Landsiedel, Julia (2017) *Prospective memory in children and adults with autism spectrum disorder.* Doctor of Philosophy (PhD) thesis, University of Kent,.

PROSPECTIVE MEMORY IN CHILDREN AND ADULTS WITH AUTISM SPECTRUM DISORDER

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A thesis submitted for the degree of Doctor of Philosophy in the Faculty of Social Science at the University of Kent, Canterbury

October 2017

DECLARATION

I declare that the work presented in this thesis is my own carried out under the normal terms of supervision. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Julia Landsiedel

October 2017

Publications

Chapter 1 of this thesis has formed the basis for the following publication: Landsiedel, J., Williams, D. M., & Abbot-Smith, K. (2017). A meta-analysis and critical review of prospective memory in autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *43(7),* 646-666. doi:10.1007/s10803-016-2987-y

ACKNOWLEDGEMENTS

“He who would learn to fly one day must first learn to stand and walk
and run and climb and dance, one cannot fly into flying.”

– Friedrich Nietzsche –

The past three years have been a true journey for me filled with many different experiences and changes to my life. Accomplishing this journey has been my greatest challenge yet. I had to learn to stand confidently on uneven ground, to walk into unknown terrain, run down the spiralling paths of my mind, to climb over obstacles of various shapes and sizes, and to dance to the rhythm of my heart. This thesis is my attempt to fly.

I count myself lucky to have met so many wonderful people during this journey to whom I am immeasurably grateful. Your love and support carried me through this challenge. Without you, I might have gotten lost along the way.

Above all, I would like to thank *David Williams* for being an amazing supervisor. Thank you for your exceptional encouragement, tireless patience and trust, and countless words of wisdom. You gave me the freedom to explore independently but kept me on track and guided me at all times. Many thanks also to my second supervisor, *Kirsten Abbot-Smith*, for your invaluable feedback and advice, your eye for detail and dedication. I could not have wished for better mentors throughout this journey.

I would also like to sincerely thank all the children, adults, and their families, participating schools, as well as Advocacy for All and the Kent Autistic Trust who have made this research possible in the first place. You have filled my experiments with life and laughter. I have learned so much from this extraordinary experience.

Being part of a great community of colleagues and friends has made this journey unforgettable. Thank you, guys, for this incredible time, all the conversations and encouragement over cups of tea or coffee, lunch breaks, chocolate cake, Friday drinks, and many more. I will treasure all these fun memories. In no particular order thank you to *Anita Ruddle, Phil Ulrich, Hayley Beresford, Alvaro Rodriguez, Emma Garcia, Caitlin Baker, Libby Drury, Kiran Webster, Lauren Spinner, Matt Fysh, Stefan Leach, Rotem Perach, Maria Zajaczkowska, Mahsa Barzy, Jonathan Prunty, Matt Plummer, Courtney Allen, Ebru Ateş, Pelin Gül André Marques, Ana Carla Crispim, Saghi Arabi, Fadi Ifram, Zafer Özkan*, *Martina De Lillo, Giulia Mangiaracina, Ionna Kapantai,* and *Zaffie Cox.*

I also would like to thank all the support staff of the Kent Child Development Unit, *Megan Spruce, Annabel Carter, Nicole Yuen*, and *Mafalda Costa*. It was a pleasure to work with you. Thank you for your fantastic support, making my work as Child Development Unit lab coordinator such an enjoyable and easy one. Equally, I would like to thank the technical support team, A*dam Britcher, Frank Gasking, John Allen*, and *Gary Samson,* for always providing swift, uncomplicated and reliable help at all times.

A warm thank you goes to the two lovely ladies with whom I shared an office with, *Kayleigh Ann Parratt* and *Louise Kotiadis*. You have been awesome office mates and friends. Thank you for your kindness and support during my ups and downs in this rollercoaster ride. Furthermore, a big thank you to *Catherine Grainger, Jo Black*, and *Toby Nicholson*, for sharing your experience and companionship with me. Without you, the long hours of testing participants would not have been nowhere nearly as enjoyable as they were.

Special thanks go to two very dear friends, *Jo Black* and *Lazaros Gonidis*. You have been the kind of friends I thought I would never find. You have made me see life from a new perspective. Thank you for everything; for all the little things that make life worthwhile, for listening to me whenever I needed you, and for supporting me no matter what. Your friendship is a true gift.

A special mention also goes to the person who inspired me to pursue a PhD, *Amir-Homayoun Javadi*. You were part of my journey for a long time and taught me so much along the way. I would not be where I am today without you.

In the final year of my PhD, my life has been turned upside down. *Patrick*, you are my ray of light and energy, and the most incredible partner. You met me going through the most challenging period of my life and gave me a safe harbour to find peace for my restless mind. No matter whether months together or apart, your cheerfulness, love, and encouragement have always kept me going. Thank you for being by my side.

Although the last, not least, to my family, my *Mum* and *Dad*; my sister *Anna*, her partner *Gerald*, and my nieces *Nora* and *Olivia*, as well as my *grandparents*, although sadly both my grandpas could not watch me finish this journey. I greatly miss you all and despite the long distance between us I always carry you with me in my heart. You have given me far more than I ever could dream of. There are no words to describe how incredibly grateful I am for your unconditional love and support.

Julia Landsiedel

October 2017

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LIST OF ABBREVIATIONS

ADOS	Autism Diagnostic Observation Schedule
AQ	Autism Spectrum Quotient
ASD	Autism spectrum disorder
BRIEF	Behaviour Rating Inventory of Executive Function
EBPM	Event-based prospective memory
ES	Effect size
IA	Interoceptive accuracy
ISI	Inter-stimulus interval
NT	Neurotypical
PM	Prospective memory
PRMQ	Prospective-Retrospective Memory Questionnaire
rPFC	Rostral prefrontal cortex
SRS	Social Responsiveness Scale
TBPM	Time-based prospective memory
TAS	Toronto Alexithymia Scale
WASI	Wechsler Abbreviated Scale of Intelligence

ABSTRACT

Prospective memory (PM) or memory for delayed intentions refers to the ability to remember to carry out a planned intention at an appropriate moment in the future. Autism spectrum disorder (ASD) is a neurodevelopmental disorder characterised by a cognitive profile of strengths and weaknesses, which suggest that PM may be a challenge for individuals with this condition. A small group of studies investigating PM in ASD have produced heterogeneous evidence. Thus, the aim of this thesis was to advance our understanding of PM abilities in ASD. Based on a meta-analysis as well as a thorough review of the existing literature, the experiments in this thesis targeted two main questions. (1) What underpins time-based PM problems in ASD and how could they be addressed? (2) Is event-based PM in ASD impaired or spared? The findings in this thesis indicate that ASD is characterised by time-based PM impairments, which were related to executive functioning, on the one hand, whereas on the other hand event-based PM abilities remain spared. The theoretical and practical implications of these results, as well as directions for future research are discussed.

CHAPTER 1

INTRODUCTION TO PROSPECTIVE MEMORY IN AUTISM SPECTRUM DISORDERS: A LITERATURE REVIEW AND META-ANALYSIS

Prospective Memory

Prospective memory (PM) is the ability to remember to carry out planned actions at the appropriate point in the *future* (McDaniel & Einstein, 2007). Everyday examples of PM tasks include remembering to stop at the supermarket to buy milk on the way home from work, remembering to call somebody on their birthday, or remembering to turn off the bath taps before the bath overflows. McDaniel and Einstein (2007) have outlined the core characteristics of a PM task as follows. First, there must be a consciously formed intention or plan that should be carried out *in the future*. That is, there should be a delay between formation of an intention to act and the execution of that intention; if there was no delay, then the task would be more akin to a vigilance/monitoring task than a PM task, because the intention can be held in short-term/working memory for the entire period between formation and execution (Graf & Uttl, 2001). Second, the PM task has to be embedded in an *ongoing activity* that requires attentional resources. Thus, a person needs to consciously interrupt the ongoing task to perform their intended action for the task to be considered a measure of PM.

In experimental studies, researchers commonly distinguish between event-based and time-based PM (Einstein & McDaniel, 1990). Event-based PM involves carrying out an intention upon the occurrence of a particular event (e.g., taking the cake out of the oven when the timer goes off; taking medication after breakfast). Time-based PM involves carrying out an intention at a particular future time point (e.g., call somebody in one hour; take medication at 1pm). In experimental measures of PM (time- or event-based), an ongoing task/activity might be a lexical decision task (e.g., deciding whether items that appear on-screen are words or nonwords). In an event-based task with this ongoing activity, the PM instruction might be to “press the space bar when the item ‘Dog’ appears on screen”. In this example, the appearance of the word “Dog” represents the event that should be responded to in accordance with the PM instruction. In a time-based task with this ongoing activity, the PM instruction might be to “press the space bar at exactly 2-minute intervals throughout the task”. Additionally, in time-based PM tasks, participants need to monitor time during the task in order to carry out the PM instruction. Usually, in computer-based tasks, participants can press a pre-specified keyboard key to display a clock, which remains on screen for a short period). For both event- and time-based PM tasks, performance is usually measured by: a) the proportion of correct responses in the ongoing task (e.g., the proportion of items correctly classified as words/nonwords in the lexical decision task; *ongoing task performance/accuracy*), and b) the proportion of PM failures (the proportion of occasions that participants did not carry out the PM instruction when they should have; *PM task performance/accuracy*). Additionally, the frequency (total number) and distribution of clock checks is another measure that is usually taken in time-based PM tasks. An adaptive time-monitoring strategy would mean that a participant only makes a few clock checks at the beginning of the task establishing a feel for the passage of time (e.g., five checks within the first minute of the task), but increasingly checks the clock more frequently closer to target time (e.g., five checks within the last 20 seconds before the target time; Mäntylä, Carelli, & Forman, 2007).

Evidence for the distinction between time-based and event-based PM comes from a) neuroimaging and lesion studies, which report that distinct sub-regions of the rostral prefrontal cortex (rPFC) underpin time-based vs. event-based PM (Burgess, Gonen-Yaacovi, & Volle, 2011; Gonneaud et al., 2014; Okuda et al., 2007) and that lesions to specific regions of the rPFC impair one aspect of PM, but not the other (e.g., Volle et al., 2011); b) studies of development, which reveal different patterns of age-related improvement (in children) and decline (in older adults) in event-based versus time-based PM (Henry, MacLeod, Phillips, & Crawford, 2004; Kliegel et al., 2013); and c) neuropsychology studies that indicate possible double-dissociations between these two types of PM (Altgassen, Kretschmer, & Kliegel, 2014; Katai, Maruyama, Hashimoto, & Ikeda, 2003). One of the crucial differences between event-based and time-based PM is the retrieval context. In event-based tasks, the occurrence of the target event can automatically activate retrieval of one's intention (cued retrieval of one's intention providing one registers/perceives the event). In contrast, time-based PM tasks do not have any specific event that one needs to respond to and, thus, retrieval of one's intention must be self-initiated, which places a high demand on executive functioning.

