization of intentions in important ways and may provide a framework for future treatment strategies (Terrett et al., 2015). And the use of implementation of intentions (Gollwitzer & Sheeran, 2006) typically utilized in studies of weight loss or other long-term goal attainment has been suggested to facilitate PM (Mcdaniel, Howard, & Butler, 2008) and has been modified with mixed success as a treatment method for PM deficits in a few of the articles in this issue. These both seem to be areas of research that could be expanded in the future.

Disclosure statement

No potential conflict of interest was reported by the author.

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Prospective memory in autism: theory and literature review

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ABSTRACT

Objective: The current article set out to review all research conducted to date investigating prospective memory (PM) in autism. **Method**: All studies on PM in autism are first described, followed by a critical review and discussion of experimental findings within the multiprocess framework. PM in autism is then considered through an embodied predictive-coding account of autism. **Results**: Overall, despite somewhat inconsistent methodologies, a general deficit in PM in autism is observed, with evidence mostly in line with the multiprocess framework. That is, for tasks that are high in cognitive and attentional demand (e.g. time-based tasks; event-based cues of non-focality or low salience) PM performance of autistic participants is impaired. Building upon previous work in predictive-coding, and the way in which expected precision modulates attention, we postulate mechanisms that underpin PM and the potential deficits seen in autism. Furthermore, a unifying predictive-coding account of autism is extended under embodied predictive-coding models, to show how a predictive-coding impairment accounts not only for characteristic autistic difficulties, but also for commonly found differences in autistic movement. **Conclusions**: We show how differences in perception and action, core to the development of autism, lead directly to problems seen in PM. Using this link between movement and PM, we then put forward a number of holistic, embodied interventions to support PM in autism.

General introduction

Autism spectrum conditions (ASC; henceforth, autism) are characterized by impairments in social communication, restricted interests, and activities and, most recently, atypical reactivity to sensory input (American Psychiatric Publishing [APA], 2013). The clinical picture and cognitive skills of autistic[1] people may differ in severity (Hill, 2004). However, even autistic adults of average or above average cognitive ability find everyday life problematic (e.g. housekeeping, financial matters). They have, for example, difficulties obtaining and

maintaining employment that corresponds to their intellectual ability (Howlin, 1998) and coordinating social activities, e.g. organizing appointments with peers (Häußler, 2003) and living independently (Anderson, Shattuck, Cooper, Roux, & Wagner, 2014). Autistic children often have problems in school due to poor time management and organization, e.g. homework is often left at school (Mackinlay, Charman, & Karmiloff-Smith, 2006). These apparent organizational difficulties in autism are supported by empirical work revealing problems with prioritizing, coordinating and sequencing activities and hence, with planning ahead (Mackinlay et al., 2006; Ozonoff et al., 2004); such difficulties have been related to deficits in prospective memory (Altgassen, Koban, & Kliegel, 2012; Mackinlay et al., 2006). PM describes the ability to remember to execute intentions after a delay at a certain time (time-based tasks; TBPM) or event (event-based PM tasks, EBPM, Einstein & McDaniel, 1996), such as remembering to go to the hairdresser at 3 pm, or to buy batteries in the corner shop on the way home. Many occupational and social demands require PM, and PM is essential for the development and maintenance of autonomy and independence. Frequent failures to remember to complete planned activities may endanger professional careers, social relationships or even impose serious risks on physical well-being (Kliegel, Jäger, Altgassen, & Shum, 2008).

