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RESEARCH ARTICLE

Practice is the best of all instructors—Effects of enactment encoding and episodic future thinking on prospective memory performance in high-functioning adults with autism spectrum disorder

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Abstract

Prospective memory (PM) is the ability to remember to carry out intended actions in the future. The present study investigated the effects of episodic future thinking (EFT) and enactment encoding (EE) on PM performance in autistic adults (ASD). A total of 72 autistic individuals and 70 controls matched for age, gender, and cognitive abilities completed a computerized version of the Dresden breakfast Task, which required participants to prepare breakfast following a set of rules and time restrictions. A two (group: ASD vs. controls) by three (encoding condition: EFT vs. EE vs. standard) between-subjects design was applied. Participants were either instructed to engage in EFT or EE to prepare to the different tasks prior to performing the Dresden breakfast or received standard instructions. Analyses of variance were conducted. Autism-spectrum-disorders (ASD) participants did not differ from control participants in their PM performance, regardless of which strategy they used. Compared to the standard condition, EE but not EFT improved time-based PM performance in all participants. This is the first study to find spared time-based PM performance in autistic individuals. The results confirm earlier results of beneficial effects of EE on PM performance. Findings are discussed with regards to the methodology used, sample composition as well as autistic characteristics.

Lay Summary

The present study investigated the effects of the two encoding strategies episodic future thinking (EFT) and enactment encoding (EE) on prospective memory (PM) in autism spectrum disorders (ASD). A total of 72 ASD individuals and 70 controls matched for age, gender, and cognitive abilities completed a computerized PM task. Participants were either instructed to engage in EFT or EE to prepare to the different tasks prior to performing the PM task or received standard instructions. ASD participants did not differ from control participants in their PM performance, regardless of which strategy they used. Compared to the standard condition, EE but not EFT improved time-based PM in all participants. The results confirm earlier results of beneficial effects of EE on PM.

KEYWORDS

episodic future thinking, enactment encoding, prospective memory, intention encoding

INTRODUCTION

Autism spectrum disorders (ASD) are defined as a group of neurodevelopmental conditions characterized by difficulties in social interaction, communication, and a behavioral inflexibility, reflected in repetitive and restricted behavior and interests. The severity of symptoms differs in each individual and can change across the lifespan (APA, 2013). Studies have shown a male predominance; with ASD affecting two or three times more males than females (e.g., Kim et al., 2011; Loomes et al., 2017; Wilson et al., 2016). This diagnostic distribution toward males might result from under-recognition of autistic females (Baron-Cohen et al., 2011).

Besides difficulties in theory of mind (ToM, i.e., the ability to attribute mental states like beliefs, desires or intentions to others to explain and predict their behavior; e.g., Baron-Cohen et al., 1985) and a weak central coherence (WCC, i.e., the tendency to process information locally; see Happé & Frith, 2006), executive dysfunction is frequently observed individuals with ASD (Hill, 2004). Difficulties in executive functions seem to be present in ASD regardless of potential moderators such as age, cognitive abilities, or gender (van Eylen et al., 2015; Xie et al., 2020). For example, various studies have reported cognitive inflexibility in ASD (see Geurts et al., 2009). Similarly, difficulties in planning (e.g., organizing spaces, developing, or following a schedule) have been found most consistently in ASD (Happé & Frith, 2006; Hill, 2004; van den Bergh et al., 2014); although other research suggests that it is not entirely clear whether autistic people have problems with planning in general, or whether the observed difficulties may be attributed to possible moderators such as the severity of ASD symptoms or co-occurring psychopathology (Olde Dubbelink & Geurts, 2017).

The behavioral inflexibility in ASD is often reflected in a strong adherence to routines and a preference for sameness (Bishop et al., 2013), but also in a low tolerance to uncertainty (Boulter et al., 2014; South & Rodgers, 2017; Wigham et al., 2015), that may lead to novel situations being perceived as unpleasant, threatening or stressful (Cardon & Bradley, 2023; Hodgson et al., 2017). In everyday life, problems with executive functions can have negative consequences. Insisting on routines may make it challenging to adapt to new job situations, and adhering to dynamic work schedules can be difficult when there is no flexibility in dealing with unexpected events (Müller et al., 2003). Moreover, not only executive functioning seems to be problematic in ASD, but also difficulties in episodic memory have been reported; especially when tasks put high demands on self-initiated processing (see Griffin et al., 2022), which may lead to appointments being simply forgotten. Similarly, there is some evidence for difficulties with time perception in ASD (see Casassus et al., 2019).

The cognitive ability that enables us to remember to carry out an intended action at a predefined time in the future is defined as prospective memory (PM). Based on the type of cue that indicates the appropriate moment to initiate the intended action, research distinguishes between time-based (i.e., remembering to perform an intended action at a certain point in time) and event-based PM (i.e., remembering to perform an intended action when a specific cue is presented; Einstein & McDaniel, 1990). Prospective remembering comprises multiple processes and four phases (Kliegel et al., 2002): First, the individual has to plan which actions he/she wants to perform at a certain moment. This intention formation phase is mainly based on planning abilities. In the second phase, intention retention, the intention has to be stored in episodic memory while the individual is engaged in other ongoing activities. The third phase of intention initiation requires monitoring to detect the cue indicating the appropriate moment to inhibit the ongoing activity and switch to the intended action. In the last (fourth) phase, intention execution, the planned action is finally carried out. Thus, PM relies on a combination of various cognitive abilities, including episodic memory, working memory, attention, time perception, inhibitory control, switching as well as planning, and organizational skills (Einstein & McDaniel, 1990; Martin et al., 2003; McDaniel & Einstein, 2011). Neuroimaging studies indicate the involvement of both frontal and medial temporal structures in PM (see Burgess et al., 2011), with frontal processes (executive control) appearing to be more involved than temporal (retrospective memory) ones (Brunfaut et al., 2000; Kliegel et al., 2004). As executive functions, episodic memory and time perception are essential for successful PM performance and difficulties in these cognitive functions are typically present in ASD, impairments in PM are to be expected in autistic individuals.

While difficulties in time-based PM in children and adults with ASD have been consistently reported in the literature (e.g., Altgassen et al., 2009, 2019; Dehnavi & Khan, 2023; Henry et al., 2014; Kretschmer et al., 2014; Landsiedel & Williams, 2020; Williams et al., 2013, 2014), findings regarding event-based PM in ASD seem to be mixed. There are several studies that found spared event-based PM performance in ASD (Altgassen & Koch, 2014; Altgassen, Phillips, et al., 2010; Henry et al., 2014; Sheppard et al., 2016; Williams et al., 2013), while others reported reduced performance in ASD (Brandimonte et al., 2011; Kretschmer et al., 2014; Yi et al., 2014). Difficulties in event-based PM performance were found mainly when the PM tasks put high demands on executive functions (e.g., when cues were low in salience; Brandimonte et al., 2011; Kretschmer et al., 2014 or low in focality; Yi et al., 2014).

Time-based PM tasks are generally assumed to put higher demands on executive function resources than event-based tasks. Time-based PM tasks do not include an external cue, which may prompt automatic retrieval of the intention, but instead require the individual to keep track of the elapsing time (cf. Einstein & McDaniel, 1996). Assuming that the PM difficulties in individuals with ASD could be attributed to underlying difficulties in both, executive functions and episodic memory, PM performance could potentially be improved by reducing executive functions demands within the task and deepening encoding during intention formation (Sheppard et al., 2018). This could be achieved by providing participants with learning strategies.

Practice is known to be essential for all forms of learning. Previous experience in form of demonstration or practice helps learning action concepts by preencoding them in memory and thereby reducing cognitive demands—as the execution of the task simply requires recalling the already available information instead of first planning action execution (Engelkamp, 1998). Furthermore, practicing may reduce uncertainty about how an activity should be performed (Altermann et al., 2014). There is evidence that both, physical (motor execution or enactment, Cohen, 1989) and mental practice (movement planning or imagery, Paivio, 1969) have beneficial effects on learning (Feltz et al., 1988; Feltz & Landers, 1983; Grouios, 1992; Hinshaw, 1991); though, mental practice seems to be less effective than physical practice (i.e., Feltz et al., 1988, 2014; Hird et al., 1991). In contrast to physical practice, which implies rehearsing a motor action, mental practice refers to the act of repeatedly simulating (i.e., imagining) a motor action in one's mind without actually simultaneously executing it (e.g., Jeannerod, 1994, 1995).

As remembering a preplanned action (at a certain time or when a cue is presented) is an essential part of PM, it can be assumed that encoding strategies might be helpful for PM performance. Encoding strategies refer to the deliberate attempt to encode information into long-term memory (Mayer, 2008). McDaniel and Einstein (2000) have argued that efficient intention formation may improve PM performance by reducing the need for resource-demanding strategic processes. Encoding strategies may lead to stronger memory traces and may help to enhance cue-action association (e.g., by (mentally) preexperiencing the context in which the intention will later be performed), which may reduce the need for strategic monitoring and facilitate (automatic) retrieval, and thus, improve PM performance (Paraskevaides et al., 2010).

One strategy which combines the approaches of physical practice and encoding is known as enactment encoding (EE): Performing a physical action (enactment) seems to be an effective encoding strategy as the motoric information is incorporated into episodic memory, which may facilitate later retrieval and execution of the action (e.g., Engelkamp, 1998; Zimmer, 2001) in general. Several studies have reported beneficial effects of EE on long-term memory in individuals with ASD with average and high cognitive abilities (Grainger et al., 2014; Yamamoto & Masumoto, 2018; Zalla et al., 2010). Moreover, beneficial effects of EE on working memory were found in autistic children with lower middle and higher levels of intelligence (Wang et al., 2022), though some evidence suggests that EE might be less effective in ASD than in typically developing children (Xie et al., 2024). While there are no studies that have specifically examined EE as an encoding strategy for PM performance in autistic individuals, its beneficial effects have been shown in other populations with difficulties in executive functions and episodic memory (Pereira et al., 2015, 2018). Therefore, EE should be an effective learning strategy for individuals with ASD, particularly for improving memory recall and facilitating the transfer of learned skills to real-world situations (Roberts et al., 2022). Moreover, as autistic individuals seem to show a high attention to details as assumed by WCC theory (Happé & Frith, 2006) and a low tolerance for uncertainty (Boulter et al., 2014; Normansell-Mossa et al., 2021; South & Rodgers, 2017; Wigham et al., 2015) they may benefit even more from EE, as practice could enable both, higher precision in later execution and a reduction of uncertainty about the future process

Another promising strategy which has been shown to be beneficial for PM performance is episodic future thinking (EFT), which refers to the ability to imagine or simulate a personal future event such as the to be performed PM task (e.g., taking part in an important exam next week; Atance & O'Neill, 2001). Research suggests that both episodic and semantic memory is involved in EFT. This is supported by neuroimaging studies (Addis et al., 2007; Binder et al., 2009; Schacter & Addis, 2007, Schacter, 2012; Szpunar et al., 2007), which suggest that a common brain network, including the medial temporal lobe, prefrontal cortex, and posterior parietal cortex, underlies episodic and semantic memory as well as EFT. Consistently, populations with difficulties in episodic or semantic memory also experience challenges in thinking about future events (Addis et al., 2009; Brown et al., 2013; Irish et al., 2012; Irish & Piguet, 2013; Lind & Bowler, 2010). In EFT, however, not only memory processes appear to be involved, but also executive functioning. Hence, difficulties in future thinking might also arise in the absence of memory problems (Irish & Piguet, 2013; Summerfield et al., 2010; Vito et al., 2012). Several studies found instructing participants to engage in vivid future thinking during intention encoding to enhance PM performance (Altgassen et al., 2015; Kretschmer-Trendowicz et al., 2016; Kretschmer-Trendowicz et al., 2019, Lloyd et al., 2020; Neroni et al., 2014; Terret et al.,2016). Importantly, EFT interventions also improved PM performance in populations whose executive (and EFT) abilities were still developing (e.g., children and adolescents; Kretschmer-Trendowicz et al., 2016; Kretschmer-Trendowicz et al., 2019), already reduced (e.g., older adults;Altgassen et al., 2015; Terrett et al., 2016), or pathologically impaired (Korsakoff syndrome; Lloyd et al., 2020).