Relevant theories of PM

Two theories, the multiprocess framework (McDaniel & Einstein, 2000, 2007), as well as the preparatory attentional and memory (PAM) processes account (R. E. Smith, 2003; R. E. Smith & Bayen, 2004), have been proposed to explain the factors and processes involved in the success or failure of the execution of event-based intentions. Both models make predictions about how different task characteristics specifically affect prospective remembering. The multiprocess theory posits that, depending on (intra-)individual characteristics (motivation, personality) and situational task factors (the nature of the intention itself, the ongoing task, the PM cue, and the retention interval), intention retrieval is supported more strongly by either automatic spontaneous or strategic monitoring processes (Einstein et al., 2005). The PAM theory assumes that preparatory attentional processes are required to remember that one has to carry out an intention, which will result in costs for the concurrently performed task (R. E. Smith, 2017). Importantly, these attentional processes are thought to only be engaged during a context-dependent "performance interval", which will contain the opportunity to carry out the delayed intention.

Processes involved in time-based PM, however, have been not been addressed in either of the above models. Arguably, the lack of a clearly defined PM cue impedes the direct application of the multiprocess or PAM frameworks to time-based PM (at least those aspects that centre on the PM cue, but see Graf & Grondin, 2006, and Redshaw, Henry, & Suddendorf, 2016 for a discussion of how time-based PM may be event-cued at least in some cases). The attentional gate model (Block & Zakay, 2006) directly addresses these issues and proposes that time-based PM depends on prospective time estimates. Prospective timing can be referred to as “experienced duration”; i.e., prospective duration judgements depend on the amount of attentional resources dedicating to temporal processing. The model suggests an internal pacemaker that sends pulses through an attentional gate to an accumulator while timing an interval. In the dual-task context of a time-based PM task, the number of signals that pass through the gate, however, depend on how many executive resources are allocated to the timing process whilst dividing attention between the timing and the ongoing task. Meanwhile, the signals in the accumulator are constantly compared to a stored representation of an interval retrieved from long-term memory. Based on this comparison, pulses are accumulated until a match occurs, which results in the time-based PM target response being carried out. Thus, if few resources are allocated to timing, then less pulses enter the accumulator (as the attentional gate is narrower or closed metaphorically speaking, leading to an underestimation of the objective time) whereas if substantial resources are allocated, then more signals are allowed to pass through into the accumulator (leading to more accurate time estimates, however if too much attention is allocated to timing an overestimation of time occurs).

A theoretical approach that applies to both event-based and time-based PM is the gateway hypothesis (Burgess, Dumontheil, & Gilbert, 2007; Gilbert, Frith, & Burgess, 2005), which was developed to explain the role of rPFC in cognition. The hypothesis posits that some forms of cognition occur in response to external sensory stimuli (e.g., reading a book) whereas others are generated in the absence of sensory input (e.g., mentally imagining a story or mind wandering). The hypothesis proposes that a supervisory attentional gate coordinates and switches between the amount of cognitive resources allocated to stimulus-oriented (attention towards external stimuli) versus stimulus-independent thoughts (attention towards internal representations). The structure of PM task matches with this concept in that an individual has to perform an ongoing task (stimulus-oriented thought) while keeping an intention in mind (stimulus-independent thought). Therefore, it is no surprise that neuroimaging studies (Burgess et al., 2011; Burgess, Quayle, & Frith, 2001; Burgess, Scott, & Frith, 2003) have clearly implicated the rPFC in PM processes. Specifically, the lateral rPFC has been implicated in stimulus-independent thought and is thought to represent activation related to having a delayed intention in mind whereas the medial part seems to be involved in representing the content of a delayed intention (Barban, Carlesimo, Macaluso, Caltagirone, & Costa, 2013, 2014; Gilbert, Simons, Frith, & Burgess, 2006; Landsiedel & Gilbert, 2015; Underwood, Guynn, & Cohen, 2015). Furthermore, distinct brain activation within these PM brain regions have been implicated in time- and event-based PM (Gonneaud et al., 2014; Okuda et al., 2007; Volle et al., 2011).

Neurocognitive underpinnings of prospective memory

Executive functioning is an umbrella term for various cognitive process that enable goal-directed and problem-solving thoughts and behaviour (Diamond, 2013), including PM. It is commonly accepted that executive functioning has a tripartite structure of three separable but correlated factors: inhibition, shifting/cognitive flexibility, and updating/working memory (Miyake et al. 2000; Miyake & Friedman, 2012). Inhibition encompasses inhibitory control or response inhibition, which is the ability to consciously inhibit automatic or prepotent responses when a situation requires it, as well as interference control, which is the ability to ignore irrelevant or distracting information or stimuli. Cognitive flexibility denotes the ability to flexibly switch between behaviours and strategies in response to changing environments or task demands. Working memory is the ability to store and manipulate/process information in mind for a limited period. It is generally agreed that working memory consists of a) separable, domain-specific storage mechanisms that maintain verbal information and visuospatial information, respectively, in mind, and b) a domain-general (executive) processing component that acts on the information contained in each of the short-term stores (Repovs & Baddeley, 2006).

PM requires the complex interplay of several cognitive processes, including aspects of executive functioning (M. Martin, Kliegel, & McDaniel, 2003). Planning is involved during the formation and encoding of an intention (Kliegel, Martin, McDaniel, & Einstein, 2002), and retrospective/working memory is necessary to store the delayed intention while performing the ongoing task or filler tasks (Marsh & Hicks, 1998). At the same time, attentional monitoring of the environment is required to recognise the appropriate moment to initiate the PM action (Kliegel, Jäger, Altgassen, & Shum, 2008). Finally, in order to successfully execute one's intention, a person has to shift their attention away from the ongoing task and switch the mental focus on the PM task, which requires cognitive flexibility and inhibitory control (Kliegel et al., 2002).

Another cognitive process which is thought to play a key role in PM is episodic future thinking (the ability to project oneself mentally into the future to imagine/pre-experience future events/states of self; Atance & O'Neill, 2001). Specifically, episodic future thinking is thought to play an important role during intention formation in terms of cue-to-retrieval-context association (G. A. Brewer, Knight, Meeks, & Marsh, 2011). That is, episodic future thinking might support PM retrieval by strengthening the association between PM cues and the future context that they will appear in. For example, at the stage of encoding one's intention to visit the supermarket on the way home from work, one might imagine taking the turn at the traffic light to go the supermarket instead of heading straight home. Later, when actually at the traffic light, the similarity between the environment and one's earlier episodic simulation may help trigger the activation of the PM action (Altgassen et al., 2015). Finally, PM may well depend to some extent on mentalising ability. Specifically, the ability to represent one's own intentions would seem to be imperative for successful PM (e.g., Altgassen, Vetter, Phillips, Akgün, & Kliegel, 2014).

Autism spectrum disorder

One neurodevelopmental disorder that is characterised by impairments of several of the aforementioned neurocognitive underpinnings of PM is autism spectrum disorder (ASD). ASD is a neurodevelopmental disorder that is diagnosed on the basis of impairments in social-communication, and a restricted, repetitive repertoire of behaviour and interests (DSM 5; American Psychiatric Association, 2013; ICD-10; World Health Organisation, 2006). At the cognitive level, ASD is characterised by impairments in mentalising/theory of mind difficulties (e.g., Happé & Frith, 1995), episodic memory and future thinking (e.g., Lind, Williams, Bowler, & Peel, 2014) , as well as working memory (e.g., Kenworthy, Yerys, Anthony, & Wallace, 2008; Kercood, Grskovic, Banda, & Begeske, 2014), task switching/cognitive flexibility and planning (e.g., Williams & Jarrold, 2013). Inhibitory control, however, seems to be relatively unimpaired in ASD or only in certain cases (Hill, 2004; Lai et al., 2016). Because these neurocognitive abilities are impaired in ASD and an inherent component of PM, it would clearly follow that at least some aspects of PM should be impaired in ASD.

Importantly, ASD is a highly heterogeneous condition (Masi, DeMayo, Glozier, & Guastella, 2017). Individuals with ASD usually show a particular pattern of strengths and weaknesses in different domains, both in terms of the severity of social-communicative impairments and restricted repetitive behaviours (Hus, Gotham, & Lord, 2014) but also in terms of their cognitive difficulties (Geurts, Sinzig, Booth, & Happe, 2014). Therefore, it has been suggested that ASD cannot been seen as a unitary condition, which cannot be explained by one single theory (see e.g., Happé, Ronald, & Plomin, 2006). This behavioural heterogeneity is also reflected in the outcomes of genetic research, which to date has not identified a unique set of genes associated with overlapping ASD symptoms (Lenroot & Yeung, 2013).

As a result of heterogeneity in ASD, traditional analyses on the group level might cover up variation in PM performance. It may well be that a small number of individuals with ASD will display impaired PM performance with the majority of the ASD sample performing at a comparable level to a neurotypical (NT) control group. Similarly, there may be the opposite case for a few individuals with ASD who might perform above the average of the NT group. Therefore, depending on the respective sample, averaging performance across participants with ASD might skew their overall performance as a group towards (a) impairment (if the group contains a small number of participants that perform significantly poorer than the rest of the ASD group), (b) no-impairment comparable to the NT group (if the ASD group contains participants performing in the normal range, as well as participants who perform particularly well and worse in comparison to NT, thus performance would average to be comparable to the NT group), or potentially (c) better performance than the NT group (if the ASD sample contains individuals at or above the NT average). The sole use of group analyses would therefore bias our understanding of PM abilities in ASD. Previously, studies into cognitive abilities in ASD have addressed this issue by additionally employing a single-case analyses; e.g. (Towgood, Meuwese, Gilbert, Turner, & Burgess, 2009) used a cut-off of +/- 2SDs above or below the control group mean to identify cases of ASD participants who might show particular difficulties on a battery of neuropsychological tests. Following their example, a similar approach was adopted in this thesis to identify potential single cases of ASD individuals who might display particular problems with PM.

Regardless, whether the study of PM abilities in ASD will conclude a gross impairment on the group or case level, if individuals with ASD are indeed impaired in either or both event-based and time-based PM, this would likely have serious ramifications for every-day functioning. Impairments in PM can drastically reduce an individual's ability to live independently and maintain many activities that are often taken for granted (Mateer, Kerns, & Eso, 1996; Terry, 1988). At the extreme end of possible consequences, impaired PM could lead one to forget to take medication or to take food off the stove, which might have disastrous consequences. Less dramatically, an impairment in PM would seriously hinder opportunity to maintain employment (Howlin & Moss, 2012). Moreover, there are even potentially negative social consequences of a PM impairment. For example, forgetting to call a friend on his birthday, or to attend a funeral, could have a significant impact on social relations, which are already difficult for people with ASD. Therefore, it is crucial to investigate PM in ASD as PM deficits could contribute to social and behavioural impairments in ASD.

In this chapter, I took two approaches to explore PM research in ASD. In Part 1, I will report the results of a meta-analysis that was conducted with the aim of establishing whether or not/the extent to which PM is impaired in ASD. An initial interpretation of the meta-analytic statistics is offered. However, as discussed at length below, the results from a meta-analysis need to be interpreted carefully in light of several methodological issues with some of the studies included. Therefore, in Part 2, I provide a detailed critical reflection on the research included in the meta-analysis, which provides the background for further reflection on the analysis in Part 1.