Prospective remembering is complex, and comprises multiple processes and phases, across varying time-spans. First, the individual has to form the intention, and store it in (retrospective) memory while being engaged in other ongoing tasks (OT). This (filled) delay between encoding and retrieval of the intended action may range from seconds over minutes to several hours or days (Ellis & Kvavilashvili, 2000). When the appropriate moment for intention initiation arises, other ongoing activities have to be inhibited and the individual has to switch to the prospective action and execute it as planned (Kliegel, Martin, McDaniel, & Einstein, 2002). Research differentiates between a prospective (remembering 'that' you have to do something) and a retrospective component (remembering 'what' and 'when'). The prospective component is supported by attention demanding processes that are closely aligned with executive functioning which serve to monitor the environment for prospective cues (e.g. Smith & Bayen, 2004), inhibit performing the ongoing activity, and to switch to the prospective intention at the appropriate moment (Marsh, Hicks, & Watson, 2002; West, 2011). The retrospective component supports the encoding and subsequent retrieval of the intention when a target stimulus is encountered and shares many processes with explicit episodic memory in recognition and cued-recall tasks (Einstein & McDaniel, 1996; Smith & Bayen, 2004; West & Krompinger, 2005). Recently, episodic future thinking, the ability to mentally simulate and thus pre-experience future events (Atance & O'Neill, 2001), has been linked to the intention formation phase (Altgassen et al., 2014). In line with these behavioral data, imaging studies indicate an involvement of frontal and medial-temporal structures in prospective remembering (for a recent review see Burgess, Gonen-Yaacovi, & Volle, 2011). Frontally mediated (executive control) processes seem to influence PM performance more strongly than temporally mediated (retrospective memory) processes (Brunfaut, Vanoverberghe, & d'Ydewalle, 2000; Kliegel, Eschen, & Thöne-Otto, 2004). Most recently, Cona, Bisiacchi, Sartori, and Scarpazza (2016; Cona, Scarpazza, Sartori, Moscovitch, & Bisiacchi, 2015) further specified the underlying neural networks and involved cognitive processes in their 'Attention to Delayed Intention' model. Specifically, they state that a dorsal frontoparietal network supports top-down attentional and memory processes that are needed to monitor for the PM cue and to keep the intention in mind, whereas a ventral frontoparietal network (in addition to the insula and posterior cingulate cortex) is mainly involved in the retrieval

phase and supports bottom-up attentional processes (externally by the PM cue and internally by the mental representation of the PM cue and the intended action).

Importantly, different PM tasks vary in the extent to which they require these cognitive resources. TBPM tasks have been assumed to put higher demands on individuals' executive control resources than event-based tasks; there is no external cue that may prompt retrieval of the intended action, and the individual has to actively keep track of the elapsing time (Einstein & McDaniel, 1996). However, depending on the specific task features, EBPM tasks may also put high demands on executive control processes. Specifically, with regard to EBPM, two prominent conceptual models have been developed that allow for theory-based predictions on factors that determine the involvement of executive control in PM; namely the *multiprocess framework*[2] (McDaniel & Einstein, 2000) and the *preparatory attention and memory processes theory* (PAM, Smith, 2003; Smith & Bayen, 2004). For the multiprocess framework, McDaniel and Einstein (2000) suggested a range of factors and contexts that can determine the extent to which an EBPM task invokes relatively effortful or automatic retrieval processes: task importance, the type of PM cue (e.g. salient vs. non-salient cues or cues that are more or less focal to the OT), the OT (e.g. more vs. less demanding), and individual differences (e.g. in cognitive resources, personality). Given that PM tasks are dual task situations consisting of an ongoing activity and the embedded PM task, both tasks compete for (limited) attentional and executive control resources (Einstein & McDaniel, 1996). Hence, characteristics of both task levels will affect the more or less controlled allocation of those resources (please see McDaniel, Umanath, Einstein, & Waldum, 2015, for a recent discussion of the multiprocess framework). In contrast, the PAM model posits that that *all* PM tasks require executive control resources for the PM cue to be detected, but that the extent to which these resources are needed depends on task characteristics.