Xie et al. (2024) not only investigated the effect of EE but also explored the impact of imagined enactment on working memory for task instructions in autistic children. While positive effects on remembering instructions through EE were observed in ASD, imagined enactment, what might be seen as the equivalent to our EFT approach, did not result in improved memory for instructions. Interestingly, typically developing children benefitted from both physical and mental enactment, even though the effect of mental enactment was less pronounced than that of physical enactment.

So far, neither the effects of EE nor of EFT during intention encoding on PM performance have been investigated in autistic individuals. As the ability to engage in EFT is considered to be reduced in individuals with ASD (Hanson & Atance, 2014; Lind et al., 2014; Lind & Bowler, 2010; Marini et al., 2016; Terrett et al., 2013), but is thought to be crucial for intention formation, it is possible that PM impairments in ASD might be partly caused by underlying EFT difficulties or by a reduced tendency to spontaneously engage in EFT during intention formation (Sheppard et al., 2018). Consequently, systematically encouraging individuals with ASD to engage in the process of intention formation by providing them with practice-related encoding strategies as EFT or EE, might help to overcome impairments in planning ability and thereby enhance PM performance; as demonstrated for EE and EFT in other populations with reduced EFT and executive function abilities (Altgassen et al., 2015; Kretschmer-Trendowicz et al., 2016; Kretschmer-Trendowicz et al., 2019; Lloyd et al., 2020; Neroni et al., 2014; Terrett et al., 2016).

In this study, we therefore set out to examine the effects of two encoding strategies (EE and EFT) on event- and time-based PM performance in ASD and to compare them to standard PM instructions. Based on the mixed findings regarding PM in ASD (see Sheppard et al., 2018), we expected participants with ASD to perform worse than participants without ASD on time-based, but not event-based PM tasks. We predicted that compared to a standard encoding condition (= control group), instructing participants to engage in EE (= physical practice) or EFT (= mental practice) during intention formation would enhance participants' PM performance. We expected further that the beneficial effects of EE on PM performance would be larger than the effects of EFT on PM performance in both groups, as physical practice has been shown to be more effective than mental practice (i.e., Feltz et al.,1988, 2014; Hird et al., 1991; Xie et al., 2024). Finally, we predicted that effects of both interventions would be larger in ASD participants compared to participants without ASD, as—given ASD individuals' impaired executive function and episodic memory abilities (Griffin et al., 2022; Olde Dubbelink & Geurts, 2017)—they should benefit more from strategy-related reduced executive function demands and enhanced encoding.

METHOD

Participants

A power analysis performed using G*Power determined a minimal sample size of $N = 162$ (27 participants per condition for the ASD and nonASD group, Faul et al., 2007). In total, 72 adults with ASD (age $M = 35.03$, $SD = 12.79$; 37 women, 33 men and two diverse individuals) and 70 adults without ASD (age $M = 34.11$, SD = 12.00; 37 women and 33 men) took part in the experiment. Groups were matched closely for age, gender, and highest education degree. Participants with ASD were recruited by contacting mental healthcare facilities, through self-help groups and via social media (e.g., Facebook) in Germany, Austria, and German-speaking Switzerland. Inclusion criteria were being aged between 18 and 69 years and German mother tongue. All participants in the ASD group had formal diagnoses of the autism spectrum. Exclusion criteria were the presence of specific psychiatric disorders (schizophrenia, bipolar disorder or an acute severe depressive episode), neurological illnesses and in the control group the presence of a diagnosis of the autism spectrum.

All participants in the ASD group had formal diagnoses of ASD, according to conventional criteria (APA, 2013). Comorbid disorders in the ASD group were affective disorders such as major depression (42%), anxiety disorders (11%), ADHD (11%), and obsessive-compulsive disorder (3%). Comorbid disorders in the control group were major depression (11.5 %) and anxiety disorders (4%).

Participant characteristics and group matching statistics are presented in Table 1. All participants gave written informed consent prior to taking part in the study. Participants received payment (15 Euro) for taking part in the study. The study was conducted in line with the Helsinki declaration. Ethical approval for the study was obtained from the appropriate university ethics committee.

Tests and procedure

Individual difference variables

The autism spectrum quotient test—short version (AQ; Freitag et al., 2007) is a screening questionnaire that assesses the severity of ASD symptoms. It comprises 33 questions, which have to be answered on a 4 point Likert-Scale: strongly agree, slightly agree, slightly disagree, strongly disagree. A score of 17 or more indicates clinically significant levels of autistic traits. The AQ was found to be highly reliable (33 items; Cronbach's alphas: ASD = 0.84; nonASD = 0.83) in our sample. The questionnaire is based on three subscales (each 11 items) that can be aggregated into a total score: social interaction (Cronbach's alpha: ASD = 0.84; nonASD = 0.75),

TABLE 1 Individual difference variables.

	ASD ($n = 72$)	CG ($n = 70$)			
	M (SD)	*M* (SD)	*F* (df)	*p*	η^2
Age	35.03 (12.79)	34.11 (12.00)	.19 (1,141)	0.66	0.00
AQ					
Total score	22.06 (5.19)	9.64 (4.56)	228.96 (1,141)	0.00	0.62
Social interaction	7.46 (2.77)	2.98 (2.26)	111.42 (1,141)	0.00	0.54
Imagination	7.36 (1.93)	3.83 (1.76)	129.02 (1,141)	0.00	0.57
Communication	7.24 (1.95)	2.87 (2.02)	171.23 (1,141)	0.00	0.63
FEA–ASB	42.37 (17.27)	34.97 (21.70)	4.85 (1,141)	0.03	0.11
IUS-18	52.47 (15.62)	47.38 (11.4)	4.89 (1,141)	0.03	0.11
WAIS-IV					
WAIS-IV-NVA	10.49 (3.03)	9.83 (2.25)	2.15 (1,141)	0.15	0.02
WAIS-IV-VA	10.72 (2.99)	10.14 (2.21)	1.71 (1, 141)	0.19	0.01

Note: * indicates p < .05; ***p<.001. For the WAIS subtests, results are reported in age normed scaled scores ($M = 10$, SD = 3; range 1–19).
Abbreviations: ASD, autism spectrum disorders group; CG, control group; WAIS-IV-NVA, Wechsler Intelligence Scale non-verbal ability (matrices reasoning subtest), WAIS-IV-VA = Wechsler Intelligence Scale verbal ability (vocabulary subtest).

imagination (Cronbach's alpha: ASD = 0.59; nonASD = 0.62), and communication and reciprocity, (Cronbach's alpha: ASD = 0.61; nonASD = 0.72). The internal consistencies found in this sample are comparable to the results (Cronbach's alpha = 0.65–0.87) of Freitag et al. (2007).

The FEA-ASB (Döpfner et al., 2006) is a German psychological self-assessment questionnaire measuring the symptoms of ADHD in adults. It is part of the German ICD- and DSM-based Diagnostic System for the Assessment of Mental Disorders in Children and Adolescents (DISYPS, Döpfner et al., 2008). The questionnaire consists of 20 items that measure the 18 symptom criteria of the ICD-10 and DSM-V on a 4-point Likert-Scale. Overall, a cumulative score ranging from 20 to 60 can be achieved. The questionnaire comprises three subscales, which assess the characteristic symptom areas of attention deficit, hyperactivity, and impulsivity on the basis of various statements about one's own behavior and personal preferences. Many autistic individuals also exhibit a large number of ADHD-typical symptoms (e.g., Hanson et al., 2013; Murray, 2010). Studies have shown more severe autism symptoms (Sprenger et al., 2013) and higher rates of cognitive impairment (Thomas et al., 2018) in individuals with ASD and ADHD in comparison to those with ASD alone. The internal consistency (Cronbach's alpha) in the present sample was 0.91 for ASD and 0.91 for nonASD.

The Intolerance of Uncertainty Scale (IUS-18; Gerlach et al., 2008) is a German adaption of the original 27-item Intolerance of Uncertainty Scale (Freeston et al., 1994) and the widely used short version IU-12 (Carleton et al., 2007). Each item is evaluated on a five-point Likert scale (1 = "not at all characteristic of me" to 5 = "entirely characteristic of me"), allowing respondents to score between 18 and 90. The IUS-18 measures responses to uncertainty, ambiguous situations, and the future. People with high levels of IU find uncertainty aversive, stressful and do not function well in uncertain situations. Studies have shown that autistic individuals score significantly higher on IU Scales compared to non-autistic individuals (see Jenkinson et al., 2020). Internal consistency was excellent in both groups (Cronbach's alphas: ASD = 0.91; nonASD = 0.93) and is comparable to the results found by Riedelbauch et al. (2024) in a German sample of autistic (Cronbach's alpha = 0.93) and nonautistic adults (Cronbach's alpha = 0.93).

To assess participants, verbal and nonverbal abilities, the vocabulary and matrices reasoning subtests of the German version of the Wechsler Intelligence Scale-Fourth Edition (WAIS-IV; Wechsler, 2008) were administered. The vocabulary subtest is a verbal test that measures word knowledge and the ability to verbally express definitions of words. Matrices reasoning are a nonverbal reasoning task that requires individuals to identify patterns in designs. Raw scores are converted to age-scaled scores.

PM task

A computerized version of the Dresden Breakfast Task (DBT) was used to measure PM performance. Following Craik and Bialystok (2006), participants were asked to prepare breakfast for four people (cf. details, Altgassen et al., 2012; Altgassen et al., 2012). Participants were required to fulfill common tasks for breakfast preparation, which included setting the table in a predefined way and preparing certain foods (e.g., eggs, bread) and drinks (e.g., tea, orange juice). Participants were asked to complete all tasks within 7 min while adhering to certain rules (e.g., first putting down the tablecloth, then setting the table). The DBT comprises simple, ongoing table-setting tasks (e.g., putting salt, or pepper on the table) as well as a range of time- and event-based PM tasks. Time-based tasks were remembering to take the tea-bag out after 4 min or to put the butter on the table 5 min prior the guests will arrive. Responses were scored as correct if participants completed these tasks ± 30 s around the target times. Participants could check the elapsing time by clicking on a clock icon in the dining room, whereupon the experimental time was presented for 2 s. The fictive starting time was 09:53, end time 10:00. Event-based tasks were remembering to prepare the tea by putting hot water in the teapot when the kettle went off and changed its color from blue to red, and to turn off the egg cooker when it beeped. Responses were scored as correct if participants completed these tasks within 10 s after occurrence of these events. For further details see Altgassen et al. (2014).