Part 1: Meta-analysis of studies of PM in ASD

Sample of Studies

A literature search (see Figure 1) was conducted on Web of Science using the search terms "autism" and "prospective memory" for articles published prior to May 2016 resulting in 37 articles. Of these, 13 studies with an ASD sample were excluded as they studied something other than PM. Five literature reviews were excluded that did not provide any data of their own (two of which briefly mentioned PM in ASD, two were on PM in general, and one was unrelated to PM). Another four studies were excluded as they studied PM in a population other than ASD. Finally, three studies were excluded as they were completely unrelated to ASD and PM. Hence, 12 studies were identified that had investigated PM in ASD, which were included in the meta-analysis. No further studies were identified from reference lists of other included studies or by replicating the search using additional search engines (Pubmed, Google Scholar). Tables 1 and 2 summarise the included studies and give a brief overview of the experimental approach/protocols, as well as details of group matching, in each study. Figure 2 depicts the mean age for both ASD and the NT control groups, together with the overall age range and the verbal mental age of each experimental group.

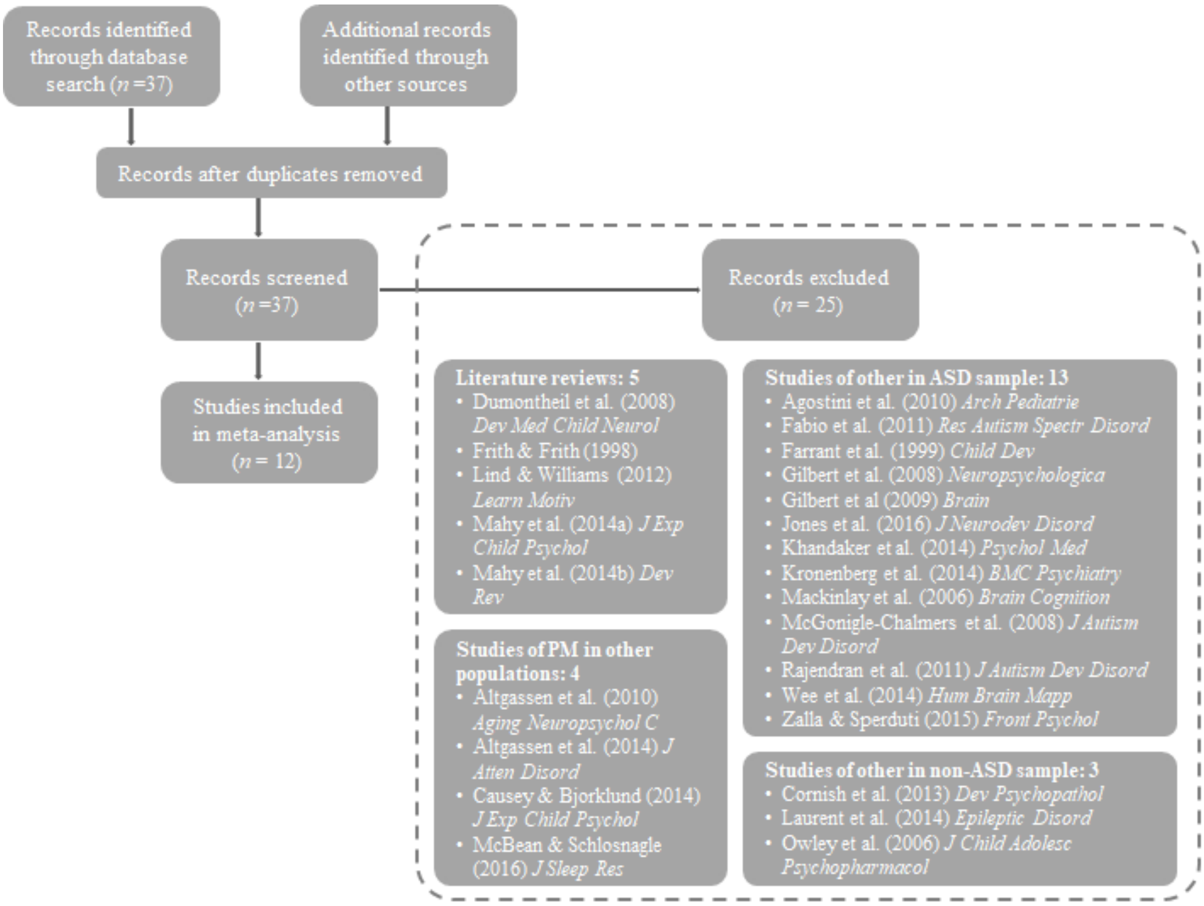

Figure 1 Flow-chart depicting literature search process

Table 1. Overview of characteristics of time-based PM studies in ASD.

Author, year	*Participants*		*Task characteristics*		*Filler tasks/ delay interval*	*Authors concluded PM impairment in ASD group (Hedges 'g)*[†]
	Sample size (male per group)	Mean age per group (range)	Ongoing task	# of PM trials		
Altgassen et al., 2009	n_{ASD} = 11 (ns.) n_{NT} = 11 (ns.)	ASD: 9.6 (7-15) NT: 10.6 (7-16)	Visuospatial working memory task	5 trials	Yes, ~10 min	Yes (g = -0.91)
Altgassen et al., 2012*	n_{ASD} = 25 (20 male) n_{NT} = 25 (19 male)	ASD: 21.8 (15-41) NT: 21.8 (15-42)	Dresden Breakfast task	2 trials	Yes ~ 15 min,	Yes (g = -0.94)
Williams et al., 2013**	n_{ASD} = 21 (20 male) n_{NT} = 21 (17 male)	ASD: 10.6 (7.8-13.8) NT: 10.6 (8-12)	Computer-based driving game simulation	6 trials	No	Yes (g = -0.66)
Williams et al., 2014**	n_{ASD} = 17 (14 male) n_{NT} = 17 (14 male)	ASD: 31.1 (19.1-54.6) NT: 31.9 (17.7-58.8)	Word memorisation task	5 trials	No	Yes (g = -0.66)
Henry et al., 2014*	n_{ASD} = 30 (24 male) n_{NT} = 30 (19 male)	ASD: 10.1 (8-12) NT: 10 (8-12)	Virtual week game, 2 within-subject condition (high vs. low task absorption)	12 trials across 3 virtual days, (2 regular/ 2 irregular per virtual day)	No	Yes (g = -1.02)
Kretschmer et al., 2014*	n_{ASD} = 27 (9 men) n_{NT} = 27 (2 men)	ASD: 35.6 (19-58) NT: 39.9 (21-52)	Virtual week game, 2 between-subject encoding conditions (implementation intentions vs. standard)	12 trials across 3 virtual days, (2 regular/ 2 irregular per virtual day)	No	Yes (g = -1.01)

Notes. *: time- and event-based PM task within the same condition; **: time- and event-based PM task in separate conditions; [†]: ES PM impairment: effect size representing the standardised bias-corrected mean difference Hedges'g (calculation according to Lipsey & Wilson, 2001); ns.: not specified

Table 2. Overview of characteristics of event-based PM studies in ASD.

Author, year	*Participants*		*Task characteristics*				*Filler task/ delay interval*	*Authors concluded PM impairment in ASD group (Hedges'g)*†
	Sample size (male per group)	Mean age (range) per group	Ongoing task	# of PM trials	# of PM cues	Focality of PM cue		
Altgassen et al., 2010	n_{ASD} = 19 (18 male) n_{NT} = 19 (16 male)	ASD: 10.6 (7–20) NT: 10.6 (7–20)	Visuospatial working memory task	5 trials	1	Non-focal	No	No (g = -0.25)
Brandimonte et al., 2011	n_{ASD} = 30 (21 male) n_{NT} = 30 (21 male)	ASD: 8.25 (6–12) NT: 8.33 (ns.)	Categorisation of pictorial images	8 trials	2	Focal	No	Yes (g = -0.96, post-hoc test, interaction not significant)
Jones et al, 2011	n_{ASD} = 94 (85 male) n_{NT} = 55 (53 male)	ASD: 15.5 (14.7–16.8) NT: 15.5 (ns.)	Rivermead Behavioural Memory Test	3 trials	1 per task	Focal	No	Yes (g = -0.41)
Altgassen et al., 2012*	n_{ASD} = 25 (20 male) n_{NT} = 25 (19 male)	ASD: 21.8 (15–41) NT: 21.8 (15–42)	Dresden Breakfast task, Red Pencil Task	2 trials for each task	2 and 1	Focal	Yes	Yes (Breakfast task: g = -0.70, Red Pencil task: g = -0.76)†
Williams et al., 2013**	n_{ASD} = 21 (20 male) n_{NT} = 21 (17 male)	ASD: 10.6 (7.8–13.8) NT: 10.6 (8–12)	Computer-based driving game simulation	6 trials	1	Focal	No	No (g = 0.17)
Williams et al., 2014**	n_{ASD} = 17 (14 male) n_{NT} = 17 (14 male)	ASD: 31.1 (19.1–54.6) NT: 31.9 (17.7–58.8)	Word memorisation task	4 trials	1	Non-focal	No	No (g = 0.42)
Yi et al., 2014	n_{ASD} = 25 (19 male) $n_{NT\text{-}MA}$ = 28 (19 male) $n_{NT\text{-}CA}$ = 25 (22 male)	ASD: 7.66 (4.9–10.3) NT_{MA}: 5.8 (4.3–9.9) NT_{CA}: 7.68 (4.6–11.2)	Naming of items on cards	5 trials	1	Focal	No	Yes (ASD vs. NT_{MA}: g = -0.59, ASD vs. NT_{CA}: g = -0.39)
Altgassen & Koch, 2014	n_{ASD} = 22 (20 male) n_{NT} = 22 (20 male)	ASD: 25.8 (17–41) NT: 25.6 (16–38)	Word categorisation task plus inhibition task	4 trials	1	Non-focal	Yes, ~10 min	No (g = -0.13)

Table 2. continued

Author, year	*Participants*		Task characteristics				*Filler task/ delay interval*	*Authors concluded PM impairment in ASD group (Hedges'g)*†
	Sample size (male per group)	Mean age (range) per group	Ongoing task	# of PM trials	# of PM cues	Focality of PM cue		
Henry et al., 2014*	n_{ASD} = 30 (24 male) n_{NT} = 30 (19 male)	ASD: 10.1 (8–12) NT: 10 (8–12)	Virtual week game 2 within-subject conditions (high vs. low task absorption) of 3 virtual days each	12 trials across 3 virtual days, (2 regular/ 2 irregular per virtual day)	4	Not clear	No	No (g = -0.10)
Kretschmer et al., 2014*	n_{ASD} = 27 (9 men) n_{NT} = 27 (2 men)	ASD: 35.6 (19–58) NT: 39.9 (21–52)	Virtual week game 2 between-subject encoding conditions (implementation intentions vs. standard)	12 trials across 3 virtual days, (2 regular/ 2 irregular per virtual day)	4	Not clear	No	Yes (g = -0.55)
Sheppard et al. 2016	$n_{ASD\text{-}severe}$ = 14 (13 male) $n_{ASD\text{-}mild}$ = 14 14 male) n_{NT} = 26 (16 male)	ASD$_{severe}$: 9.30 (6–14.5) ASD$_{mild}$: 10.05 (5.5–15.5) NT: 5.1 (5.05–6.5)	Interaction with a hand puppet (played by experimenter), playing a distractor game ('Wac-a Mole')	2 trials PM clapping task 2 trials PM feeding task 1 trial PM reward task	1 per task	Focal,	Yes, between 1 and 5 min	Yes (NT vs. ASD$_{severe}$: g = -1.43) No (NT vs. ASD$_{mild}$: g = -0.57)