Thus, there is good evidence that strong executive control, episodic memory, and future thinking abilities are critical for successful PM, particularly so when PM tasks involve, for example, cues of low salience or low focality (EBPM) that are difficult to detect, or no environmental cues at all (TBPM). It is therefore of concern that problems with executive control and memory are well known in autism. Executive difficulties are typically seen in planning (Mackinlay et al., 2006; Ozonoff et al., 2004) and switching flexibly between different tasks or foci of attention (Corbett, Constantine, Hendren, Rocke, & Ozonoff, 2009; Kenworthy, Yerys, Anthony, & Wallace, 2008; Leung & Zakzanis, 2014; Ozonoff et al., 2004; but see Geurts, Corbett, & Solomon, 2009 for a critical review). Tasks assessing the inhibition of prepotent responses have resulted in more ambiguous findings (Corbett et al., 2009; Geurts, Verte, Oosterlaan, Roeyers, & Sergeant, 2004; Lopez, Lincoln, Ozonoff, & Lai, 2005; Pellicano et al., 2017). Evidence from retrospective (episodic) memory studies indicate impairments in free recall tasks that provide little memory support (Bowler, Gardiner, Grice, & Saavalainen, 2000), whereas more structured tasks that put lower demands on self-initiated processing, such as cued recall and recognition tasks (Barth, Fein, & Waterhouse, 1995; Bowler, Gardiner, & Grice, 2000), seem to be spared. In line with the well-documented deficits of autistic individuals in episodic memory and theory of mind (e.g. Baron-Cohen, Leslie, & Frith, 1985; Leekam & Perner, 1991; Perner, Frith, Leslie, & Leekam, 1989; see Baron-Cohen, 2000 for a review), reduced episodic future thinking has been reported in autism (e.g. Lind & Bowler, 2010; Lind, Bowler, & Raber, 2014; Lind, Williams, Bowler, & Peel, 2014; Terrett et al., 2013). It may be that these memory deficits are in some way related to impaired executive functioning, given the correlations found in other clinical populations between executive functions and episodic

memory (Baudic et al., 2006; Greene, Hodges, & Baddeley, 1995) as well as future thinking (de Vito et al., 2012)

Furthermore, it is possible that these executive functions, seen as important to PM, are driven by attentional processes (Garon, Bryson, & Smith, 2008; Posner & Rothbart, 2000), processes which have also been shown as impaired in autism (e.g. problems with disengagement, Landry & Bryson, 2004) visual attention (Mann & Walker, 2003), joint attention (e.g. looking at or listening to people, Klin, Jones, Schultz, & Volkmar, 2003; Schultz, 2005), and reduced divided attention (Althaus, De Sonneville, Minderaa, Hensen, & Til, 1996; Ciesielski, Knight, Prince, Harris, & Handmaker, 1995) (cf. a review, Allen & Courchesne, 2001). Indeed, problems with attending to relevant sensory information have even been situated as core to autism (Lawson, Rees, & Friston, 2014; Pellicano & Burr, 2012; Van de Cruys, Van der Hallen, & Wagemans, 2017; Van de Cruys et al., 2014). Such problems would thus have a profound impact on PM performance in autism.

In summary, PM represents a ubiquitous daily process, critical to independent living. Successful execution of PM tasks requires the recruitment and coordination of several (socio) cognitive processes, processes that may rely fundamentally on effective attentional and executive control processes. Given the weight of evidence demonstrating autistic impairment in such processes, and the potentially debilitating PM failures this may lead to, it is vital to better understand prospective remembering in autism, its underlying mechanisms and the environmental conditions that best support it.

Therefore, the first section of the current review will summarize all literature directly investigating PM in autism to date, arriving at the conclusion that, relative to the non-autistic population, PM in autism appears to be impaired. Then, in an attempt to better understand why autistic individuals in particular may demonstrate such difficulties, we will consider the complex dynamic nature of PM, the environment in which it is situated, and the demands this puts on individuals to coordinate and act under such an environment. With this in mind, we will build upon the cognitive explanations of the PM process offered by the multiprocess framework (McDaniel & Einstein, 2000) by considering PM as embedded within a complex dynamic environment, and, as such, apply and further develop an existing account of autism, namely the Bayesian predictive-coding account of Van de Cruys et al. (2014, 2017). Finally, we will describe how this account, and the multiprocess framework, leads to useful, embodied interventions, many of which are already widely implemented in practice.