With regards to the task's validity, there is some evidence from the noncomputerized version of the DBT. Here, significant correlations were observed (see Altgassen et al., 2012) between time-based PM in the Breakfast task and a laboratory PM test (red pencil test; Dobbs & Rule, 1987; Zeintl et al., 2007) as well as with executive functioning as assessed in the lab (switching assessed with the trail making test; Rodewald et al., 2012, and working memory, assessed with the digit ordering test; Hoppe et al., 2000) and per self-report regarding everyday performance (DEX questionnaire, Behavioural Assessment of the Dysexecutive Syndrome test battery; Wilson et al., 1996).

Procedure

The entire data collection was conducted online. Before taking part in the experiment, participants were asked to fill in a questionnaire assessing sociodemographic information and the psychological self-assessment tests (the autism spectrum quotient test—short version), Freitag et al., 2007; Fragebogen zur Erfassung von ADHS im Erwachsenenalter, aktuelle Probleme, Selbstbeurteilung (FEA-ASB) (Döpfner et al., 2006; The Intolerance of Uncertainty Scale—Short Form, Gerlach et al., 2008). Data were collected via the online platform SoSci Survey (Leiner, 2019). Following the completion of the online questionnaire, participants could sign up for an appointment for the online testing session. As part of the online testing via Microsoft Teams the vocabulary and matrices reasoning subtests of the WAIS-IV were first conducted with the participants. After that participants were introduced to the DBT and technical details were explained and demonstrated. Participants worked on the DBT through the screen sharing function of Microsoft Teams. Further details regarding the test procedure can be found in the Data S1.

All participants were assigned to one of two experimental conditions (EFT) or (EE) or a control condition. In the EFT condition, participants were first instructed to practice future thinking on a specific example (i.e., imagine calling a friend/relative at 8 p.m.). Participants were instructed to imagine the example event as vividly and in as much detail as possible in their mind's eye. They were also encouraged to close their eyes during imagery. The practice phase took about 3–5 min. Thereafter, participants were told to apply the same encoding strategy to the DBT and to imagine themselves executing the four PM tasks on the computer while taking into account the other tasks that they have to complete and the rules they have to adhere. Participants were first instructed to say aloud what they were imagining for 20 s before they were given a further 20 s imagine the same task for themself. After the exercise, participants were asked to rate on a 5-point likert scale the vividness of their imagery.

The EE condition comprised a practical exercise phase of the four PM tasks. The four PM tasks were presented to the participants one at a time. The participants were asked to tell the experimenter how they intended to perform the PM tasks at the computer taking into account the other tasks and rules. After that participants were encouraged to demonstrate the task execution to the experimenter. Unlike the EFT condition, there was no specific instruction to mentally imagine task execution.

Introductions to both experimental conditions took about 8–10 min.

After having been introduced to the DBT, control participants were once again presented with the list of tasks and rules of the DBT that had already been shown to all participants in the instructions earlier and asked to study them.

Thereafter, participants were asked to develop a plan on how and in which order they wanted to perform the different subtasks of the DBT. The participants were given 8 min to do this. They then had to verbalize their plans orally to the experimenter, who rated the overall quality of their plans. Plan performance was measured as a composite score of prioritizations (number of important tasks that were mentioned in the plan), rule adherence (number of rules that were mentioned in the plan), and specification of actions (number of specified subtasks and number of specifically elaborated orders of tasks that were mentioned in the plan). The maximum score was 20.

Participants were asked to work on a computerized version of the Tower of Hanoi, before performing the PM task (DBT). This task was merely intended to introduce a temporal delay for the execution of the PM task. Therefore, the results were not used for the statistical analyses. The completion of the Tower of Hanoi took about 5 min. It was ensured that the execution did not exceed the time span of 5 min. The DBT was carried

TABLE 2 Mean and standard deviations of performance of the autism spectrum disorders (ASD) and the control group in the Dresden breakfast task.

	EFT		EE		CC	
	ASD ($n = 24$)	CG ($n = 22$)	ASD ($n = 24$)	CG ($n = 24$)	ASD ($n = 24$)	CG ($n = 24$)
	M (SD)	*M* (SD)	*M* (SD)	*M* (SD)	*M* (SD)	*M* (SD)
General cognitive abilities						
Vocubulary test	11.33 (3.29)	10.27 (2.71)	10.46 (2.50)	10.21 (1.41)	10.38 (3.16)	9.96 (2.42)
Matrices test	11.04 (2.81)	10.14 (2.25)	10.67 (3.17)	9.29 (2.12)	9.75 (3.17)	10.08 (2.36)
Dresden breakfast task						
General task performance	64.04 (18.94)	62.09 (18.68)	66.21 (18.38)	63.63 (17.61)	53 (17.97)	63.33 (17.34)
PM performance						
Event-based	1.08 (0.88)	1.09 (.87)	1.33 (.70)	1.29 (.69)	.88 (.85)	1.0 (0.78)
Time-based	.88 (0.74)	.59 (.73)	.71 (.69)	.96 (.81)	.29 (.55)	.63 (0.65)
Planning						
Plan quality	13.71 (2.9)	15.14 (2.66)	14.21 (2.28)	13.63 (3.09)	13.25 (2.95)	14.33 (2.44)
Switching						
Rule adherence	2.0 (1.32)	1.77 (1.2)	2.37 (1.3)	2.13 (1.15)	1.50 (.93)	1.96 (1.1)
Time monitoring	3.79 (3.17)	2.73 (2.14)	4.5 (2.78)	3.42 (3.42)	3.08 (3.09)	4.67 (3.94)

Note: General task performance represents ongoing task performance.
Abbreviations: ASD, autism spectrum disorders group; CC, control condition; CG, control group; EE, enactment encoding; EFT, episodic future thinking.

out directly afterwards and was completed in about 10 min.

Dependent variables for PM ability were performance (PM task accuracy) in the two event-based and two time-based PM tasks. Ongoing task performance was evaluated by using a measure of overall task performance (assessment of the fulfillment of the single subtasks which also included the PM tasks). We also explored switching ability (participants were explicitly encouraged to consider switching between tasks in order to complete all tasks in time), which measured as the number of task- and room-switches, efficiency (participants efficiency in the fulfillment of the subtasks, e.g., not taking more items to the living room than needed) and time-monitoring abilities. Time-monitoring behavior across the task was assessed as number of clock checks. The instructions for the DBT and the encoding strategies can be found in the Data S1.

Statistical analyses

The data were analyzed using IBM SPSS Statistics (Version 27). We conducted additional Bayesian statistics to estimate the strength of evidence for the null hypothesis. Mediation analyses and Bayesian ANOVAs were implemented in JASP (JASP Team 2023, Version 0.17.3). The support for our hypotheses is described by the Bayes factor (BF). The BF_{10} describes the ratio between the evidence for the hypothesis H_1 relative to the null hypothesis H_0 (see van den Bergh et al., 2020).

RESULTS

Several analyses of variance (two-way ANOVAs) were performed to analyze the effects of encoding condition (EFT vs. EE vs. control) and group (ASD vs. nonASD) on task performance. The means and results of the analyses can be found in Table 2 and Table 3. Figure 1 illustrates the main effects of event-based PM and time-based PM performance across the different experimental conditions.

Testing statistical assumptions

Kolmogorov–Smirnov tests revealed that, except for overall task performance (all $ps > 0.20$), none of the dependent measures was normally distributed (all $ps < 0.05$). Levene's tests indicated that assumption of homogeneity of variances were met by all dependent measures, apart from time monitoring. As ANOVAs are considered robust against violations of the normal distribution and homoscedasticity assumption with a sufficient sample size ($N > 30$), all analyses were conducted as planned.

PM performance

To analyze the effects of type of PM task (event-based vs. time-based), experimental condition (EFT vs. EE vs. Control) and group (ASD vs. nonASD) on task performance a $2 \times 3 \times 2$ mixed ANOVA was conducted.

TABLE 3 Comparison of performance in the Dresden breakfast task.

	Condition				Group				Interaction			
	F (df)	*p*	η^2	BF_{10} [a]	*F* (df)	*p*	η^2	BF_{10} [a]	*F* (df)	*p*	η^2	BF_{10} [a]
General cognitive abilities												
Vocabulary test	0.72 (2,136)	0.49	0.01	0.13	1.67 (1.142)	0.20	0.01	0.39	0.30 (2,136)	0.74	0.00	0.05
Matrices test	0.91 (2,136)	0.41	0.01	0.15	2.10 (1,142)	0.15	0.01	0.48	1.31 (2,136)	0.27	0.02	0.07
Dresden breakfast task												
General task performance	0.92 (2,136)	0.52	0.48	0.31	0.21 (1,142)	0.69	0.10	0.22	1.94 (2,136)	0.15	0.03	0.07
PM performance												
Event-based	2.69 (2,136)	0.07	0.04	0.69	.051 (1,142)	0.82	0.00	0.19	0.14 (2,136)	0.87	0.00	0.13
Time-based	3.69 (2,136)	0.03*	0.05	1.48	.72 (1,142)	0.40	0.01	0.25	2.68 (2,136)	0.07	0.04	0.37
Planning												
Plan quality	.69 (2,136)	0.50	0.01	0.12	1.96 (1,142)	0.16	0.01	0.41	1.83 (2,136)	0.16	0.03	0.05
Switching												
Rule adherence	2.57 (2,136)	0.08	0.04	0.59	0.00 (1,142)	0.97	0.00	0.18	1.45 (2,136)	0.24	0.02	0.11
Time monitoring	.71 (2,136)	0.49	0.01	0.12	0.15 (1,142)	0.70	0.00	0.19	2.86 (2,136)	0.06	0.04	0.02

Note: General task performance represents ongoing task performance. Effects of Experimental condition, group and interaction between condition and group.
Abbreviation: ASD, autism spectrum disorder.
*$p < 0.05$.
[a] BF_{10} describes the likelihood of the data under H_1 compared to H_0, BF_{10} = 1/3–1/10, moderate evidence for H_0; BF_{10}=1–1/3, anecdotal evidence for H_0, BF_{10} = 1–3, anecdotal evidence for H_1, BF_{10} = 3–10, moderate evidence for H_1, BF_{10} = 10–30 strong evidence for H_1.