Notes. *: time- and event-based PM task within the same condition; **: time- and event-based PM task in separate conditions; †: ES PM impairment: effect size representing the standardised bias-corrected mean difference Hedges'*g* (calculation according to Lipsey & Wilson 2001); ns.: not specified

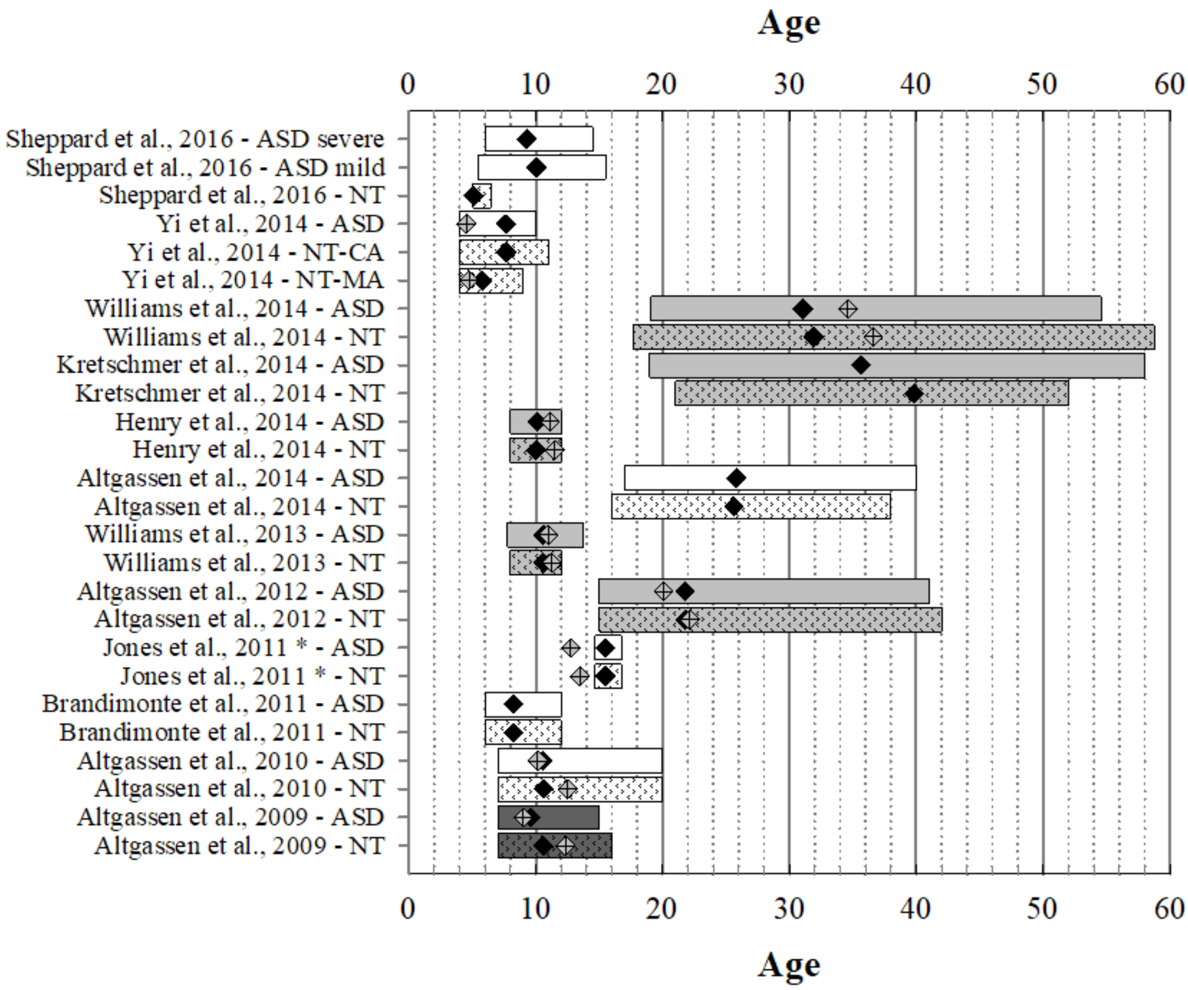

*Figure 2 Depiction of the mean age (black diamond marker) and the minimum and maximum age range for each experimental group for all studies investigating prospective memory in ASD (white bars represent event-based PM only studies, dark grey bars represent time-based PM only studies, light grey bars represent studies that tested event- and time-based PM). Where possible the verbal mental age of each group was plotted onto the age distribution (marked with the grey crossed diamond) to illustrate the relation of chronological vs. mental age in each study. * Jones et al. (2011) did not study event-based PM per se but investigated everyday memory in ASD*

Meta-analytic procedure

Meta-analytic statistics were calculated following the guidelines of Lipsey and Wilson (2001), separately for time-based PM and event-based PM studies. Effect sizes were calculated for the difference in PM performance between ASD and NT participants. The effect size estimate was the bias-corrected standardised mean difference (Hedges' *g*), which corrects an overestimation bias of effect sizes in small-scale studies (Hedges, 1981; Hedges & Olkin, 1985). In the meta-analysis, a fixed-effects model was used to calculate the mean effect, expressing group differences in PM, weighted for sample size, and a 95% confidence interval (CI) was calculated based on its standard error (SE). The direction of the effect size was negative if performance of the ASD group was worse than the control group and effect sizes were classified according to Cohen's (1988) criteria (> 0.20 is "small", > 0.50 is "medium", and > 0.80 is "large"). A z-test for the overall effect was conducted to test the significance of the mean weighted effect. A homogeneity analysis was conducted to test for homogeneity of the effect size distribution. A significant homogeneity parameter indicates that the variability of the included effect sizes is greater than to be expected from sampling error and suggests that other explanatory variables should be investigated. In this case, a conservative approach was adopted and an additional effect size estimate was calculated using the random-effects model.

Multiple Effect Sizes from Single Studies

To satisfy the independence assumption of meta-analyses when calculating the mean weighted effect for time- and event-based PM, respectively, each participant could contribute to only one group contrast for statistical analytic purposes. Therefore, it was not possible to include all calculable effect sizes in three of the included studies, because doing so would have violated the assumption of independence in one of the following ways: a) multiple ASD groups but only one NT group would have meant that the NT group would be included in the meta-analysis more than once if all reported group contrasts were included (Sheppard, Kvavilashvili, & Ryder, 2016); b) multiple NT groups but only one ASD group would have meant that the ASD group would be included more than once if all reported group contrasts were included (Yi et al., 2014); or c) multiple PM measures from the same participants would mean that each participant would be included more than once if performance on all measures was included (Altgassen, Koban, & Kliegel, 2012). Furthermore, to avoid biasing the mean weighted effects, group contrasts that explored the effect of attempts to improve PM in the ASD were excluded (Kretschmer, Altgassen, Rendell, Bolte, & Bölte, 2014)[1].

Results

Time-based PM. A total of 118 participants with ASD and 118 NT control participants from six studies were included using a fixed-effects model. The mean weighted effect for the between-group difference in performance was -0.87 (*SE* = 0.14, 95% *CI:* -1.14 to -0.60; z = 6.38, $p < .001$). The homogeneity test was not significant (Q = 1.22, p = .94) indicating that the variance across the included effect sizes was not greater than expected by sampling error. These findings indicate a large and consistent impairment of time-based PM in ASD across studies (see Figure 3).

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[1] In four studies, a decision had to be made about which of the multiple effect sizes reported should be included in the meta-analysis. The decision was based entirely on the rationale for the study and/or study hypotheses, and not on study results. Importantly, taking alternative decisions would not have changed the results of the meta-analysis substantially. Moreover, for completeness, the effect sizes that were not included in the meta-analysis are displayed in the forest plots (see Figures 2 and 3). In Sheppard et al. (2016), who tested a mildly and severely autistic group of children, the effect size from the group contrast between the severely autistic vs. NT children was used in line with Sheppard et al.'s (2016) hypothesis that only severely autistic children would show a PM impairment. In Yi et al. (2014), who included two comparison groups (one matched for chronological age with the ASD group, and one matched for mental age with the ASD group) in their study, the contrast between ASD and the ability-matched NT group was used as the age-matched NT group performed at absolute ceiling on the PM task making valid comparison with the ASD group impossible. For Altgassen et al. (2012) who used a standard measure of PM in addition to a naturalistic PM task, the standardised mean differences for the two contrasts (which were very similar) were averaged into a composite effect size. Finally, Kretschmer et al. (2014) manipulated a between-subject factor that aimed to improve PM using an encoding strategy in comparison to a standard no strategy condition. As this meta-analysis aimed to estimate the extent of true PM impairment in ASD, inclusion of the strategy contrast in the analysis would bias the mean weighted effect size. Hence, the contrast where participants performed the PM task under the no-strategy condition was selected.

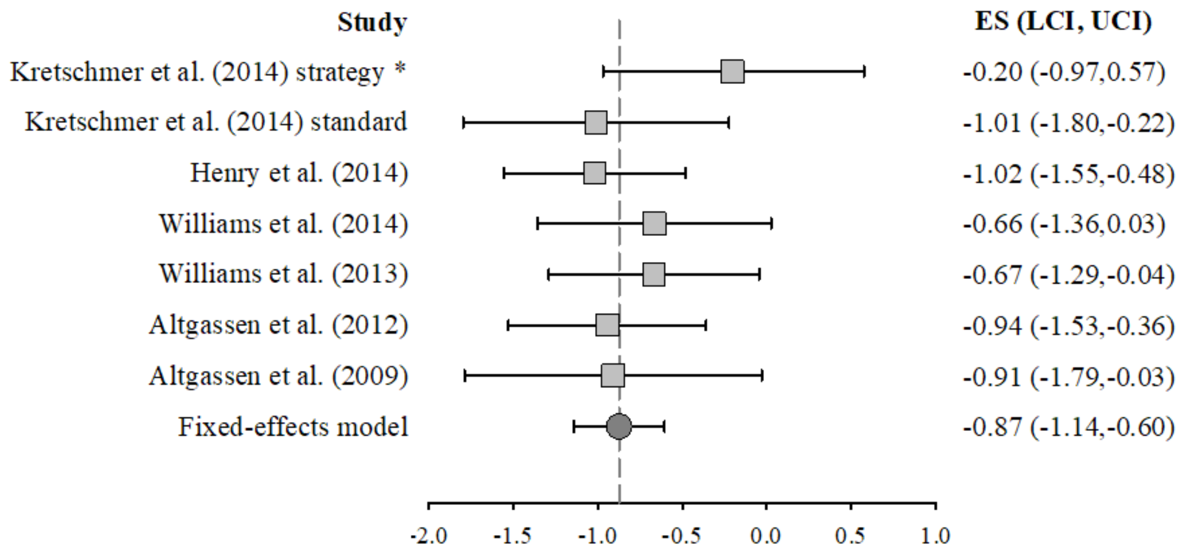

*Figure 3 Forest plot for effect sizes and 95% confidence interval for time-based PM studies as well as the mean weighted effect and its 95% confidence interval (dark grey circle marker). Notes: The vertical grey line marks the weighted mean effect of the fixed-effects model. Studies marked with an * were not included in the meta-analysis but are included for illustrative purposes.*

Event-based PM. A total of 311 participants with ASD and 287 NT control participants from 11 studies were included in the fixed-effects model. The weighted effect for the between-group difference in performance was -0.41 (*SE* = 0.08, 95% *CI:* -0.57 to -0.24; *z* = 4.83, *p* <.001). However, the test for homogeneity of effect sizes was highly significant (*Q* = 25.14, *p* =.005), which suggests that the variance among the included effect sizes was greater than expected by sampling error. Subsequently, the data was re-entered into a random-effects model that includes random effects variance (due to random differences between studies) in the weighting of the individual effect sizes in the model. This revealed a significant weighted effect of -0.43 (*SE* = 0.13, 95% *CI*: -0.69 to -0.17; *z* = 3.20, *p* < .01). Hence, both models indicate a small impairment of event-based PM in ASD, although the underlying effect sizes are heterogeneous across studies (see Figure 4).