PM in autism – literature review

A literature search was conducted on the Web of Science for all papers including the terms 'autism' and 'prospective memory', in the title, published up until December 2016. The search returned 36 studies. After the inclusion of 2 of the current authors' unpublished works, and subsequent screening, 13 studies were available for review (see Figure 1). The following section will review each of the studies, beginning with three studies demonstrating spared PM ability, followed by five studies demonstrating a PM deficit, and ending with five studies revealing mixed results (e.g. preserved EBPM but diminished TBPM). For brevity, the studies will only be summarized, with key points highlighted. A full description of the methods and results is presented in Table 1, but for an in-depth description and critique of all studies, including further statistical data (such as effect sizes), we refer to the recently published meta-analysis of Landsiedel, Williams, and Abbot-Smith (2017) on PM in autism. Finally, an

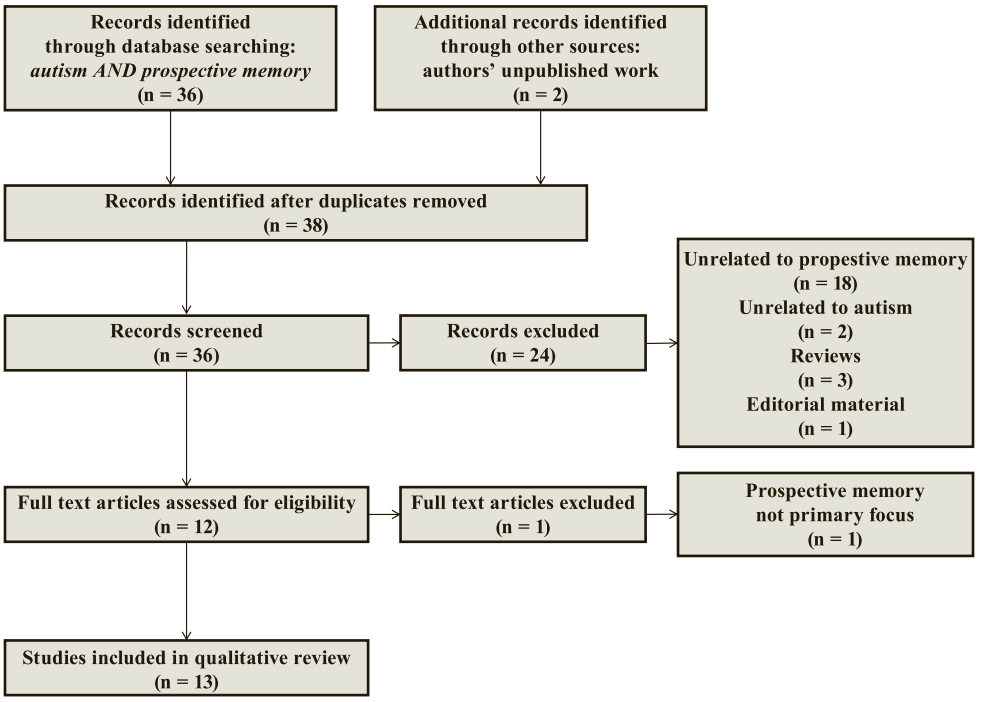

Figure 1. PRISMA flow-chart (Moher, Liberati, Tetzlaff, Altman, & Group, 2009) illustrating literature search process.

overall summary will be presented, describing patterns or commonalities evident between the studies to help elucidate variations in performance, and to discern possible cognitive functions that may contribute to the variation in PM performance.

Intact PM in autism

The three papers to find intact PM in autism investigated EBPM in children of around 10 years old (Altgassen, Schmitz-Hübsch, & Kliegel, 2010; Sheppard, Terrett, Rendell, & Altgassen, 2017) and young adults (Altgassen & Koch, 2014). All three studies employed a typical Einstein–McDaniel computer-based EBPM paradigm in which participants first completed a single, computer-based task (OT). They were then informed they would work on the task again in the near future, but it would contain an additional task (PM), which they completed after a short, filled delay,

No main group effects for EBPM emerged, a result in support of intact EBPM in autism. With the exception of the 'low salience' condition in Sheppard et al. (2017), all PM cues were rather salient (distinctive, as compared to the OT) being either a change of target word color to blue (Altgassen & Koch, 2014), a change of border color from black to red (Sheppard et al., 2017) or a whole screen color change to yellow (Altgassen, Schmitz-Hübsch, & Kliegel, 2010b). PM cues were focal for the Altgassen and Koch (2014) study non-focal for the other two studies.