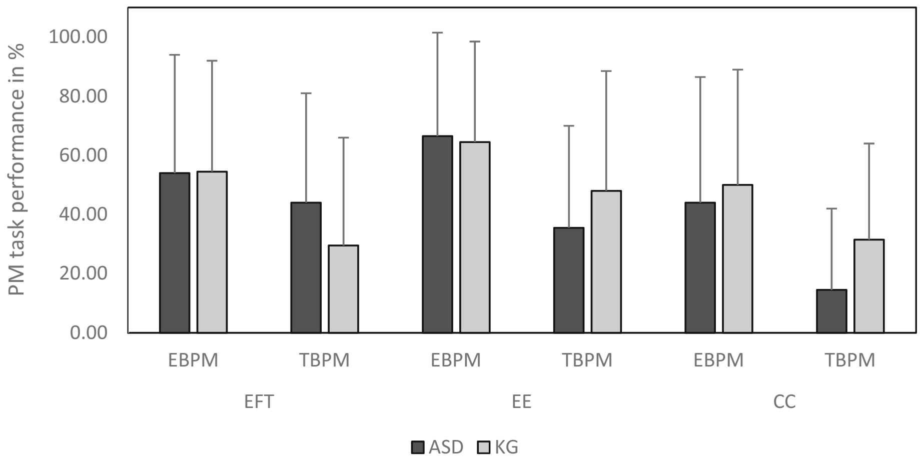

FIGURE 1 Prospective memory (PM) task performance in the different experimental conditions and groups.

There was a significant main effect of type of PM task, *F* (1,136) = 33.01, $p < 0.001$, $\eta_p^2 = 0.19$, and experimental condition, *F* (2,136) = 4.71, $p = 0.01$, $\eta_p^2 = 0.07$ on total PM accuracy. Post hoc Tukey test showed that both groups performed significantly better in the event-based than in the time-based PM tasks, (.49, 95%-CI [0.29, 0.59]). Further Tukey analyses indicated that participants in the EE condition achieved higher PM accuracy ($p < 0.01$) than participants of the control condition (.75, 95%-CI [0.17, 1.33]). There were no differences between the EFT and the EE condition and no differences between the EFT and the control condition. The main effect of group was not significant, *F* (1,136) = 0.51, $p = 0.821$, $\eta_p^2 = 0.00$. There were no significant interaction effects between group and experimental condition, *F* (2,124) = 2.53, $p = 0.063$, $\eta_p^2 = 0.04$ or type of PM task, *F* (2,124) = 0.29 $p = 0.748$, $\eta_p^2 = 0.01$. No interaction effect between experimental condition and type of

PM task was found, F (2,124) = 1.32, $p = 0.267$, $\eta_p{}^2 = 0.04$.

Ongoing task performance

A 3 × 2 two-way ANOVA to analyze the effects of encoding condition (EFT vs. EE vs. Control) and group (ASD vs. nonASD) on overall ongoing task performance resulted in no significant effects. There were no significant differences in groups' ongoing task accuracy, F (1,136) .21, $p = 0.69$, $\eta_p{}^2 = 0.10$, no effect of encoding condition on ongoing task performance, F (2,136) = 0.92, $p = 0.52$, $\eta_p{}^2 = 0.48$ and no interaction effect, F (2,136) = 1.94, $p = 0.15$, $\eta_p{}^2 = 0.03$. The ASD group ($M = 61.08$, $SD = 19.1$) and the control group ($M = 63.04$, SD = 17.37) did not differ in their ongoing task performance.

Additional test variables

Three 3 × 2 two-way ANOVA were conducted to analyze the effects of encoding condition (EFT vs. EE vs. Control) and group (ASD vs. nonASD) on plan quality, rule adherence, and time monitoring.

The ASD group ($M = 13.72$ SD = 2.72) and the control group ($M = 14.34$, SD = 2.78) did not differ in their plan quality, F (1,136) = 1.96, $p = 0.16$, $\eta_p{}^2 = 0.01$. There was no effect of the encoding condition on plan quality, F (2,136) = 0.69, $p = 0.50$, $\eta_p{}^2 = 0.01$ and no interaction effect, F (2,136) = 1.83, $p = 0.16$, $\eta_p{}^2 = 0.03$.

There were no significant group difference, F (1,136) = 0.00, $p = 0.97$, $\eta_p{}^2 = 0.00$ or effect of encoding condition on rule adherence, F (2,136) = 0.00, $p = 0.97$, $\eta_p{}^2 = 0.00$, and no interaction effect, F (2,136) = 1.45, $p = 0.24$, $\eta_p{}^2 = 0.02$. The ASD group ($M = 1.96$, SD = 1.24) and the control group ($M = 1.96$, SD = 1.01) did not differ in rule adherence.

There was no significant difference between the ASD group ($M = 3.81$, SD = 3.04), and the control group ($M = 3.63$, SD = 3.34) in their time monitoring, F (1,136) = 0.15, $p = 0.70$, $\eta_p{}^2 = 0.00$. There was also no effect of encoding condition on time monitoring, F (2,136) = 0.71, $p = 0.49$, $\eta_p{}^2 = 0.01$ and no interaction effect, F (1,136) = 2.86, $p = 0.06$, $\eta_p{}^2 = 0.04$.

Explorative correlation and mediation analyses

Correlational analyses were conducted to explore the association between individual difference variables and the performance in DBT. The results for the ASD and the control group can be found in Table 4 and Table 5, respectively.

Higher general DBT performance correlated with higher FEA-ASB and higher IU-18 total score as well as higher nonverbal ability in the ASD group. Furthermore, better event- and time-based PM in the ASD group were associated with better nonverbal ability. In the control group, increased event-based PM was related to higher intolerance of uncertainty. Higher rule adherence was correlated with better general DBT performance and event- and time-based PM in both groups. Furthermore, increased time-monitoring was associated with better general DBT performance, better time-based PM and stronger rule adherence in both groups. In the control group, better plan quality was related to stronger rule adherence and to more frequent time-monitoring.

Based on the observed correlations, explorative mediation analyses were conducted to better understand the relationship between the individual difference variables and PM performance in the total ASD group. The results can be found in the Data S1.

DISCUSSION

Several studies on PM in individuals with ASD have found difficulties in performance as compared to controls without ASD. While evidence has been mixed with regards to problems in event-based PM (Altgassen & Koch, 2014; Altgassen, Phillips, et al., 2010; Henry et al., 2014; Sheppard et al., 2016; Williams et al., 2013), difficulties in time-based PM have consistently been found across different studies (Altgassen et al., 2009, 2019; Henry et al., 2014; Kretschmer et al., 2014; Landsiedel & Williams, 2020; Williams et al., 2013, 2014). As problems in PM may impact individuals' performance in a broad range of everyday life activities (e.g., meeting deadlines at work, paying bills on time, or keeping appointments with friends) understanding how to improve PM performance can help to develop therapeutic interventions.

The aim of the present study was to investigate whether specific encoding strategies, namely EFT and EE, can improve PM performance in adults with ASD. Previous research suggests that encoding strategies may lead to stronger memory traces and help to enhance cue-action association, which may facilitate intention retrieval and reduce monitoring and switching demands. This in turn might lead to improved performance in PM (Paraskevaides et al., 2010). We predicted that compared to a standard condition (= control group), EE (= physical practice) or EFT (= mental practice) would enhance PM performance in autistic and nonautistic participants. We expected further that in both groups effects of EE on PM performance would be larger than those of EFT, as various studies have shown that physical practice is superior to mental practice (i.e., Feltz et al.,1988, 2014; Hird et al., 1991). Additionally, Xie et al. (2024) found beneficial effects of EE on working memory in autistic children, but not of imagined enactment. We further predicted that effects of both strategies would be larger in ASD

TABLE 4 Correlations of study variables in the autism spectrum disorder (ASD) group.

	Individual difference variables								Dresden breakfast task				
Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Individual difference variables													
(1) AQ-total score													
(2) AQ-social interaction	0.86**												
(3) AQ-imagination	0.75**	0.51**											
(4) AQ-communication	0.68**	0.37**	0.29*										
(5) FEA-ASB-total Score	−0.17	−0.16	−0.27*	0.04									
(6) IU-18	0.14	0.18	0.09	0.06	−0.55**								
(7) WAIS.IV-NVA	0.20	0.36**	0.18	−0.14	−0.27*	0.20							
(8) WAIS-IV-VA	0.27*	0.30**	0.28*	0.02	−0.49**	0.29*	0.36**						
Dresden breakfast task													
(9) General task performance	0.15	0.20	0.13	−0.02	−0.33**	0.36*	0.33**	0.15					
PM performance													
(10) Event-based	−0.03	0.12	−0.05	−0.22	0.01	0.07	0.25*	0.03	0.40**				
(11) Time-based	0.07	0.03	0.08	0.06	0.01	0.07	0.23*	0.17	0.34**	0.31**			
Planning													
(12) Plan quality	0.18	0.32	0.09	−0.07	0.11	−0.14	0.28*	0.13	0.22	0.38**	0.09		
Switching													
(13) Rule adherence	0.01	0.09	0.00	−0.14	−0.17	0.33**	0.27*	0.02	0.65**	0.57**	0.37**	0.22	
(14) Time monitoring	0.27*	0.23	0.28*	0.12	−0.22	0.12	0.19	0.23	0.38**	0.10	0.32**	0.09	0.30*

Note: General task performance represents ongoing task performance.
Abbreviations: WAIS-IV-NVA, Wechsler Intelligence Scale non-verbal ability (matrices reasoning subtest); WAIS-IV-VA, Wechsler Intelligence Scale verbal ability (vocabulary subtest).
*$p < 0.05$.
**$p < 0.01$.

TABLE 5 Correlations of study variables in the control group.

	Individual difference variables								Dresden Breakfast task				
Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Individual difference variables													
(1) AQ-total score													
(2) AQ-social interaction	0.79**												
(3) AQ-imagination	0.66**	0.25*											
(4) AQ-communication	0.80**	0.45**	35**										
(5) FEA-ASB-total score	0.16	0.04	0.25	0.10									
(6) IU-18	−0.03	−0.08	0.05	−0.02	0.58**								
(7) WAIS.IV-NVA	0.04	0.09	0.07	−0.06	0.04	0.12							
(8) WAIS-IV-VA	−0.12	0.07	−0.28*	−0.11	−0.54**	−0.36**	0.32**						
Dresden breakfast task													
(9) General task performance	0.07	0.08	0.10	−0.01	−0.01	0.01	0.00	0.05					
PM performance													
(10) Event-based	0.03	0.06	0.17	−0.15	0.17	0.26*	0.01	−0.00	0.51**				
(11) Time-based	0.07	0.17	0.12	−0.13	−0.03	−0.04	0.08	0.19	0.35**	0.31**			
Planning													
(12) Plan quality	0.03	−0.05	0.21	−0.05	0.49**	0.29	0.21	−0.16	0.37	0.34**	0.14		
Switching													
(13) Rule adherence	−0.12	−0.07	0.03	−0.21	0.02	0.16	0.11	0.10	0.64**	0.62**	0.45**	0.37**	
(14) Time monitoring	0.08	0.05	0.23	−0.05	−0.04	−0.18	0.10	0.06	0.56**	0.23	0.28*	0.29*	0.30*

Note: General task performance represents ongoing task performance.
Abbreviations: WAIS-IV-NVA, Wechsler Intelligence Scale non-verbal ability (matrices reasoning subtest); WAIS-IV-VA, Wechsler Intelligence Scale verbal ability (vocabulary subtest).
*$p < 0.05$.
**$p < 0.01$.

participants compared with participants without ASD, given ASD individuals' impaired executive function and episodic memory abilities (Griffin et al., 2022; Olde Dubbelink & Geurts, 2017), which should make them benefit more from strategy-related reduced executive function demands and enhanced encoding.