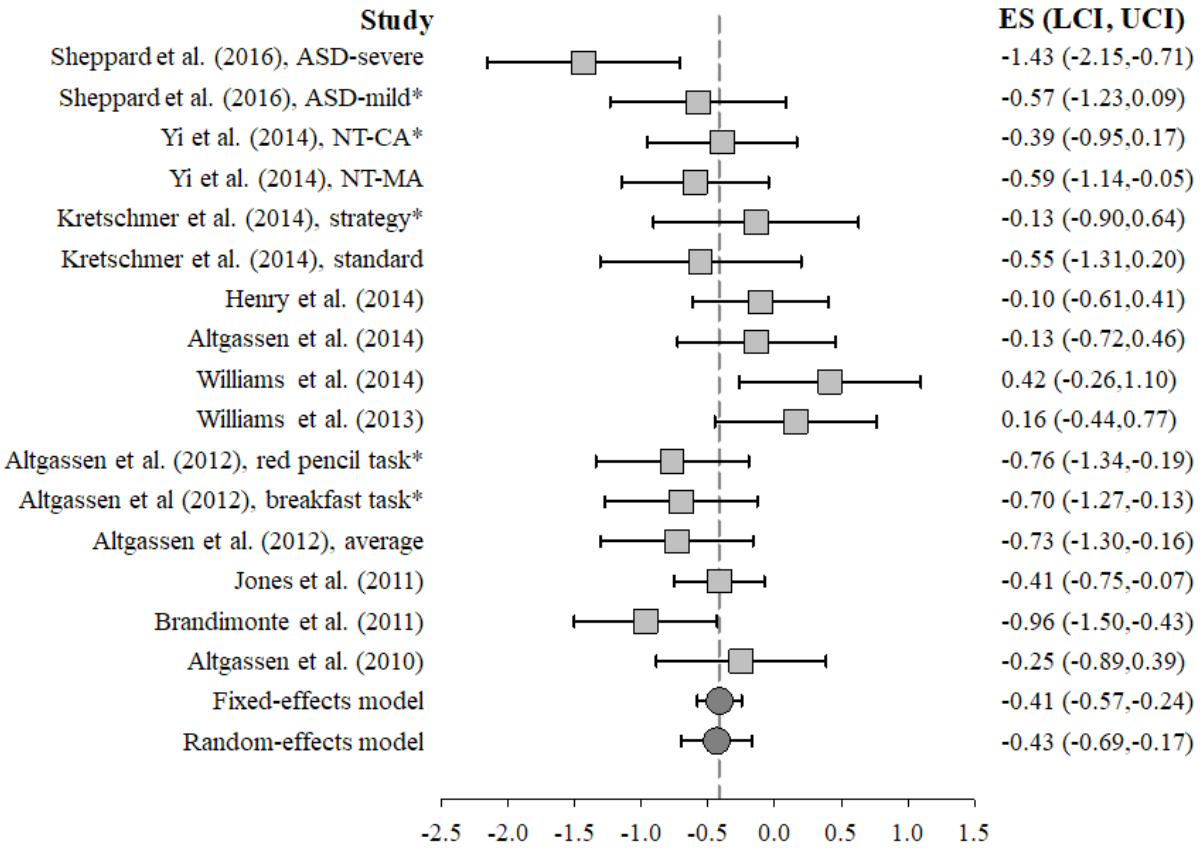

*Figure 4 Forest plot for effect sizes and 95% confidence interval for event-based PM studies as well as the mean weighted effect and its 95% confidence interval for both fixed- and random-effects models (dark grey, circle marker). Notes: The vertical grey line marks the mean weighted effect of the random-effects model. Studies marked with an * were not included in the meta-analysis but are included for illustrative purposes.*

Conclusion

Although the results of the meta-analysis provide some indication of a relatively minor impairment in event-based PM in ASD, this stands in stark contrast to the clear and strong effect of a time-based PM impairment in individuals with this condition. Some caution might be taken when interpreting the findings with regard to event-based PM, however. Although results from the random effects model suggest that a significant weighted effect for event-based PM overall cannot be solely due to significant heterogeneity of effect-sizes across studies, the existence of such heterogeneity is nonetheless important to consider. Indeed, in Part 2, I provide a detailed critical analysis of the studies included in the meta-analysis and conclude that the meta-analytic findings of a small impairment in event-based PM derive in large part from methodological issues in some of the studies, which might render conclusions from the meta-analysis alone unreliable if they are not considered *in context.*

Part 2: Critical analysis of studies of PM in ASD

Methodological and conceptual issues in the study of prospective memory in ASD

In order to interpret the results of case-control studies of PM ability with confidence several issues should be considered. Table 3 presents an overview of all studies included in the meta-analysis, as well as an indication of whether any of the potential methodological problems described below apply to them.

(1) *Group matching procedure:* In case-control studies, experimental groups need to be carefully matched for baseline characteristics that are likely to relate to the dependent variable. Evidence suggests that PM has a clear developmental trajectory (Kliegel, Mackinlay, & Jäger, 2008), and that both verbal (Uttl, 2006; Uttl, White, Gonzalez, McDouall, & Leonard, 2013) and nonverbal (Cockburn & Smith, 1991; Maylor, 1996) intelligence are related to it. Furthermore there is some evidence for a female advantage in PM tasks (Palermo et al., 2015). Therefore, when studying PM in ASD, it is important for groups to be matched for verbal and nonverbal ability (mental age), as well as for chronological age and gender (between-group differences should only be small in size – Cohen's $d < 0.50$; McCartney, Burchinal, & Bub, 2006) . Failure to match groups for baseline characteristics can result in type I errors, because group differences in PM may result from group differences in the baseline characteristics of groups, rather than from diagnostic status (Mervis & Klein-Tasman, 2004).

(2) *Ongoing task performance:* A typical PM task is always embedded into an ongoing task. Thus, similar to a dual-task design, attentional and cognitive resources are divided between the completion of the ongoing task and completion of the PM action/intention. It is important that groups are matched for ongoing task performance. Otherwise, analyses of

between-group differences in PM performance may be "contaminated" by the effects of between-group differences in ongoing task performance. For example, if the ASD group performs significantly *less* well than the control group(s) on the ongoing task, then poorer PM task performance in the ASD group could merely reflect the fact that ASD participants had fewer cognitive resources than control participants to devote to the PM task as a result of their difficulty with the ongoing task. Alternatively, if the ASD group performs significantly *less* well than the control group(s) on the ongoing task, but *equivalently* to the control group on the PM task, this may reflect differential allocation of cognitive resources performance in the ASD group (i.e., PM performance is being scaffolded/prioritised at the expense of ongoing task performance).

(3) *Retrospective memory for the PM instruction:* PM requires an individual to encode and store an intention to act in the future, which relies on *retro*spective memory. While it is clear that retrospective and prospective memory are related, factor analytic studies (among other types of study) show that they are clearly distinguishable (Crawford, Smith, Maylor, Della Sala, & Logie, 2003; Maylor, Smith, Della Sala, & Logie, 2002). PM failure could result either from a failure of the specific mechanisms that underpin PM retrieval, *or* from a failure of retrospective memory (i.e., when the intention is not even encoded/stored properly). Given well-established difficulties with spontaneous, episodic recall in ASD (Boucher, Mayes, & Bigham, 2012), it may be that people with this disorder have PM impairments purely as a result of retrospective memory difficulties. This would be important to know, of course, and would have implications for the management of PM difficulties in ASD. However, most studies have the aim of discovering whether the mechanisms that *specifically* underpin PM retrieval are impaired in ASD (i.e., whether PM is impaired over and above retrospective memory). To achieve this aim, it is necessary to assess retrospective memory for the PM instruction/action immediately after completion of the experimental PM task. If a participant cannot recall the

PM action even after prompting, it shows that PM failure is a consequence of retrospective memory difficulties only. Hence, studies should exclude those participants who, after prompting, cannot remember the PM instruction/action.

(4) *Mixed PM experiments:* Some studies of PM use paradigms that test both time- and event-based PM within the same condition. Although this *may* be more representative of real-life PM demands, the approach suffers from difficulties that limit interpretation of results. Specifically, if individuals with ASD have reliable impairments in only one aspect of PM, then difficulties with this aspect would leave fewer cognitive resources than would otherwise be the case for the usually-undiminished aspect. Thus, the recommended approach is to investigate time- and event-based PM in separate experiments (or experimental conditions of a task) within the same sample.

Having considered these potential methodological issues, I now discuss four landmark studies that serve as a foundation for considering other studies of PM in ASD. Then, further laboratory studies are examined, as well as studies that explored PM in ASD in a more naturalistic context.

Table 3. Overview of included studies with regard to key methodological issues

	Matching on baseline characteristics & Cohen's *d* for matched variables				**Matching on ongoing task performance & Cohen's *d***		**Retrospective memory for PM instruction**	**Mixed PM experiment**
Altgassen et al. (2009)	Yes	Age: 0.36	VA: 0.50	NVA: 0.30	No	1.19	Not reported	No
Altgassen et al. (2010)	Partly	Age: 0.01	VA: 0.58	NVA: 0.25	Yes	0.09	Not reported	No
Brandimonte et al. (2011)	Partly	Age: 0.04	FSIQ: 0.29	-	No	0.55	Yes	No
Jones et al. (2011)	Yes	Age: 0.0	VIQ: 0.25	PIQ: 0.04	NA	-	Yes	No
Altgassen et al. (2012)	Yes	Age: 0.0	VA: 0.44	NVA: 0.15	No	1.60	Not reported	Yes
Williams et al. (2013)	Yes	Age: 0.01	VIQ: 0.18	PIQ: 0.18	Yes	0.5	Yes	No
Williams et al. (2014)	Yes	Age: 0.07	VIQ: 0.21	PIQ: 0.25	Yes	0.03	Yes	No
Altgassen & Koch (2014)	Partly	Age: 0.03	-	NVA: 0.1	No	0.94	Not reported	No
Henry et al. (2014)	Yes	Age: 0.07	VIQ: 0.28	PIQ: 0.24	NA	-	No	Yes
Kretschmer et al. (2014)	Yes	Age: 0.45	VA: 0.25	NVA: 0.03	NA	-	No	Yes
Yi et al. (2014)	No (ASD vs. NT_{MA})	Age: 1.29	VA: 0.13	NVA: 0.63	Not reported	-	Not reported	No
	No (ASD vs. NT_{CA})	Age: 0.01	-	NVA: 0.65	Not reported	-	Not reported	No
Sheppard et al. (2016)	No ($\text{ASD}_{\text{severe}}$ vs. NT)	Age: 3.05	R: 0.15, W: 0.64	N: 0.16	NA	-	Not reported	No
	No (ASD_{mild} vs. NT)	Age:2.76	R: 0.33, W:0.07	N: 0.46	NA	-	Not reported	No

Notes. VA: verbal abilities; NVA: nonverbal abilities; VIQ: verbal IQ; PIQ: performance IQ; FSIQ: full scale IQ; R: Reading national curriculum point score; W: Writing national curriculum point score; N: Number national curriculum point score; NA: not applicable

Landmark studies of PM in ASD. In the first study of *event-based* PM in ASD, Altgassen, Schmitz-Hübsch, and Kliegel (2010) compared 19 children/adolescents with ASD to 19 age- and ability-matched NT peers. The ongoing task tapped visuospatial working memory. In a study phase of this task, participants viewed a number of geometric shapes, and had to encode and store the configuration of shapes. After a short delay, a second set of geometric shapes appeared on the screen and participants had to decide whether the shape configuration was same or different to the first one (recognition phase). The background colour on which the shapes were presented changed randomly after each trial. For the PM component, participants were instructed to press a pre-specified keyboard key whenever they noticed a change in background colour to yellow. Participants performed the ongoing task alone for 10 trials (single-task block), followed by the PM condition (dual-task block). The results revealed no between-group differences in ongoing or PM task performance. The authors concluded that event-based PM, which depends on cued retrieval, is unimpaired in ASD.