No group effects were found in OT performance (differences in Altgassen & Koch, 2014; were limited by ceiling effects). Two studies showed adverse effects of the additional PM

Table 1. Overview of all studies on prospective memory in autism.

	Participant information				PM					OT				
Intact PM	Sample size (mean age)	Gender	Intellectual ability measures	Severity of ASC symptoms	Diagnostic and exclusion criteria	Task description	(Filled) delay length	Main effects	Interactions	Task description	Number of trials	Main effects	Interactions	Control variables
Altgassen, Schmitz-Hubsch, and Kliegel (2010)	19 ASC children ($M = 10.6$) 19 controls ($M = 10.6$)	ASC: 18 m, 1 f Controls: 16 m, 3 f	WISC-III vocabulary test: ASC $M = 9.6$ Controls $M = 11.8$ Block design: ASC $M = 10.1$ Controls $M = 11.0$	High-functioning ASC (IQ > 85)	Diagnoses established with ADI-R* and ADOS** No exclusion criteria mentioned	Non-focal EBPM: • press specific key when background turns yellow (5 PM trials)	~10min filled delay (other cognitive tests)	No effects for accuracy and reaction times	–	Computerized visuo-spatial working memory task	• single task block: 10 • dual-task block: 100	Accuracy • no group effect • effect of task block: single OT > dual-task No effects for reaction times	No significant interaction	DEX: ASC < controls ASC: DEX correlates negatively with PM hits
Altgassen and Koch (2014)	22 ASC adults ($M = 25.8$) 22 controls ($M = 25.6$)	ASC: 20 m, 2 f Controls: 20 m, 2 f	WASI matrices: ASC $M = 10.5$ Controls $M = 10.2$	9 high-functioning ASC (IQ > 85) 13 Asperger's syndrome	Expert clinical evaluation according to DSM-IV criteria Exclusion criteria: other psychiatric or neurological disorders, drug or alcohol abuse	Non-focal EBPM: • press specific key when color of words turns blue (4 PM trials per inhibitory load block)	~10min filled delay (other cognitive tests)	No effects for accuracy	No significant interaction	Computerized word categorization task Within-subject manipulation of inhibitory load (high, low)	• single OT: 20 • single inhibition task (high or low): 20 • dual-task: OT plus inhibiton task (high or low): 46 • triple task: OT plus inhibition task (high or low) plus PM: 96	Accuracy OT • group effect: controls > ASC • task block effect: single OT > dual-task low inhibitory load > dual-task high inhibitory load > both triple task blocks Accuracy inhibition • no group effect • inhibitory load effect: single task conditions > dual- and triple-tasks low inhibitory load > dual- and triple-tasks high inhibitory load	No significant interactions	–

Sheppard et al. (2017)	24 ASC ($M = 11.3$) 23 controls ($M = 11.1$)	ASC: 24 m, 0 f Controls: 7 m, 16 f	WISC-III & WNV vocabulary test: ASC $M = 11.7$ Controls $M = 10.4$ Matrices: ASC $M = 61.6$ Controls $M = 53.8$	High-functioning ASC (IQ > 85) SRS T score: ASC > Ctrl $M_{ASC} = 72.86$ $M_{ctrl} = 43.95$ SSP – visual: ASC > Ctrl $M_{ASC} = 18.19$ $M_{ctrl} = 23.85$ SSP – auditory: ASC > Ctrl $M_{ASC} = 14.29$ $M_{ctrl} = 25.35$	Expert clinical evaluation according to DSM-IV criteria Exclusion criteria: other psychiatric or neurological disorders	Focal EBPM: • press specific key on presentation of PM targets 3 conditions, within-subjects, each with 4 different PM cues • low salience • high Visual • high auditory	~8 min (vocabulary, matrices, digit span tests)	No effects for accuracy Reaction times: • no group effect • salience effect: low salience > high salience	Reaction times: • for both groups low salience > high visual salience, but only ASC: low salience > high auditory salience	Computerized picture-based categorization task	• single task block: 20 • dual-task block: 70	No effects for accuracy Reaction times • no group effect • task block effect: single OT < dual-task blocks; low salience > high salience (visual and auditory)	No significant interactions	–
Altgassen et al. (2009)	11 ASC children ($M = 9.6$) 11 controls ($M = 10.6$)	ASC: 9 m, 2 f Controls: 6 m, 5 f	WISC-III vocabulary test: ASC $M = 9.4$ Controls $M = 11.6$ Block design: ASC $M = 12.9$ Controls $M = 11.0$	High-functioning ASC (IQ > 85)	Diagnoses established with ADOS and 3di Exclusion criteria: other psychiatric or neurological disorders	TBPM: Press specific key every 2min (5 PM trials) Press other specific key for clock check	~10 min (other cognitive tests)	Correct PM responses: ASC < controls Clock checks: • group effect: ASC < controls • interval effect: increased time monitoring when target times approached	Interaction ($p < .06$): controls checked time more frequently as target time approached	Computerized visuo-spatial working memory task	• single task block: 10 • dual-task block: 85	Accuracy • group effect: ASC< controls in the dual task No effects for reaction times but: cost to OT by adding PM task: controls > ASC	No significant interactions	–