In line with our expectations, there was an effect of encoding condition on PM performance. Overall, participants completed more PM tasks correctly after using the EE strategy than participants of the control condition did. This is the first study to show that EE can improve PM performance in individuals with ASD.

Research suggests that EE can improve task performance by enhancing the encoding and retrieval of information (McDaniel & Scullin, 2010; Pereira et al., 2012a) following stronger memory traces: when actively engaging with information through EE, stronger memory traces are created that are more easily retrieved when needed. EE involves multiple sensory modalities, such as visual, auditory, and motor, which can strengthen memory associations and make them more distinctive (Bäckman & Nilsson, 1985; Engelkamp, 1998). In addition, EE may help to better understand and remember the steps involved in completing a task (Engelkamp, 1998). Interestingly, we only found a beneficial effect of EE for time- PM, but not for event-based PM. The interaction effect between group and condition in time-based prospective memory (TBPM) narrowly missed significance. One possible explanation for this could be that time-based PM tasks, unlike event-based PM tasks, do not provide an external memory cue that may prompt retrieval of the intended action. Time-based PM relies more strongly on episodic memory and executive functioning than event-based PM, as participants must monitor the elapsing time and remember the task on their own initiative (cf. Einstein & McDaniel, 1996), and may therefore be more responsive to enhanced encoding following EE.

Another explanation could be that both EE and EFT instructions had positive effects on time-monitoring of ASD participants. Although the interaction effect of group and condition on time-monitoring also narrowly missed significance, descriptively comparing the means in the individual groups suggests that ASD participants in the EFT and EE conditions checked the time more frequently than participants without ASD, whereas non-ASD participants exhibited more time-monitoring than autistic participants in the control condition. Possibly, both, EE and EFT strategies, led to more effective encoding of the instructions for time-based PM tasks in ASD.

However, contrary to our prediction and previous research, overall participants in the EFT condition did not perform better in the PM tasks than those in the control condition. Research in nonautistic populations has shown that engaging in EFT can enhance PM performance (Altgassen et al., 2015; Kretschmer-Trendowicz et al., 2016; Kretschmer-Trendowicz et al., 2019; Lloyd et al., 2020; Terrett et al., 2016) by helping individuals to create a vivid mental representation of the future event, which may create a stronger memory trace, making it easier to remember to perform the intended action (Paraskevaides et al., 2010). Possibly, the missing beneficial effect of EFT on PM in ASD is due to ASD individuals' difficulties in EFT (Hanson & Atance, 2014; Lind et al., 2014; Lind & Bowler, 2010; Marini et al., 2016; Terrett et al., 2013) and their assumed difficulties in imagery (Lind et al., 2014); though research in other populations with problems in EFT still found beneficial effects of EFT during intention encoding on intention execution (e.g., Altgassen et al., 2015; Kretschmer-Trendowicz et al., 2016; Lloyd et al., 2020; Terrett et al., 2016). As executive functions are significantly involved in EFT (Irish & Piguet, 2013; Summerfield et al., 2010; Vito et al., 2012), the difficulties commonly associated with executive functioning in ASD (Hill, 2004) may have also led to our EFT instructions being less effective in ASD than those for the EE. However, control participants also did not benefit from this encoding strategy, which also argues against reduced EFT abilities in ASD underlying to the lacking effect.

Another explanation as to why EFT did not show the expected beneficial effects in our study could be the high number of participants, both in the ASD and the control group that reported a diagnosis of an affective disorder. Excessive worry or rumination about negative outcomes can make it difficult to engage in productive planning and decision-making (D'Argembeau & Van der Linden, 2006). Similarly, research indicates that intolerance for uncertainty may influence the perceptions and behavior of individuals with ASD by enhancing anxieties (Boulter et al., 2014; Normansell-Mossa et al., 2021; South & Rodgers, 2017; Wigham et al., 2015), which may have influenced their EFT ability (see Wu et al., 2015 about EFT in generalized anxiety disorder). Possibly, the high desire for task accuracy in individuals with ASD as postulated by WCC (see Happé et al., 2001; Happé & Frith, 2006) may have led them to benefiting more from physical (EE) than mental practice (EFT), as practical repetition reduces more uncertainties than imagery alone. Finally, contrary to our expectations and previous findings that reported weaker time-based PM performance in autistic adults and children compared with control participants (Altgassen et al., 2009, 2019; Henry et al., 2014; Kretschmer et al., 2014; Landsiedel & Williams, 2020; Williams et al., 2013, 2014), we did not find any differences in PM performance between groups, neither for event- nor time-based PM. This study is the first to not find any impairments in time-based PM in ASD. This could have various reasons. First, different PM tasks were used in the three studies assessing time-based PM in autistic adults (e.g., virtual week, Kretschmer et al., 2014; computer-based driving game, Williams et al., 2013).

Not all of them were computer-based (e.g., a nonvirtual version of the DBT, Altgassen et al., 2009) and none of them took place in an online setting. In fact, our study is the first to use a virtual version of the breakfast task in adults with ASD and the first one that was conducted in an online setting. The performance of our participants in the control condition was comparable to that of participants (with and without ADHD diagnosis) in the study of Altgassen et al. (2014) who also completed the computer version of the DBT, but performance was significantly lower than that of participants performing the noncomputer version (Altgassen et al., 2009).

Certainly, the everyday relevance of the DBT could have played a role. Preparing breakfast is a fairly common task, so participants will most likely be experienced in the tasks we asked them to do, which could have helped overcome potential PM difficulties.

Importantly, our sample comprised autistic participants with highly developed cognitive abilities, consequently these findings may not generalize to all individuals with ASD, as there is significant heterogeneity within the autism spectrum (see Masi et al., 2017). Sheppard et al. (2018) had already suggested that problems in PM might be correlated with cognitive functioning, noting that the previous PM evidence does not fully represent the entire autistic spectrum. Specifically, Sheppard et al. (2016) found stronger PM impairment in severely autistic children with low cognitive abilities. Indeed, in our study, better event- and time-based PM as well as higher plan quality were associated with higher nonverbal intelligence in the ASD group but not in the control group.

Since the participants had high cognitive abilities, this might have allowed them to compensate for difficulties in executive functions. The fact that no group differences were found in other indicators of executive functioning as the overall plan quality and the required switching abilities reinforces this explanatory approach.

In addition to cognitive functions, other characteristics of the participants could have affected the results of our study. Our correlational analyses suggest that ADHD symptoms may have affected the overall performance of autistic participants in the DBT, but not in the PM tasks. One reason for this could be that traits such as impulsivity and inattention may have affected working on the ongoing tasks of the DBT, such as setting the table with dishes, more than the PM tasks. Possibly, the ongoing tasks require a higher level of concentration and suppression of impulsive behavior compared with the PM tasks. Furthermore, we found that the effect of intolerance of uncertainty on PM was completely mediated by rule adherence in the ASD group, but not in the control group. Possibly, autistic individuals with high levels of intolerance of uncertainty tend to seek maximum predictability of events and therefore may have a desire for clear rules or structures to adhere to. The desire for predictability or fear of unforeseen events could potentially lead to increased planning and consequently contribute to improved PM performance in individuals with high intolerance of uncertainty, as forgetting tasks may lead to disorganization and thus unpredictability. We also found associations between increased time monitoring and both increased imaginative abilities and better time-based PM. However, a mediation of the effect of time monitoring on time-based PM through imagination narrowly missed significance. Research suggests an altered perception of time in ASD, although the exact neurological causes are poorly understood (see Casassus et al., 2019). The Imagination scale of the AQ-K essentially measures difficulties in imagination, ToM, and creativity. It is plausible that time perception also requires a certain degree of imagination, namely in estimating how much time has passed without checking it. Perhaps an awareness of the difficulties in time perception led autistic participants to check the time more frequently, resulting in better performance in the time-based PM tasks; however, this assumption remains highly speculative at this point. Future studies should aim to investigate how autistic characteristics, like intolerance for uncertainty, may lead to compensatory behaviors (possibly acquired over the lifespan) such as increased monitoring behavior (i.e., checking the time) and how this might positively impact PM.

The sample in our study differs from other studies due to the high percentage of autistic women (almost 60%). Several studies have examined gender differences in PM in nonautistic populations and results are somewhat mixed. Some studies have found no significant differences between males and females in terms of overall PM performance (Crawford et al., 2003), while others found that women outperformed men (Maylor & Logie, 2010; Palermo et al., 2016). The proportion of women in previous studies on PM in autistic samples rarely exceeded 30%. To date, no study has compared the PM performance of men and women with ASD directly. We did not find any gender differences in PM performance, neither in the ASD nor in the control group. This aligns with studies that suggest that autistic women have comparable or even more difficulties in executive functions than autistic men, especially with regards to planning, working and short-term memory, impulse control, and cognitive flexibility (White et al., 2017). Perhaps these findings can also be applied to the PM performance of autistic women. Given the increase in ASD diagnoses among women (see Maenner et al., 2023), future research is needed that focusses on gender differences in ASD.

In summary, it can be concluded that EE is a promising strategy for improving PM performance in both autistic and nonautistic individuals. Problems in executive functions, specifically in activity planning and remembering, pose challenges for autistic individuals in their daily lives. Our results suggest that support in the form of practical encoding practice can improve PM performance. By engaging in practical training of a task, it is possible that autism-specific characteristics, such as a high intolerance for uncertainty, might be overcome. Future research should focus on how these findings can be implemented in appropriate therapeutic approaches for autistic individuals.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

This study gained ethical approval from the Research Ethics Committee at the Department of Psychology, Johannes Gutenberg-University Mainz, Germany.

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REFERENCES

Addis, D. R., Sacchetti, D. C., Ally, B. A., Budson, A. E., & Schacter, D. L. (2009). Episodic simulation of future events is impaired in mild Alzheimer's disease. *Neuropsychologia*, *47*, 2660–2671. https://doi.org/10.1016/j.neuropsychologia.2009.05.018

Addis, D. R., Wong, A. T., & Schacter, D. L. (2007). Remembering the past and imagining the future: Common and distinct neural substrates during event construction and elaboration. *Neuropsychologia*, *45*, 1363–1377. https://doi.org/10.1016/j.neuropsychologia.2006.10.016

Altermann, C. D., Martins, A. S., Carpes, F. P., & Mello-Carpes, P. B. (2014). Influence of mental practice and movement observation on motor memory, cognitive function and motor performance in the elderly. *Brazilian journal of physical therapy*, *18*(2), 201–209. https://doi.org/10.1590/s1413-35552012005000150

Altgassen, M., Koban, N., & Kliegel, M. (2012). Do adults with autism spectrum disorders compensate in naturalistic prospective memory tasks? *Journal of autism and developmental disorders*, *42*(10), 2141–2151. https://doi.org/10.1007/s10803-012-1466-3

Altgassen, M., & Koch, A. (2014). Impact of inhibitory load on remembering delayed intentions in autism. *International Journal of Developmental Disabilities*, *60*, 198–204. https://doi.org/10.1179/2047387714Y.0000000042

Altgassen, M., Kretschmer, A., & Kliegel, M. (2014). Task dissociation in prospective memory performance in individuals with ADHD. *Journal of Attention Disorders*, *18*(7), 617–624. https://doi.org/10.1177/1087054712445484

Altgassen, M., Phillips, L. H., Henry, J. D., Rendell, P. G., & Kliegel, M. (2010). Emotional target cues eliminate age differences in prospective memory. *Quarterly Journal of Experimental Psychology*, *63*(6), 1057–1064.