Altgassen and colleagues were also the first to investigate *time-based* PM performance in individuals with ASD. Altgassen, Williams, Bölte, and Kliegel (2009) assessed 11 children/teenagers with ASD and 11 age- and ability-matched NT control participants. The ongoing task required participants to perform a visuospatial working memory task similar to the one used by Altgassen et al. (2010). In the PM condition, participants were instructed to press a pre-specified keyboard key at 2-minute intervals throughout the ongoing task. During this condition, participants could, at any time, bring up an on-screen clock that displayed the time elapsed by pressing a specified key. Importantly, the ongoing task was carried out twice - once as single-task block (ongoing-only condition), and once as dual-task block together with the PM instruction (PM condition). The ASD group performed significantly worse in the ongoing task during the PM condition, but not in the ongoing-only condition. More importantly, the results revealed significantly better PM performance, as well as a more adaptive time-monitoring curve, in NT children. Therefore, the authors concluded that the diminished PM performance in ASD might originate from difficulties with self-initiated processing, as reflected by a less-than-optimal pattern of time monitoring.

Despite some methodological concerns regarding Altgassen et al.’s (2009) study (see Williams, Boucher, Lind, & Jarrold, 2013), the conclusions drawn both from this study (that time-based PM is impaired in ASD) and the study by Altgassen et al. (2010) (that event-based PM is unimpaired in ASD) are supported by the results from two studies by Williams and colleagues (2013, 2014). Williams, Boucher, Lind, and Jarrold (2013) examined both time-based and event-based PM in a sample of 21 children with ASD and 21 NT children matched on age, and IQ. Time-based versus event-based PM were assessed separately as two within-subject conditions carried out within the context of a computer-based driving game (the ongoing task). The ongoing task required participants to collect tokens and avoid obstacles while driving down a road. For the time-based PM task, participants were told that their car had only a limited amount of fuel, which would run out after 80 seconds unless they remembered to refuel it. The fuel level could be monitored at any time by pressing a particular keyboard key, which caused a fuel gauge to be displayed on screen temporarily. Importantly refuelling was only possible after the fuel level dropped to a critical level (between 60 and 80 seconds). For the event-based PM task participants had to press a specific keyboard key whenever they passed a truck. Results revealed a significant Group (ASD/control) × Condition (event-based/time-based) interaction effect on PM task performance, reflecting preserved event-based PM performance but impaired time-based PM in the ASD group. More adaptive time monitoring (i.e., a greater number of fuel checks prior to the period where refuelling was possible) was related to fewer time-based PM failures in both groups. Importantly, groups did not differ in ongoing task performance, nor time-monitoring frequency or pattern.

The results of Williams et al. (2013) were replicated precisely in a subsequent study by Williams, Jarrold, Grainger, and Lind (2014) of 17 *adults* with ASD and 17 age-, and verbal and performance IQ-matched NT adults. The same ongoing task (which tapped verbal short-term memory) was used for both PM conditions, which were carried out separately in counter-balanced order. In the ongoing task, participants studied sequences of seven words across 40 trials. After each study trial, a test list of seven words appeared on-screen and participants had to decide whether all seven had been present on the immediately-preceding study list. The event-based PM instruction required participants to press a specific key when one of the test list words represented a musical instrument. For the time-based PM task, participants had to press a specific key every two minutes throughout the ongoing task. Participants could bring up a clock displaying the elapsed time via key press. Williams et al. (2014) found a significant Group × Condition interaction, reflecting diminished time-based but spared event-based PM performance in the ASD group. Again, groups did not differ in ongoing task performance or time-monitoring frequency.

In summary, there seems to be a consistent pattern emerging from these initial studies suggesting that time-based PM is impaired, but event-based PM is unimpaired, in ASD. To explore this pattern further, first four additional studies are reviewed, which have investigated event-based PM *separately* from time-based PM, followed by a review of more naturalistic studies of time- and/or event-based PM.

Is ASD characterised by truly unimpaired event-based PM? Firstly, Yi et al. (2014) studied the role of executive functioning in event-based PM in a sample of 25 children with ASD and two NT comparison groups. One comparison group was reported to be matched with the ASD group for chronological age ($\mathrm{NT}_{\mathrm{CA}}$, $n = 25$), whereas the other comparison group was reported to be matched with the ASD group for verbal *mental age* and nonverbal *IQ*, $\mathrm{NT}_{\mathrm{MA}}$, $n = 28$). In Yi et al.'s paradigm, the ongoing task involved naming pictorial items on a series of cards. The PM task was to hand the experimenter a "target" card that had a red heart-shaped sticker on it. The ASD group performed significantly worse than both comparison groups on the PM task. Although this is an interesting study, there are two potential methodological issues with Yi et al.'s procedure that might lead to caution when interpreting the results. Firstly, ongoing task performance was not reported and memory for the PM task instruction was not checked at the end. It is not clear whether participants with ASD either noticed the target sticker on the relevant cards or even that they encoded the instruction to hand the cards with such a sticker to the experimenter. Secondly, based on the data provided, it appears as if the groups were not equated on baseline cognitive abilities. The NT_{CA} group was not equated for verbal mental age or nonverbal IQ, whereas the NT_{MA} group was not matched on nonverbal IQ or chronological age. Although the authors stated that the NT_{MA} group was matched with the ASD group for nonverbal IQ this was not accurate. Rather, the groups were matched for *raw* scores on the Combined Raven's Matrices test of nonverbal ability, but not for the *standardised* scores (i.e., not for nonverbal IQ). Crucially, the reported standardised score among ASD participants was an average of 11 or 12 points below that of the comparison groups and was in the "below average" range (*M* = 79.17, *SD* = 21.83). In general, it is not clear why Yi et al. adopted this matching strategy. Ideally, case and control groups are matched for age and IQ, as other studies have shown is possible when investigating PM in ASD (see Williams et al., 2014).

The second such study also examined solely event-based PM in a similar age group. Brandimonte, Filippello, Coluccia, Altgassen, and Kliegel (2011) studied event-based PM and response inhibition among 30 primary school-aged children with ASD, as well as 30 age-, and full-scale IQ-matched NT comparison participants. All participants completed a computerised ongoing task that involved sorting pictorial items into one of two categories (food and animals) via key press. The participants of each experimental group (*n* = 30 per group) were assigned to *one* of three between-subject conditions of the ongoing task. In a "PM condition", $n = 10$ ASD and $n = 10$ NT participants completed the ongoing task as described, but had the additional requirement to press a particular keyboard key whenever pre-specified images appeared. In other words, participants had to encode and retain a PM instruction while completing the ongoing categorisation task (hence, this was a standard PM task). In a "response inhibition" condition, $n = 10$ ASD and $n = 10$ NT participants completed the ongoing task, but had the additional requirement to *not respond* (i.e., not make a categorisation judgement) when pre-specified images appeared. The requirements of this condition resemble a classic "Go/No-Go" task (Verbruggen & Logan, 2008). Finally, in an "ongoing-only" condition, $n = 10$ ASD and $n = 10$ NT participants completed the ongoing task as described, but with no additional secondary requirements. This ongoing-only condition could be considered a control condition to establish how able participants with ASD are to perform the ongoing task independent of their PM or response inhibition skills. Brandimonte et al. (2011) performed two ANOVAs on their data. First, a 2 (Group: ASD/NT) × 3 (Condition: ongoing/PM/response inhibition condition) was conducted with ongoing task accuracy (percentage of correctly categorised images) as the dependent variable. There was a significant main effect of group, indicating that the comparison groups performed better than the ASD groups ($\eta_p^2 = .07$, $p = .05$) in the image categorisation task.

Second, a 2 (Group: ASD/NT) × 2 (Condition: PM/response inhibition) ANOVA was conducted using secondary task accuracy (percentage of PM successes/percentage of responses correctly inhibited) as the dependent variable. In this ANOVA, there was a significant main effect of group ($\eta_p^2 = .10$, $p < .05$) indicating better performance in both secondary tasks (PM *and* response inhibition) in the comparison group than in the ASD group. Crucially, the Group × Condition interaction was reported as non-significant and associated with a negligible effect size ($\eta_p^2 = .02$, p-value not reported). Despite the minimal interaction effect, Brandimonte et al. (2011) nonetheless broke it down using planned comparisons. These comparisons suggested that the ASD group was less accurate (η_p^2 = .11, $p < .05$) and responded slower (η_p^2 = .42, $p < .01$) than the NT group only in the PM task, whereas no between-group differences were evident in the Go/No-Go task (no effect sizes reported). Therefore, the authors concluded that individuals with ASD have a deficit in event-based PM, but are less affected in their response inhibition. However, there are some methodological issues that need to be addressed. First, breaking down non-significant interaction effects is problematic both statistically and conceptually, and may lead to erroneous conclusions being drawn (see Gelman & Stern, 2006). Second, groups were clearly not equated for ongoing task performance and the difficulties with this aspect of the experiment for participants with ASD could account for their difficulties with the secondary tasks (i.e., PM and response inhibition). Finally, although Brandimonte et al. (2011) matched the participant groups for age and FSIQ overall, it is not clear that this was the case for *each* of the between-subjects experimental conditions (i.e., PM, inhibitory control and the ongoing-task-only conditions). It is quite possible (but not reported in the paper) that diagnostic groups for each between-group condition were not comparable on these baseline variables, which could have generated artificial group differences in PM performance.