(*Continued*)

Table 1. (*Continued*).

	Participant information				PM					OT				
Intact PM	Sample size (mean age)	Gender	Intellectual ability measures	Severity of ASC symptoms	Diagnostic and exclusion criteria	Task description	(Filled) delay length	Main effects	Interactions	Task description	Number of trials	Main effects	Interactions	Control variables
Brandimonte et al. (2011)	Study 1: 30 ASC ($M = 8.3$) 30 controls ($M = 8.3$) Study 2 focuses on ADHD instead of ASC and will not be discussed here	ASC: 21 m, 9 f Controls: 21 m, 9 f	WISC-III Full Scale IQ: ASC $M = 87.0$ Controls $M = 89.0$	CARS: $M_{ASC} = 35.5 \rightarrow$ mild to moderate ASC	Diagnoses according to DSM-IV criteria Exclusion criteria: other behavioral disorders, learning deficits, chromosomal or neurological conditions	Focal EBPM: press specific key on presentation of PM target Go/NoGo: press nothing on presentation of target EBPM + Go/NoGo 2 cues; each 4× Single OT: no additional task	No filled delay	Accuracy • group effect for PM hits: ASC < controls • no group difference in the Go/NoGo condition Reaction times for the PM task: ASC> controls	–	Computerized categorization task; between-subjects	• single OT: 80 • dual-task block: 80 • OT plus Go/NoGo task: 80	Accuracy • group effect: ASC < controls • no category effect • costs to OT by adding PM task only for controls: single OT > dual-task Reaction times • group effect: ASC> controls • no category effect	No significant interactions	–
Yi et al. (2014)	25 ASC ($M = 7.7$) 25 age-matched controls ($M = 7.7$) 28 ability-matched controls ($M = 5.8$)	ASC: 19 m, 6 f Age-matched controls: 19 m, 6 f Ability-matched controls: 19 m, 6 f	PPVT-R: ASC $M = 4.56$ Age-matched controls N/A Ability-matched controls $M = 4.75$ Raven test: ASC $M = 21.1$ Age-matched controls $M = 31.8$ Ability-matched controls $M = 21.4$	No information	Expert clinical evaluation, diagnoses according to DSM-IV criteria Exclusion criteria: other developmental or psychiatric disorders, intellectual disability, congenital deafness	Non-focal EBPM: • hand card with heart shape to experimenter (5 PM trials)	No filled delay	Accuracy ASC < controls (age- and ability-matched); age-matched controls > ability-matched controls	–	Card naming game	5 sets of 10 cards	–	–	ASC: PM predicted by Raven Test and Block Span Ability-matched controls: PM predicted by Day–Night Stroop Age-matched controls: no correlations