Altgassen, M., Rendell, P. G., Bernhard, A., Henry, J. D., Bailey, P. E., Phillips, L. H., & Kliegel, M. (2015). Future thinking improves prospective memory performance and plan enactment in older adults. *Quarterly journal of experimental psychology (2006)*, *68*(1), 192–204. https://doi.org/10.1080/17470218.2014.956127

Altgassen, M., Sheppard, D. P., & Hendriks, M. P. H. (2019). Do importance instructions improve time-based prospective remembering in autism spectrum conditions? *Research in developmental disabilities*, *90*, 1–13. https://doi.org/10.1016/j.ridd.2019.04.008

Altgassen, M., Williams, T. I., Bölte, S., & Kliegel, M. (2009). Time-based prospective memory in children with autism spectrum disorder. *Brain Impairment*, *10*(1), 52–58. https://doi.org/10.1375/brim.10.1.52

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). American Psychiatric Publishing, Inc. https://doi.org/10.1176/appi.books.9780890425596

Atance, C. M., & O'Neill, D. K. (2001). Episodic future thinking. *Trends in cognitive sciences*, *5*(12), 533–539. https://doi.org/10.1016/s1364-6613(00)01804-0

Bäckman, L., & Nilsson, L. G. (1985). Prerequisites for lack of age differences in memory performance. *Experimental aging research*, *11*(2), 67–73. https://doi.org/10.1080/03610738508259282

Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a "theory of mind"? *Cognition*, *21*(1), 37–46. https://doi.org/10.1016/0010-0277(85)90022-8

Baron-Cohen, S., Lombardo, M. V., Auyeung, B., Ashwin, E., Chakrabarti, B., & Knickmeyer, R. (2011). Why are autism spectrum conditions more prevalent in males? *PLoS biology*, *9*(6), e1001081. https://doi.org/10.1371/journal.pbio.1001081

Binder, J. R., Desai, R. H., Graves, W. W., & Conant, L. L. (2009). Where is the semantic system? A critical review and meta-analysis of 120 functional neuroimaging studies. *Cereb. Cortex*, *9*, 2767–2796. https://doi.org/10.1093/cercor/bhp055

Bishop, S. L., Hus, V., Duncan, A., Huerta, M., Gotham, K., Pickles, A., Kreiger, A., Buja, A., Lund, S., & Lord, C. (2013). Subcategories of restricted and repetitive behaviors in children with autism spectrum disorders. *Journal of autism and developmental disorders*, *43*, 1287–1297. https://doi.org/10.1007/s10803-012-1671-0

Boulter, C., Freeston, M., South, M., & Rodgers, J. (2014). Intolerance of uncertainty as a framework for understanding anxiety in children and adolescents with autism spectrum disorders. *Journal of autism and developmental disorders*, *44*(6), 1391–1402. https://doi.org/10.1007/s10803-013-2001-x

Brandimonte, M. A., Filippello, P., Coluccia, E., Altgassen, M., & Kliegel, M. (2011). To do or not to do? Prospective memory versus response inhibition in autism spectrum disorder and attention-deficit/hyperactivity disorder. *Memory*, *19*, 56–66. https://doi.org/10.1080/09658211.2010.535657

Brown, A. D., Root, J. C., Romano, T. A., Chang, L. J., Bryant, R. A., & Hirst, W. (2013). Overgeneralized autobiographical memory and future thinking in combat veterans with posttraumatic stress disorder. *Journal of Behavior Therapy and Experimental Psychiatry*, *44*, 129–134. https://doi.org/10.1016/j.jbtep.2011.11.004

Brunfaut, E., Vanoverberghe, V., & d'Ydewalle, G. (2000). Prospective remembering of Korsakoffs and alcoholics as a function of the prospective-memory and on-going tasks. *Neuropsychologia*, *38*(7), 975–984.

Burgess, P. W., Gonen-Yaacovi, G., & Volle, E. (2011). Functional neuroimaging studies of prospective memory: What have we learnt so far? *Neuropsychologia*, *49*(8), 2246–2257. https://doi.org/10.1016/j.neuropsychologia.2011.02.014

Cardon, G., & Bradley, M. (2023). Uncertainty, sensory processing, and stress in autistic children during the COVID-19 pandemic. *Research in autism spectrum disorders*, *106*, 102202. https://doi.org/10.1016/j.rasd.2023.102202

Carleton, R. N., Norton, M. A., & Asmundson, G. J. (2007). Fearing the unknown: a short version of the Intolerance of Uncertainty Scale. *Journal of anxiety disorders*, *21*(1), 105–117. https://doi.org/10.1016/j.janxdis.2006.03.014

Casassus, M., Poliakoff, E., Gowen, E., Poole, D., & Jones, L. A. (2019). Time perception and autistic spectrum condition: A systematic review. *Autism research: official journal of the International Society for Autism Research*, *12*(10), 1440–1462. https://doi.org/10.1002/aur.2170

Cohen, R. L. (1989). Memory for action events: The power of enactment. *Educational Psychology Review*, *1*(1), 57–80. https://doi.org/10.1007/BF01326550

Craik, F. I. M., & Bialystok, E. (2006). Planning and task management in older adults: Cooking breakfast. *Memory & Cognition*, *34*, 1236–1249.

Crawford, J. R., Smith, G., Maylor, E. A., Della Sala, S., & Logie, R. H. (2003). The prospective and retrospective memory questionnaire (PRMQ): Normative data and latent structure in a large non-clinical sample. *Memory (Hove, England)*, *11*(3), 261–275. https://doi.org/10.1080/09658210244000027

D'Argembeau, A., & Van der Linden, M. (2006). Individual differences in the phenomenology of mental time travel: The effect of vivid visual imagery and emotion regulation strategies. *Consciousness and cognition*, *15*(2), 342–350. https://doi.org/10.1016/j.concog.2005.09.001

Dehnavi, F., & Khan, A. (2023). Time-Based and event-based prospective memory in adults with autism spectrum disorder: A virtual week investigation. *Journal of autism and developmental disorders*. https://doi.org/10.1007/s10803-023-05975-y

Dobbs, A. R., & Rule, B. G. (1987). Prospective memory and self-reports of memory abilities in older adults. *Canadian Journal of Psychology/Revue canadienne de psychologie*, *41*(2), 209–222. https://doi.org/10.1037/h0084152

Döpfner, M., Lehmkuhl, G., Görtz-Dorten, A., Breuer, D., Lehmkuhl, G., & Görtz-Dorten, A. (2008). *DISYPS-II: Diagnostik-System für psychische Störungen nach ICD-10 und DSM-IV für Kinder und Jugendliche-II*. Huber: Hogrefe Testverl.

Döpfner, M., Lehmkuhl, G., & Steinhausen, H.-C. (2006). Kinder-Diagnostik-System (KIDS). In *Band 1: Aufmerksamkeitsdefizit- und Hyperaktivitätsstörungen (ADHS)*. Hogrefe.

Einstein, G. O., & McDaniel, M. A. (1990). Normal aging and prospective memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*(4), 717–726. https://doi.org/10.1037/0278-7393.16.4.717

Einstein, G. O., & McDaniel, M. A. (1996). *Retrieval processes in prospective memory: Theoretical approaches and some new empirical findings* (pp. 115–141). Prospective Memory. http://psycnet.apa.org/psycinfo/2002-02930-005

Engelkamp, J. (1998). *Memory for actions*. Psychology Press/Taylor & Francis (UK). https://doi.org/10.2307/1423386

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*, 175–191.

Feltz, D. L., & Landers, D. M. (1983). The effects of mental practice on motor skill learning and performance: A meta-analysis. *Journal of Sport Psychology*, *5*, 25–57.

Feltz, D. L., Landers, D. M., & Becker, B. J. (1988). A revised meta-analysis of the mental practice literature on motor skill learning. In: National Research Council, editor. In *Enhancing human performance, Part III: Improving motor performance*. National Academy Press. 10.1123/jsp.5.1.25.

Feltz, D. L., Landers, D. M., & Becker, B. J. (2014). Mental representation and mental practice: Experimental investigation on the functional links between motor memory and motor imagery. *PloS one*, *9*(4), e95175. https://doi.org/10.1371/journal.pone.0095175

Freeston, M. H., Rheaume, J., Letarte, H., Dugas, M. J., & Ladouceur, R. (1994). Why do people worry? *Personality and Individual Differences*, *17*, 791–802. https://doi.org/10.1016/0191-8869(94)90048-5

Freitag, C. M., Retz-Junginger, P., Retz, W., Seitz, C., Palmason, H., Meyer, J., Rösler, M., & Gontard, A. V. (2007). AQ—Autismus-Spektrumquotient [Autism-spectrum quotient; Autismus-Spektrumquotient (AQ)—deutsche Kurzversion AQ-k]. *Kurznachweis. Zeitschrift für Klinische Psychologie und Psychotherapie*, *36*(4), 280–289.

Gerlach, A. L., Andor, T., & Patzelt, J. (2008). Die Bedeutung von Unsicherheitsintoleranz fuer die generalisierte Angststoerung Modellueberlegungen und Entwicklung einer deutschen Version der Unsicherheitsintoleranz-Skala. *Zeitschrift fuer Klinische Psychologie und Psychotherapie*, *37*(3), 190–199. https://doi.org/10.1026/1616-3443.37.3.190

Geurts, H. M., Corbett, B., & Solomon, M. (2009). The paradox of cognitive flexibility in autism. *Trends in cognitive sciences*, *13*(2), 74–82. https://doi.org/10.1016/j.tics.2008.11.006

Grainger, C., Williams, D. M., & Lind, S. E. (2014). Online action monitoring and memory for self-performed actions in autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *44*(5), 1193–1206. https://doi.org/10.1007/s10803-013-1987-4

Griffin, J. W., Bauer, R., & Gavett, B. E. (2022). The episodic memory profile in autism spectrum disorder: A Bayesian meta-analysis. *Neuropsychology review*, *32*(2), 316–351. https://doi.org/10.1007/s11065-021-09493-5

Grouios, G. (1992). Mental practice: A review. *Journal of Sport Behavior*, *15*(1), 42. https://doi.org/10.2466/pms.110.3.888-896

Hanson, E., Cerban, B. M., Slater, C. M., Caccamo, L. M., Bacic, J., & Chan, E. (2013). Brief report: Prevalence of attention deficit/hyperactivity disorder among individuals with an autism spectrum disorder. *Journal of autism and developmental disorders*, *43*(6), 1459–1464. https://doi.org/10.1007/s10803-012-1677-7

Hanson, L. K., & Atance, C. M. (2014). Brief report: Episodic foresight in autism spectrum disorder. *Journal of autism and developmental disorders*, *44*(3), 674–684. https://doi.org/10.1007/s10803-013-1896-6

Happé, F., Briskman, J., & Frith, U. (2001). Exploring the cognitive phenotype of autism: Weak "central coherence" in parents and siblings of children with autism: I. experimental tests. *Journal of child psychology and psychiatry, and allied disciplines*, *42*(3), 299–307.