Third and most recently, Sheppard et al. (2016) investigated the effect of autism symptom severity on event-based PM in 28 children with ASD and 26 NT controls. Severity of autism symptoms in the ASD group was assessed with the Child Autism Rating Scale (Schopler, Reichler, DeVellis, & Daly, 1980). Scores were used to divide the ASD sample into "severe ASD" and "mild ASD" groups (n = 14 each). In a game-like procedure, participants interacted with a hand-puppet wolf (Wally, acted out by the experimenter) playing a distractor task game alternating with the completion of three different PM tasks, and a retrospective memory task. Thus, there was no ongoing task as such. The PM tasks required the child to remember to a) clap when they heard music being played (two trials, *PM clapping task*); b) remove a toy food item out of Wally's view because he could not eat them (two trials, *PM feeding task*); and c) collect their reward at the end of the session (signalled by the experimenter saying "The games are now finished, time to go back to class.", *PM reward task*). For the PM clapping and the PM reward tasks, participants were prompted once *at the end of* each trial if they did not spontaneously remember the PM activity (children were asked: "Can you hear the music?" for the PM clapping task, and "Have you forgotten anything?" for the PM reward task). Collapsed across all three PM tasks, a significant main effect of group (η_p^2 = .13) was found. Post-hoc tests revealed that this was driven by the significant difference between the severe ASD and the NT group (*d* = 1.39). When examining the results separately, a similar pattern was found for the PM feeding task (η_p^2 = .14). Further, although there were no group differences on the first trial of the PM clapping task (similar performance without prompting, as well as similar performance improvement for all groups after being prompted), both ASD groups performed significantly worse than the NT group (who significantly improved their performance from the first to the second unprompted trial) on the second unprompted trial. No significant group differences emerged for the PM reward task. The authors concluded that severely autistic children can succeed on certain event-based PM tasks if task characteristics are adjusted to their needs (i.e., rewarding circumstances, specific PM cues). Further they suggested that, although children with ASD benefitted from prompts in the individual trials of the PM clapping task, this did not positively affect their performance from the first two the second trial in contrast to the NT group. The authors suggested this could be explained by information processing deficits in ASD when the ability to connect and integrate information across tasks is required (Olu-Lafe, Liederman, & Tager-Flusberg, 2014).

Although Sheppard et al.'s (2016) study is interesting, it suffers from a major methodological issue in terms of matching procedure. Groups were not matched for age or gender, and no standardised measure was employed to equate groups for cognitive ability.

Instead groups were matched only for national curriculum point scores for reading, writing, and number skills. The authors argue that "the demands of standard IQ tests such as WASI (Wechsler Abbreviated Scale of Intelligence, Wechsler, 1999) or even BPVS (British Picture Vocabulary Test, Dunn, Dunn, Styles, & Sewell, 2009) make this type of matching unsuitable for children with severe ASD" (pp. 6-7). However, it is counterintuitive that, if a child is not capable–because of their severe social-communication deficits–of completing standard IQ tests, they could complete an experimental task as complex as the task(s) used in this study (some of which were inherently social).

Fourth and finally, Altgassen and Koch (2014) studied the contribution of inhibitory control demands on event-based PM performance in 22 adults with ASD and 22 age- and nonverbal ability-matched NT adults. For this purpose, they used a *triple task* within-subject design. Participants completed two experimental conditions in counter-balanced order. The ongoing task involved a word categorisation paradigm (deciding which of two words belongs to the same category as a third word). The colour of all three words changed randomly every trial. The PM instruction was to press a pre-specified key whenever all three words were printed in blue font. Simultaneously, inhibitory load was manipulated using an auditory mental arithmetic task. In a "low inhibitory load" condition, participants were presented with a sequence of numbers via headphones and were required to add five to each number and state the resulting sum. In a "high inhibitory load" condition, the procedure was the same but participants had to withhold saying the sum aloud when it equalled eight or 15. Contrary to the hypothesis of the authors, there were no between-group differences in PM in either condition (i.e., regardless of inhibitory load), or in the extent to which responses were correctly withheld in the high-inhibitory control condition. These findings are striking and suggest that event-based PM is not impaired in ASD even when demands on executive resources associated with successful performance are high. However, in *both* inhibitory load conditions, performance on the ongoing *categorisation* task itself was significantly superior in the comparison group than in the ASD group (η_p^2 = .18). As such, it remains a possibility that participants with ASD were allocating relatively more of their cognitive resources to completion of the PM task and the ongoing *inhibition* task than were comparison participants. Therefore, it may be that participants with ASD were using alternative, compensatory strategies to succeed on the PM component of the task at the expense of performance on the ongoing activity. Problems with multimodal integration (Baum, Stevenson, & Wallace, 2015) in this particular triple-task design might have led individuals with ASD to focus more on one of the three tasks. That is, it might be that when attentional demands of the environment are high, people with ASD may need to prioritise carrying out the planned PM action *at the expense of* other activities to an extent that NT individuals do not. Either way, the fact that participants with ASD in Altgassen and Koch's study performed comparably to NT individuals on a PM task that had very high executive demands suggests that this ability cannot be grossly impaired in adults with this disorder.

Overall, with the exception of study of Altgassen and Koch (2014), the studies discussed above, suggest that event-based PM is impaired in ASD contrary to the initial landmark studies reviewed. However, based on the critical analysis of the studies' methodology, such a conclusion should be drawn tentatively at best. Below a final set of studies exploring PM in ASD in more naturalistic settings will be discussed.

"Real-life/naturalistic" studies of time- and event-based PM. To explore both time- and event-based PM in a naturalistic setting Altgassen et al. (2012) tested 25 adults with ASD and 25 NT participants matched for chronological age and intellectual abilities. The ongoing task consisted of preparing breakfast (using props) for four people following a simple set of rules. Two time-based (taking the tea bag out of the tea after three minutes; putting butter on the table six minutes before guests arrive) and two event-based (preparing tea immediately after kettle went off, which was indicated by the kettle changing colour; turning off the egg cooker when it beeped) PM components were embedded the breakfast preparation routine. The aim of this complex paradigm was to mirror real life PM demands. In addition, participants also completed a standard measure of event-based PM (Red Pencil Test; Salthouse, Berish, & Siedlecki, 2004), in which participants were asked to repeat the words ‘red pencil’ whenever the experimenter said ‘red pencil’ throughout the experimental session (which happened twice). Based on previous research, the authors predicted that only time-based PM would be diminished in the ASD group. In fact, however, participants with ASD showed diminished performance (i.e., more failures to complete the PM action) across all PM tasks. In relation to the time-based PM components of the breakfast task, the ASD group also monitored the time less often than the NT group.

The authors concluded that all aspects of PM ability are impaired *under real-life conditions* in individuals with ASD. Although this conclusion may well be accurate, whether or not one can be certain of this from the data in this study is debateable. As the study required participants to carry out both time- and event-based PM tasks within the same ongoing task (breakfast preparation), difficulties with time-based PM could have potentially carried over to the event-based PM performance in the ASD group. Thus, it may well be that ASD participants might not have been impaired in event-based PM in a real-life setting if they were not simultaneously having to carry out time-based PM. Moreover, the ongoing task itself appeared to be significantly more challenging for the ASD group than for the comparison group, as indicated by significantly worse overall ongoing task completion, as well as significantly less rule adherence and less efficient performance throughout the experiment among ASD participants. Finally, it is highly problematic that memory for the PM instruction was not checked after task completion. This is crucial, because there was a minimum delay of 15 minutes between encoding the PM instruction and the beginning of the experimental task, which might have promoted forgetting of the task rules.

Two other studies aimed to explore PM in ASD in a more “real-life” setting. Both used the Virtual Week paradigm (see Rendell and Henry, 2009 for full details of the paradigm). The Virtual Week is a computerised single player board game that simulates five to seven days of a week. Depending on the version of the task, the day and time of the virtual day are either always visible, or appear only after a particular keyboard key is pressed by the participant. The player rolls a die and moves a token around a board of 121 squares that represents one virtual day. On each virtual day, the player will pass 10 squares, which require them to pick up an action card. Each action card poses a question about an activity for that time of the day that the participant has to make a decision about (e.g., choosing between three options for that day’s breakfast). Importantly, each choice determines whether the player has to roll a specific, an odd, or any number with their die on their next move to be allowed to continue moving their token around the board (which is revealed to them after selecting an activity option). Participants are unable to move on and have to repeat rolling the die until they have rolled the specific die number required. Hence the demands of rolling the die, moving the token around the board and making decisions about the activities to participate in, serve as the ongoing activity. Due to this board game nature of the task, the Virtual Week does not provide a measure of ongoing task performance per se, unlike more laboratory PM tasks. Additionally, each day, a total of four time- and four event-based PM tasks have to be carried out, in addition to the 10 activity-related decisions that are inherent to the game. The event-based PM tasks have to be carried when a particular event occurs (as indicated by the action cards; e.g., take medication at breakfast would be triggered by the breakfast card). The time-based PM tasks have to be carried out at a set time of the virtual day (e.g., phone the plumber at 5pm). Some PM tasks require execution on a regular basis whereas others are irregular. The regular ones are the same on each day of the Virtual Week (two time-based, two event-based). The irregular ones are one-off tasks that are instructed at the beginning of, or during, a new virtual day (two time-based, two event-based). Thus, the retrospective memory load for the irregular PM tasks is higher compared to the regular ones. At the appropriate moment to execute a PM task, the participant has to press a "perform task" button to bring up a list of possible tasks, and then choose the correct one.

One of the two studies which have used this Virtual Week paradigm with individuals with ASD was that of Henry et al. (2014). This study explored how differential levels of task absorption (i.e., the level of engagement in the ongoing task) affected PM in 30 children with ASD and 30 NT children matched for age and IQ. Tasks in the Virtual Week were adjusted to reflect children's everyday life. Further, to reduce/eliminate time-monitoring demands, the time of each virtual day was always present in the centre of the screen. Participants completed the Virtual Week game under two conditions (each lasting three virtual days) in counterbalanced order. In the *high task absorption* condition, participants could only continue moving their token around the board if they rolled a specific number after an event card (see description above), whereas in the *low absorption condition,* the outcome of the next die roll was not restricted. The authors predicted that high task absorption may lead to greater PM impairment in the ASD group. A 2 (Group: ASD/NT) × 2 (Task absorption: low/high) x 2 (Type of PM task: event-based/time-based) × 2 (Regularity: regular/irregular) mixed ANOVA was conducted to explore effects on PM performance. Most importantly, a significant Group × PM task interaction (η_p^2 = .21) was found indicating that the ASD group was only impaired in time-based but not event-based PM, which ties in with the consistent pattern found by the landmark (tightly controlled) studies summarised above. Contrary to author predictions, high task absorption did not affect the ASD group to a greater extent. Further, the Group × Regularity interaction approached significance (p = .06, η_p^2 = .06). The authors broke this marginally non-significant interaction down using post-hoc t-tests. These t-tests showed no performance difference between regular and irregular PM tasks within the ASD group (η_p^2 = .02), whereas NT individuals performed slightly better on regular PM tasks (p = .04, η_p^2 = .07). However, in comparison to the NT group, participants with ASD were still less accurate on both regular (η_p^2 = .21) and irregular (η_p^2 = .16) PM tasks. Therefore, authors concluded that PM difficulties in children with ASD are not a result of retrospective memory processes. Instead, they suggested that a monitoring deficit might underlie their PM deficits as time-based PM requires more self-initiated monitoring processes.