Altgassen et al. (2012)	25 ASC (M = 21.8) 25 controls (M = 21.8)	ASC: 20 m, 5 f Controls: 19 m, 6 f	WASI Vocabulary test: ASC M = 9.2 Controls M = 10.2 Matrices: ASC M = 11.0 Controls M = 11.4	High-functioning ASC (IQ > 85) or Asperger's syndrome	Expert clinical evaluation, diagnoses according to DSM-IV criteria Diagnoses established with ADI-R and ADOS	EBPM: prepare tea when water is boiling and kettle changing color; switch off egg cooker when it is beeping TBPM: remove tea bag after 3min; put butter on table 6min prior to guests' arrival Red Pencil: repeat 'red pencil' after experimenter	~10 min (digit ordering, trail making test, Tower of Hanoi)	EBPM accuracy: ASC < controls TBPM accuracy: ASC < controls Red pencil: ASC < controls	–	Real-life breakfast task: participants had to prepare breakfast for 4 people following certain rules and time constraints	–	ASC < controls on all measures (rule adherence; planning; plan adherence; efficiency) except switching	–	EBPM and TBPM correlates with planning, task completion, rule adherence, switching, efficiency TBPM (but not EBPM) correlates with Red Pencil, DEX, trail making test, digit ordering, and marginally Tower of Hanoi
Kretschmer et al. (2014)	17 ASC (M = 35.6) 17 controls (M = 39.9)	ASC: 14 m, 19 f Controls: 4 m, 31 f	PPVT-4: ASC M = 212.1 Controls M = 210.1 Raven: ASC M = 40.8 Controls M = 40.6	High-functioning ASC (IQ > 80)	Expert clinical evaluation Diagnoses established with ADI-R and ADOS Exclusion criteria: neurological or psychiatric disorders, present or past drug or alcohol abuse	EBPM: e.g. take medication at dinner TBPM: e.g. use inhaler at 11 am EBPM & TBPM each day 4 tasks (2 regular, 2 irregular); total PM=24 2 conditions, between-subject: • implementation intentions • standard instructions	No filled delay	Accuracy • group effect: ASC < controls • PM cue effect: EBPM > TBPM • regularity effect: regular > irregular • no effect of encoding	• regularity: group x irregular ASC < controls; ASC regular > ASC irregular; no effect controls • regularity x PM cue: both conditions EBPM > TBPM; TBPM regular > TBPM irregular; EBPM no difference • Encoding x PM cue: both conditions EBPM > TBPM • no other interaction	Virtual week (computerized; 3 days)	–	–	–	–

(*Continued*)

Table 1. (*Continued*).

	Participant information					PM				OT				
Intact PM	Sample size (mean age)	Gender	Intellectual ability measures	Severity of ASC symptoms	Diagnostic and exclusion criteria	Task description	(Filled) delay length	Main effects	Interactions	Task description	Number of trials	Main effects	Interactions	Control variables
Henry et al. (2014)	30 ASC (M = 10.1) 30 controls (M = 10.0)	ASC: 24 m, 6 f Controls: 19 m, 11 f	WASI Full Scale IQ: ASC M = 112.9 Controls M = 115.3 Verbal IQ: ASC M = 110.3 controls M = 114.9 Performance IQ: ASC M = 114.5 controls M = 118.3	Highfunctioning ASC or Asperger's syndrome	Expert clinical evaluation, diagnoses according to DSM-IV criteria Exclusion criteria: other psychiatric or neurological disorders	EBPM: e.g., take medication at dinner TBPM: e.g., use asthma inhaler at 11 am EBPM & TBPM each 4 tasks per day (2 regular, 2 irregular); total PM=24	No filled delay	Accuracy - group effect: ASC < control - PM cue effect: EBPM > TBPM - absorption: Low > High - no effect of regularity	- group x PM cue: TBPM: ASC < controls; EBPM: ASC = controls - regularity x PM cue: EBPM: regular = irregular; TBPM: regular > irregular - no other interaction	Virtual week (computerized; children's version, 3 days) within-subjects: high absorption: specific die rolls before moving on, manual movement low absorption: any die roll, auto movement	–	–	–	ASC: TBPM correlates with Full Scale IQ, ABAS, Stroop switching; no correlations for EBPM Controls: TBPM with semantic switching, ABAS; EBPM with semantic switching Williams,
Williams et al. (2013)	21 ASC (*M* = 10.6) 21 controls (*M* = 10.6)	Not reported	WASI Verbal IQ: ASC *M* = 103.6 Controls *M* = 106.5 Performance IQ: ASC *M* = 110.2 Controls *M* = 107.5	13 autistic disorder, 8 Asperger's syndrome	Diagnoses established according to conventional criteria	Focal EBPM: press specific key when passing a lorry (max 6) TBPM: refuel car by pressing key (6 trials), check fuel by pressing other specific key	No filled delay	PM accuracy • EBPM: no group effects • TBPM: ASC< controls Fuel checks • linear increase per interval • no group effect	ASC: TBPM< EBPM, controls: TBPM=EBPM	Video game of driving car (collecting tokens and avoid hitting hazards)	–	Accuracy • no group effect • effect of condition: TBPM block < EBPM	No significant interactions	ASC: TBPM failures with mentalizing Controls: TBPM failures with Wisconsin Card Sorting test (approaching significance)