Happé, F., & Frith, U. (2006). The weak coherence account: Detail-focused cognitive style in autism spectrum disorders. *Journal of autism and developmental disorders*, *36*(1), 5–25. https://doi.org/10.1007/s10803-005-0039-0

Henry, J. D., Terrett, G., Altgassen, M., Raponi-Saunders, S., Ballhausen, N., Schnitzspahn, K. M., & Rendell, P. G. (2014). A virtual week study of prospective memory function in autism spectrum disorders. *Journal of Experimental Child Psychology*, *127*, 110–125. https://doi.org/10.1016/j.jecp.2014.01.011

Hill, E. L. (2004). Executive dysfunction in autism. *Trends in cognitive sciences*, *8*(1), 26–32. https://doi.org/10.1016/j.tics.2003.11.003

Hinshaw, K. E. (1991). The effects of mental practice on motor skill performance: Critical evaluation and meta-analysis. *Imagination, Cognition and Personality*, *11*(1), 3–35. https://doi.org/10.2190/X9BA-KJ68-07AN-QMJ

Hird, J. S., Landers, D. M., Thomas, J. R., & Horan, J. (1991). Physical practice is superior to mental practice in enhancing cognitive and motor performance. *Journal of Sport & Exercise Psychology*, *13*, 281–293. https://doi.org/10.1123/jsep.13.3.281

Hodgson, A. R., Freeston, M. H., Honey, E., & Rodgers, J. (2017). Facing the unknown: Intolerance of uncertainty in children with autism spectrum disorder. *Journal of applied research in intellectual disabilities: JARID*, *30*(2), 336–344. https://doi.org/10.1111/jar.12245

Hoppe, C., Müller, U., Werheid, K., Thöne, A., & Von Cramon, D. Y. (2000). Digit ordering test: Clinical, psychometric, and experimental evaluation of a verbal working memory test. *Clinical Neuropsychologist*, *14*, 38–55. https://doi.org/10.1076/1385-4046(200002)14:1;1-8;FT038

Irish, M., Addis, D. R., Hodges, J. R., & Piguet, O. (2012). Considering the role of semantic memory in episodic future thinking: Evidence

from semantic dementia. *Brain*, *135*, 2178–2191. https://doi.org/10.1093/brain/aws119
Irish, M., & Piguet, O. (2013). The pivotal role of semantic memory in remembering the past and imagining the future. *Frontiers in Behavioral Neuroscience*, *7*, 27. https://doi.org/10.3389/fnbeh.2013.00027
Jeannerod, M. (1994). The representing brain: Neural correlates of motor intention and imagery. *Behavioral and Brain Sciences*, *17*(2), 187–202. https://doi.org/10.1017/S0140525X00034026
Jeannerod, M. (1995). Mental imagery in the motor context. *Neuropsychologia*, *33*(11), 1419–1432. https://doi.org/10.1016/0028-3932(95)00073-c
Jenkinson, R., Milne, E., & Thompson, A. (2020). The relationship between intolerance of uncertainty and anxiety in autism: A systematic literature review and meta-analysis. *Autism: the international journal of research and practice*, *24*(8), 1933–1944. https://doi.org/10.1177/1362361320932437
Kim, Y. S., Leventhal, B. L., Koh, Y. J., Fombonne, E., Laska, E., Lim, E. C., Cheon, K. A., Kim, S. J., Kim, Y. K., Lee, H., Song, D. H., & Grinker, R. R. (2011). Prevalence of autism spectrum disorders in a total population sample. *The American journal of psychiatry*, *168*(9), 904–912. https://doi.org/10.1176/appi.ajp.2011.10101532
Kliegel, M., Eschen, A., & Thöne-Otto, A. I. T. (2004). Planning and realization of complex intentions in traumatic brain injury and normal aging. *Brain and Cognition*, *56*(1), 43–54. https://doi.org/10.1016/j.bandc.2004.05.005
Kliegel, M., Martin, M., McDaniel, M. A., & Einstein, G. O. (2002). Complex prospective memory and executive control of working memory: A process model. *Psychological Test and Assessment Modeling*, *44*(2), 303.
Kretschmer, A., Altgassen, M., Rendell, P. G., & Bölte, S. (2014). Prospective memory in adults with high-functioning autism spectrum disorders: Exploring effects of implementation intentions and retrospective memory load. *Research in developmental disabilities*, *35*(11), 3108–3118. https://doi.org/10.1016/j.ridd.2014.07.052
Kretschmer-Trendowicz, A., Ellis, J. A., & Altgassen, M. (2016). Effects of episodic future thinking and self-projection on children's prospective memory performance. *PloS one*, *11*(6), e0158366. https://doi.org/10.1371/journal.pone.0158366
Kretschmer-Trendowicz, A., Schnitzspahn, K. M., Reuter, L., & Altgassen, M. (2019). Episodic future thinking improves children's prospective memory performance in a complex task setting with real life task demands. *Psychological research*, *83*(3), 514–525. https://doi.org/10.1007/s00426-017-0908-0
Landsiedel, J., & Williams, D. M. (2020). Increasing extrinsic motivation improves time-based prospective memory in adults with autism: Relations with executive functioning and mentalizing. *Journal of autism and developmental disorders*, *50*(4), 1133–1146. https://doi.org/10.1007/s10803-019-04340-2
Leiner, D. J. (2019). *SoSci survey (version 3.1.06) [computer software]*. Available at https://www.soscisurvey.de
Lind, S. E., & Bowler, D. M. (2010). Episodic memory and episodic future thinking in adults with autism. *Journal of Abnormal Psychology*, *119*(4), 896–905. https://doi.org/10.1037/a0020631
Lind, S. E., Williams, D. M., Bowler, D. M., & Peel, A. (2014). Episodic memory and episodic future thinking impairments in high-functioning autism spectrum disorder: An underlying difficulty with scene construction or self-projection? *Neuropsychology*, *28*(1), 55–67. https://doi.org/10.1037/neu0000005
Lloyd, B., Oudman, E., Altgassen, M., Walvoort, S. J. W., Kessels, R. P. C., & Postma, A. (2020). Episodic future thinking together with observational learning benefits prospective memory in high-functioning Korsakoff's syndrome patients. *The British journal of clinical psychology*, *59*(3), 369–383. https://doi.org/10.1111/bjc.12251
Loomes, R., Hull, L., & Mandy, W. P. L. (2017). What is the male-to-female ratio in autism spectrum disorder? A systematic review and meta-analysis. *Journal of the American Academy of Child and Adolescent Psychiatry*, *56*(6), 466–474. https://doi.org/10.1016/j.jaac.2017.03.013
Maenner, M. J., Warren, Z., Williams, A. R., Amoakohene, E., Bakian, A. V., Bilder, D. A., Durkin, M. S., Fitzgerald, R. T., Furnier, S. M., Hughes, M. M., Ladd-Acosta, C. M., McArthur, D., Pas, E. T., Salinas, A., Vehorn, A., Williams, S., Esler, A., Grzybowski, A., Hall-Lande, J., … Shaw, K. A. (2023). Prevalence and characteristics of autism spectrum disorder among children aged 8 years—Autism and developmental disabilities monitoring network, 11 sites, United States, 2020. *Morbidity and Mortality Weekly Report. Surveillance Summaries (Washington, D.C.: 2002)*, *72*(2), 1–14. https://doi.org/10.1585/mmwr.ss7202a1
Marini, A., Ferretti, F., Chiera, A., Magni, R., Adornetti, I., Nicchiarelli, S., Vicari, S., & Valeri, G. (2016). Brief report: Self-based and mechanical-based future thinking in children with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *46*, 3353–3360. https://doi.org/10.1007/s10803-016-2867-5
Martin, M., Kliegel, M., & McDaniel, M. (2003). The involvement of executive functions in prospective memory performance of adults. *International Journal of Psychology.*, *38*, 195–206. https://doi.org/10.1080/00207590344000123
Masi, A., DeMayo, M. M., Glozier, N., & Guastella, A. J. (2017). An overview of autism spectrum disorder, heterogeneity and treatment options. *Neuroscience bulletin*, *33*(2), 183–193. https://doi.org/10.1007/s12264-017-0100-y
Mayer, R. E. (2008). *Learning and instruction* (2nd ed.). Pearson Merrill Prentice Hall.
Maylor, E. A., & Logie, R. H. (2010). A large-scale comparison of prospective and retrospective memory development from childhood to middle age. *Quarterly journal of experimental psychology (2006)*, *63*(3), 442–451. https://doi.org/10.1080/17470210903469872
McDaniel, M. A., & Einstein, G. O. (2000). Strategic and automatic processes in prospective memory retrieval: A multiprocess framework. *Applied Cognitive Psychology*, *14*, S127–S144. https://doi.org/10.1002/ACP.775
McDaniel, M. A., & Einstein, G. O. (2011). The neuropsychology of prospective memory in normal aging: A componential approach. *Neuropsychologia*, *49*(8), 2147–2155. https://doi.org/10.1016/j.neuropsychologia.2010.12.029
McDaniel, M. A., & Scullin, M. K. (2010). Implementation intention encoding does not automatize prospective memory responding. *Memory & Cognition*, *38*, 221–232. https://doi.org/10.3758/MC.38.2.221
Müller, E., Schuler, A., Burton, B. A., & Yates, G. B. (2003). Meeting the vocational support needs of individuals with Asperger syndrome and other autism spectrum disabilities. *Journal of Vocational Rehabilitation*, *18*(3), 163–175.
Murray, M. J. (2010). Attention-deficit/hyperactivity disorder in the context of autism spectrum disorders. *Curr Psychiatry Reports*, *2010*(12), 382–388. https://doi.org/10.1007/s11920-010-0145-3
Neroni, M. A., Gamboz, N., & Brandimonte, M. A. (2014). Does episodic future thinking improve prospective remembering? *Consciousness and cognition*, *23*, 53–62. https://doi.org/10.1016/j.concog.2013.12.001
Normansell-Mossa, K. M., Top, D. N., Jr., Russell, N., Freeston, M., Rodgers, J., & South, M. (2021). Sensory sensitivity and intolerance of uncertainty influence anxiety in autistic adults. *Frontiers in psychology*, *12*, 731753. https://doi.org/10.3389/fpsyg.2021.731753
Olde Dubbelink, L. M., & Geurts, H. M. (2017). Planning skills in autism spectrum disorder across the lifespan: A meta-analysis and meta-regression. *Journal of autism and developmental disorders*, *47*(4), 1148–1165. https://doi.org/10.1007/s10803-016-3013-0
Paivio, A. (1969). Mental imagery in associative learning and memory. *Psychological Review*, *76*(3), 241–263. https://doi.org/10.1037/H0027272
Palermo, L., Cinelli, M. C., Piccardi, L., Ciurli, P., Incoccia, C., Zompanti, L., & Guariglia, C. (2016). Women outperform men in

remembering to remember. *Quarterly journal of experimental psychology*, *69*(1), 65–74. https://doi.org/10.1080/17470218.2015.1023734

Paraskevaides, T., Morgan, C. J. A., Leitz, J. R., Bisby, J. A., Rendell, P. G., & Curran, H. V. (2010). Drinking and future thinking: Acute effects of alcohol on prospective memory and future simulation. *Psychopharmacology*, *208*, 301–308. https://doi.org/10.1007/s00213-009-1731-0

Pereira, A., Altgassen, M., Atchison, L., De Mendonça, A., & Ellis, J. (2018). Sustaining prospective memory functioning in amnestic mild cognitive impairment: A lifespan approach to the critical role of encoding. *Neuropsychology*, *32*(5), 634–644. https://doi.org/10.1037/neu0000441

Pereira, A., De Mendonça, A., Silva, D., Guerreiro, M., Freeman, J., & Ellis, J. (2015). Enhancing prospective memory in mild cognitive impairment: The role of enactment. *Journal of clinical and experimental neuropsychology*, *37*(8), 863–877. https://doi.org/10.1080/13803395.2015.1072499

Pereira, A., Ellis, J., & Freeman, J. (2012a). Is prospective memory enhanced by cue-action semantic relatedness and enactment at encoding? *Consciousness and Cognition: An International Journal*, *21*, 1257–1266. https://doi.org/10.1016/j.concog.2012.04.012

Riedelbauch, S., Gaigg, S. B., Thiel, T., Roessner, V., & Ring, M. (2024). Examining a model of anxiety in autistic adults. *Autism*, *28* (3), 565–579. https://doi.org/10.1177/13623613231177777

Roberts, B. R. T., MacLeod, C. M., & Fernandes, M. A. (2022). The enactment effect: A systematic review and meta-analysis of behavioral, neuroimaging, and patient studies. *Psychological bulletin*, *148*(5-6), 397–434. https://doi.org/10.1037/bul0000360

Rodewald, K., Bartolovic, M., Debelak, R., Aschenbrenner, S., Weisbrod, M., & Roesch-Ely, D. (2012). Eine Normierungsstudie eines modifizierten trail making tests im deutschsprachigen Raum. *Zeitschrift Fur Neuropsychologie*, *23*, 37–48. https://doi.org/10.1024/1016-264X/A000060

Schacter D.L. (2012) Constructive memory: past and future. *Dialogues Clin Neurosci*, *14*(1), 7–18. doi: doi:10.31887/DCNS.2012.14.1/dschacter.

Schacter, D. L., & Addis, D. R. (2007). The cognitive neuroscience of constructive memory: remembering the past and imagining the future. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *362*, 773–786. https://doi.org/10.1098/rstb.2007.2087

Sheppard, D. P., Bruineberg, J. P., Kretschmer-Trendowicz, A., & Altgassen, M. (2018). Prospective memory in autism: Theory and literature review. *The Clinical Neuropsychologist*, *32*(5), 748–782. https://doi.org/10.1080/13854046.2018.1435823

Sheppard, D. P., Kvavilashvili, L., & Ryder, N. (2016). Event-based prospective memory in mildly and severely autistic children. *Research in Developmental Disabilities*, *49–50*, 22–33. https://doi.org/10.1080/13854046.2018.1435823

South, M., & Rodgers, J. (2017). Sensory, emotional and cognitive contributions to anxiety in autism spectrum disorders. *Frontiers in Human Neuroscience*, *11*, 20. https://doi.org/10.3389/fnhum.2017.00020

Sprenger, L., Bühler, E., Poustka, L., Bach, C., Heinzel-Gutenbrunner, M., Kamp-Becker, I., & Bachmann, C. (2013). Impact of ADHD symptoms on autism spectrum disorder symptom severity. *Research in developmental disabilities*, *34*(10), 3545–3552. https://doi.org/10.1016/j.ridd.2013.07.028

Summerfield, J. J., Hassabis, D., & Maguire, E. A. (2010). Differential engagement of brain regions within a "core" network during scene construction. *Neuropsychologia*, *48*(5), 1501–1509. https://doi.org/10.1016/j.neuropsychologia.2010.01.022

Szpunar, K. K., Watson, J. M., & McDermott, K. B. (2007). Neural substrates of envisioning the future. *PNAS*, *104*, 642–647. https://doi.org/10.1073/pnas.0610082104

Terrett, G., Rendell, P. G., Raponi-Saunders, S., Henry, J. D., Bailey, P. E., & Altgassen, M. (2013). Episodic future thinking in children with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *43*(11), 2558–2568. https://doi.org/10.1007/s10803-013-1806-y

Terrett, G., Rose, N. S., Henry, J. D., Bailey, P. E., Altgassen, M., Phillips, L. H., Kliegel, M., & Rendell, P. G. (2016). The relationship between prospective memory and episodic future thinking in younger and older adulthood. *Quarterly journal of experimental psychology (2006)*, *69*(2), 310–323. https://doi.org/10.1080/17470218.2015.1054294

Thomas, S., Sciberras, E., Lycett, K., Papadopoulos, N., & Rinehart, N. (2018). Physical functioning, emotional, and behavioral problems in children with ADHD and comorbid ASD: A cross-sectional study. *Journal of attention disorders*, *22*(10), 1002–1007. https://doi.org/10.1177/1087054715587096

Van den Bergh, D., Van Doorn, J., Marsman, M., Draws, T., Van Kesteren, E., Derks, K., & Wagenmakers, E. (2020). A tutorial on conducting and interpreting a Bayesian ANOVA in JASP. *L'Année psychologique*, *120*, 73–96.

Van den Bergh, S. F., Scheeren, A. M., Begeer, S., Koot, H. M., & Geurts, H. M. (2014). Age related differences of executive functioning problems in everyday life of children and adolescents in the autism spectrum. *Journal of autism and developmental disorders*, *44*(8), 1959–1971. https://doi.org/10.1007/s10803-014-2071-4

Van Eylen, L., Boets, B., Steyaert, J., Wagemans, J., & Noens, I. (2015). Executive functioning in autism spectrum disorders: Influence of task and sample characteristics and relation to symptom severity. *European Child & Adolescent Psychiatry*, *24*, 1399–1417. https://doi.org/10.1007/s00787-015-0689-1

Vito, S. D., Gamboz, N., Brandimonte, M. A., Barone, P., Amboni, M., & Sala, S. D. (2012). Future thinking in Parkinson's disease: An executive function? *Neuropsychologia*, *50*, 1494–1501.

Wang, L., Xie, T., Ma, H., Xu, M., & Xie, X. (2022). Subject-performed task effect on working memory performance in children with autism spectrum disorder. *Autism research: official Journal of the International Society for Autism Research*, *15*(9), 1698–1709. https://doi.org/10.1002/aur.2710

Wechsler, D. (2008). *Wechsler adult intelligence scale* (4th ed.). Pearson.

White, E. I., Wallace, G. L., Bascom, J., Armour, A. C., Register-Brown, K., Popal, H. S., Ratto, A. B., Martin, A., & Kenworthy, L. (2017). Sex differences in parent-reported executive functioning and adaptive behavior in children and young adults with autism spectrum disorder. *Autism research: Official Journal of the International Society for Autism Research*, *10*(10), 1653–1662. https://doi.org/10.1002/aur.1811

Wigham, S., Rodgers, J., South, M., McConachie, H., & Freeston, M. (2015). The interplay between sensory processing abnormalities, intolerance of uncertainty, anxiety and restricted and repetitive behaviours in autism spectrum disorder. *Journal of autism and developmental disorders*, *45*(4), 943–952. https://doi.org/10.1007/s10803-014-2248-x

Williams, D., Boucher, J., Lind, S., & Jarrold, C. (2013). Time-based and event-based prospective memory in autism spectrum disorder: The roles of executive function and theory of mind, and time-estimation. *Journal of autism and developmental disorders*, *43*(7), 1555–1567. https://doi.org/10.1007/s10803-012-1703-9

Williams, D. M., Jarrold, C., Grainger, C., & Lind, S. E. (2014). Diminished time-based, but undiminished event-based, prospective memory among intellectually high-functioning adults with autism spectrum disorder: relation to working memory ability. *Neuropsychology*, *28*(1), 30–42. https://doi.org/10.1037/neu0000008

Wilson, B. A., Alderman, N., Burgess, P. W., Emslie, H., & Evans, J. J. (1996). *Behavioural assessment of the dysexecutive syndrome BADS. Bury St*. Edmunds: Thames Valley Test Company.

Wilson, C. E., Murphy, C. M., McAlonan, G., Robertson, D. M., Spain, D., Hayward, H., Woodhouse, E., Deeley, P. Q., Gillan, N., Ohlsen, J. C., Zinkstok, J., Stoencheva, V., Faulkner, J., Yildiran, H., Bell, V., Hammond, N., Craig, M. C., & Murphy, D. G. (2016). Does sex influence the diagnostic evaluation of autism spectrum disorder in adults?

Autism: The International Journal of Research and Practice, *20*(7), 808–819. https://doi.org/10.1177/1362361315611381

Wu, J. Q., Szpunar, K. K., Godovich, S. A., Schacter, D. L., & Hofmann, S. G. (2015). Episodic future thinking in generalized anxiety disorder. *Journal of Anxiety Disorders*, *36*, 1–8. https://doi.org/10.1016/j.janxdis.2015.09.005

Xie, R., Sun, X., Yang, L., & Guo, Y. (2020). Characteristic executive dysfunction for high-functioning autism sustained to adulthood. *Autism Research: Official Journal of the International Society for Autism Research*, *13*(12), 2102–2121. https://doi.org/10.1002/aur.2304

Xie, T., Ma, H., Wang, L., & Du, Y. (2024). Can enactment and motor imagery improve working memory for instructions in children with autism spectrum disorder and children with intellectual disability? *Journal of Autism and Developmental Disorders*, *54*, 131–142. https://doi.org/10.1007/s10803-022-05780-z

Yamamoto, K., & Masumoto, K. (2018) Brief Report: Memory for Self-Performed Actions in Adults with Autism Spectrum Disorder: Why Does Memory of Self Decline in ASD?. *J Autism Dev Disord*, *48*(9), 3216–3222. https://doi.org/10.1007/s10803-018-3559-0

Yi, L., Fan, Y., Joseph, L., Huang, D., Wang, X., Li, J., & Zou, X. (2014). Event-based prospective memory in children with autism spectrum disorder: The role of executive function. *Research in Autism Spectrum Disorders*, *8*(6), 654–660. https://doi.org/10.1016/j.rasd.2014.03.005

Zalla, T., Daprati, E., Sav, A.-M., Chaste, P., Nico, D., & Leboyer, M. (2010). Memory for self-performed actions in individuals with Asperger syndrome. *PLoS ONE*, *5*(10), e13370. https://doi.org/10.1371/journal.pone.0013370

Zeintl, M., Kliegel, M., & Hofer, S. M. (2007). The role of processing resources in age-related prospective and retrospective memory within old age. *Psychology and Aging*, *22*(4), 826–834. https://doi.org/10.1037/0882-7974.22.4.826

Zimmer, H. D. (2001). Why do actions speaker louder than words? Action memory as a variant of encoding manipulations or the result of a specific memory system? In H. D. Zimmer, R. L. Cohen, M. J. Guynn, J. Engelkamp, R. Kormi-Nouri, & M. A. Foley (Eds.), *Memory for action: A distinct form of episodic memory?* (pp. 151–198). Oxford University.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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