Williams et al. (2014)	17 ASC (*M* = 31.1) 17 controls (*M* = 31.9)	ASC: 14 m, 3 f Controls: 14 m, 3 f	WASI Full Scale IQ: ASC *M* = 114.1 Controls *M* = 117.7 Verbal IQ: ASC *M* = 111.4 Controls *M* = 114.6 Performance IQ: ASC *M* = 113.5 Controls *M* = 116.9	4 autistic disorder, 13 Asperger's syndrome	Diagnoses established according to conventional criteria (13 with ADOS) Exclusion criteria: psychotropic medication, illegal drugs. neurological or psychiatric disorders-	Non-focal EBPM: press 'm' every time a musical instrument appeared in list TBPM: press 'P' every 2mins; spacebar for clock	No filled delay	PM accuracy • no group effect • effect of cue: TBPM < EBPM PM RT/precision • group effect: ASC > controls • no effect of cue Clock checks • linear increase per interval • no group effect	PM accuracy ASC < controls in TBPM, but not EBPM PM RT/precision • no interaction Clock checks • no interaction	Computerized presentation of single words (N=7) for 1s followed by all 7 words for 4s: final list same or different?	40 lists for EBPM and 40 for TBPM	Accuracy • no main effects no response times reported	No significant interactions	ASC: EBPM correlates with verbal storage span, verbal processing No correlations for TBPM Controls: EBPM correlates with visual storage span No correlations for TBPM
Sheppard et al. (2016)	14 severe ASC (*M* = 9.3) 14 mild ASC (*M* = 10.1) 26 controls (*M* = 5.1)	ASC: 27 m, 1 f Controls: 14 m, 3 f	No information; measures of reading, writing and number skills	CARS: Severe ASC *M* = 42.3 mild ASC *M* = 30.9	Diagnoses according to DSM-IV criteria	EBPM: 1) clap when hear music (2 trials); 2) don't feed puppet grapes (2 trials); 3) get reward at end (1 trial) memory: name of puppet	Distractor game (60s)	Accuracy • Total PM: Severe ASC < Mild ASC = controls (same for clapping & feeding tasks) • Reward: no group effect • Name recall: no group effect	–	Feed puppet food	–	–	–	Correlation between PM and CARS scores approaching significance

Notes: ABAS = Adaptive Behavior Assessment Scale; ADI-R = Autism Diagnostic Interview – Revised; ADOS = Autism Diagnostic Observation Scale; ASC = Autism Spectrum Condition; CARS = Childhood Autism Rating Scale; DEX = Dysexecutive Questionnaire; 3di = Developmental, Dimensional and Diagnostic Interview; EBPM = Event-Based Prospective Memory; PM = Prospective Memory; PPVT = Peabody Picture Vocabulary Test; OT = Ongoing Task; SRS = Social Responsiveness Scale; SSP = Short Sensory Profile; TBPM = Time-Based Prospective Memory; WASI = Wechsler Abbreviated Scale of Intelligence; WISC-III = Wechsler Intelligence Scale for Children – Third Edition; WNV = Wechsler Non-Verbal scale of ability.