Another study which used the Virtual Week set-up was that of Kretschmer et al. (2014). Rather than focusing on the degree of absorption (which presumably affects retrieval of the original intention to carry out an action), Kretschmer et al. (2014) used this paradigm to investigate the effects of different encoding strategies on PM in a sample of 27 adults with ASD and 27 NT adults matched for age, verbal, and non-verbal abilities. The Virtual Week setup and tasks were as described above, but participants had to complete only three virtual days, and needed to press a specific keyboard key to display the time of the day. PM encoding was compared across two between-subject conditions, the first being a ‘standard’ condition and the second requiring implementation intentions, which is an encoding strategy that requires to form ‘if-then’ statements; that is, creating a specific situation when, where, and how to perform one’s intention (Gollwitzer, 1999). Implementation intentions have been shown to improve PM in NT studies (Chen et al., 2015) and are thought to support episodic future thinking (Atance & O'Neill, 2001). Hence, this was the first study exploring strategies to enhance PM in ASD. Specifically, in the implementation intention condition, participants had to form such an ‘if-then’ statement for each irregular PM task instructions of that day after the instructions had been presented on-screen (e.g., say out-loud, “when it is 5pm, then I will press the ‘perform task’ button and select the ‘phone the plumber’ action”; Kretschmer et al. (2014), p. 3112).

The logic here was that forcing participants with ASD to form implementation intentions would support their PM and, thus, raise their performance level to one commensurate with that among NT participants. No additional instructions were given in the standard condition. To analyse experimental task performance, the authors ran a 2 (Group: ASD/NT) × 2 (Encoding condition: standard/implementation intention) × 2 (Type of PM task: event-based/time-based) × 2 (Regularity: regular/irregular) mixed ANOVA to analyse PM performance across all three virtual days. They found a main effect of group (η_p^2 = .14), as well as a significant Group × Regularity (η_p^2 = .12) interaction. Interestingly, post-hoc test results revealed no within-group differences for NT adults, but ASD participants performed better on regular than irregular PM tasks (η_p^2 = .17). Because no Group × PM task interaction emerged, the authors concluded that individuals with ASD have a general deficit across *both* time- and event-based PM. The Group × Encoding condition interaction was non-significant with a small to medium effect size (p = .08, η_p^2 = .06). Nonetheless, the authors broke down the interaction effect. Post-hoc between-participant tests revealed that, relative to comparison participants, individuals with ASD showed diminished performance in the *standard* condition only; whereas in the implementation intentions condition, the between-group differences in performance were non-significant. Based on these results, the authors concluded that implementation intentions might present a strategy to support PM in individuals with ASD. However, a closer inspection of the results suggests that this conclusion is not entirely warranted. Kretschmer (personal communication, October 2016) provided the group means and standard deviations, which indicated that the ASD group only benefitted from employing implementation intentions for event-based PM (ASD: $M_{\text{ImplementationIntentions}}$ = .81, SD = 0.22, M_{Standard} = .62, SD = 0.33; NT: $\text{M}_{\text{ImplementationIntentions}}$ = .84, SD = 0.22, M_{Standard} = .80, SD = 0.29). However, rather than implementation intentions improving time-based PM performance in ASD, they instead *decreased* the performance of comparison participants relative to the standard condition performance (ASD:

$M_{\text{ImplementationIntentions}} = .53$, $SD = 0.32$, $M_{\text{Standard}} = .49$, $SD = 0.32$; NT: $M_{\text{ImplementationIntentions}} = .58$, $SD = 0.25$, $M_{\text{Standard}} = .79$, $SD = 0.24$). Further, in contrast to Henry et al. (2014), the authors concluded that retrospective memory demands are important to understand PM deficits in ASD as participants only showed significant impairments in the irregular (one-off non-routine) PM tasks ($p < .001$, $\eta_p^2 = .27$), which place particularly high demands on retrospective memory. Unfortunately, the authors could not check whether participants actually remembered the irregular PM task instructions after each virtual day; although participants had to repeat the PM instruction three times aloud at the stage of encoding (which was supposed to ensure later remembering), there is no way of knowing whether the instruction was stored for the duration of the Virtual Week task. As such, retrospective memory limitations in ASD might explain entirely the group difference in the number of times irregular PM tasks were completed.

The Virtual Week is an interesting approach to study PM in ASD. The game format makes it easily accessible and it attempts to mirror everyday PM demands in several respects. However, the PM demands of the task are arguably much greater than (and of a different quality to) those in real life; participants have to remember *24* PM tasks (requiring the execution of *both* time- and event-based tasks and changing retrospective memory load) during a short period of time and without the use of any external reminders. Further, in the version used for both studies on ASD, the Virtual Week version did not offer the possibility to check whether participants actually remembered their PM tasks for each virtual day, which would have been particularly important for irregular PM tasks. However, Henry et al. (2014) pointed out that this feature is now part of the newest version of Virtual Week.

The results of the two studies that employed the Virtual Week studies differ in one major respect. Henry et al. (2014) found only time-based PM to be diminished in *children* with ASD, which is in line Williams et al.'s findings (2013, 2014). In contrast, Kretschmer et al. (2014) observed impairments of both time- *and* event-based PM in *adults*. This is surprising and requires further exploration. Kretschmer et al. (2014) employed a version of the Virtual Week that was equivalent to Henry et al.'s (2014) high-absorption condition. A possible explanation for the differing pattern of results could be the aforementioned retrospective memory difficulties in the ASD group. Kretschmer et al. (2014) found that the ASD group performed worse on the irregular PM tasks that posed the highest retrospective memory demand. This result may reflect the viable possibility that participants with ASD simply forgot the PM instruction more frequently. In general, the possibility that event-based PM deficits in ASD are observed only when demands on retrospective memory are high is brought into focus by the findings from a very large study of "everyday memory" by Jones et al. (2011).

Jones et al. (2011) investigated everyday memory in 94 adolescents with ASD and 55 age-, and IQ-matched (verbal, performance, and full scale) NT peers. Jones et al. used the Rivermead Behavioural Memory Test (Wilson & Baddeley, 1991) to assess everyday memory across multiple subtests, three of which tested event-based PM. These sub-tests involved a) reminding the experimenter about the location of a pen upon the occurrence of a particular verbal cue; b) asking the experimenter a question when an alarm went off; and c) remembering to pick up an envelope before walking a route as demonstrated by the experimenter. The ASD group achieved a significantly lower PM composite score (across the three subtests) than the comparison group, indicating significant event-based PM impairments in this very large sample of ASD participants. However, Williams et al. (2013) noted that Jones et al.'s analysis included participants who had failed to remember the PM task instruction at all. When the data from Jones et al. (2011) were re-analysed excluding participants who completely failed to recall the PM instruction, there was no hint of any between-group differences in PM task performance (Williams et al., 2013, p. 1564). This re-analysis underscores the importance of controlling for retrospective memory demands when drawing conclusions about PM ability in ASD.

Discussion

Why is time-based PM impaired in ASD? The evidence from the meta-analysis presented in Part 1, as well as the review of the evidence in Part 2, strongly suggest that time-based PM in ASD is impaired. Of course, the challenge remains to explore the underlying reasons for this impairment. Several studies have explored the underlying cognitive correlates of time-based PM in ASD (see Table 4[2]). Although these correlation analyses offer some indication about the underlying cause of time-based PM impairments in ASD, they are far from conclusive. In general, time-based PM performance appears to be related to executive functioning processes in ASD. Given that time-based PM requires self-initiated (rather than cued) retrieval of intentions, it is unsurprising that executive processes might be related to task performance, since self-initiated retrieval of information from memory is considered to place a high demand on executive functioning (e.g., McDaniel & Einstein, 2007). It may be, therefore, that well-established difficulties with aspects of executive functioning in ASD underpin time-based PM deficits in ASD.

An alternative possibility is that difficulties with representing mental states (i.e., mindreading/theory of mind) in ASD make it particularly difficult for people with ASD to introspect/retrieve their own intentions (e.g., Williams & Happé, 2010) . Given the link between PM and theory of mind in NT individuals (e.g., Ford, Driscoll, Shum, & Macaulay, 2012), this could explain time-based PM deficits in ASD. Indeed, the association found by Williams et al. (2013) between time-based PM and theory of mind supports this possibility. The idea is that theory of mind is relevant for mental self-projection, i.e., the ability to shift one's perspective from the immediate present to alternative perspectives (Buckner & Carroll,

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[2] Table 4 also outlines the cognitive correlates of event-based PM. However, given that a number of the studies included had methodological drawbacks, even where significant relationships with potential cognitive underpinnings were found, these need to be interpreted with caution.

2007), which overlaps with episodic future thinking processes. Hence, NT individuals might not only think more frequently about their delayed intentions but also, if they do, mentally simulate their execution, strengthening relevant context associations for later PM retrieval. Therefore, if individuals with ASD have difficulties with theory of mind and with generating future episodic representations as a result of diminished self-projection ability (see Lind, Williams, Bowler, & Peel, 2014, for relevant evidence), this would be expected to contribute to poor time-based PM performance (see Williams et al., 2013, for a discussion of this possibility).

One final possibility to consider is that time-based PM deficits in ASD may result from difficulties with time perception. There is mixed evidence with regards to time estimation abilities in ASD when comparing studies using different or even the same kind of tasks. These performance difference also seem to depend on the length of the intervals or durations used in different studies. Shah, Hall, Catmur, and Bird (2016) asked adult participants to estimate the length of three intervals (19, 37, and 49 seconds) and found no group difference in accuracy between ASD and NT control group. In another study with children and adolescents, Wallace and Happé (2008) explored time estimation, time production, as well as time reproduction abilities for durations ranging between two to 45 seconds. The group comparison revealed similar performance for time estimation and production and even a trend for superior time reproduction performance in the ASD group compared to the NT group. Importantly, Wallace and Happé (2008) found similar patterns of performance in both groups; i.e. a trend to overestimate duration decreased with longer durations in the time estimation tasks whereas participants more consistently underestimated time regardless of the length of the interval in the time (re-)production task. Furthermore, Gil, Chambres, Hyvert, Fanget, and Droit-Volet (2012) found no sign of impairments in a temporal bisection task which covered both short (0.5 and 1 second, 1.25 and 2.5 seconds) and long (3.12 and 6.25, 7.81 and 16.62 seconds) duration pairs. However, other studies using temporal bisection tasks (Allman, DeLeon, & Wearden, 2011) or time reproduction (J. S. Martin, Poirier, & Bowler, 2010; Szelag, Kowalska, Galkowski, & Pöppel, 2004) found poorer performance in ASD using short durations (between 1 to 8 seconds). These studies concluded that individuals with ASD had problems discriminating between "longer" durations and underestimate durations in the time reproduction tasks. Altogether, this suggests that individuals with ASD may experience difficulties with time estimation, especially when it comes to fine-grained discrimination of short durations, however, timing abilities in ASD seem to be intact for longer durations. With regards to time-based PM, this suggests that overall time-estimation should not greatly affect performance in ASD. However, given the above evidence, it may be that timeliness of time-based PM responses in the range of seconds may be worse in ASD.

Data from studies of time-based PM are also informative. In five out of the aforementioned six studies of time-based PM, participants had to monitor the elapsed time during the experiment (by pressing a keyboard key to bring up a clock), which depends on time perception. Two of these studies did not find any indication of between-group differences in time monitoring despite finding significant time-based PM impairments (Williams et al., 2013; 2014), whereas two reported significantly fewer clock-checks in ASD (Altgassen et al., 2009, 2012). However, in the studies by Altgassen et al. memory for task instructions was not assessed, meaning that between-group differences in time-monitoring might be attributable to a failure to recall that the time even needed to be checked. Overall, the existing evidence regarding time perception in ASD does not provide strong support for the hypothesis that impaired time monitoring is the major cause of time-based PM problems in ASD, although future research should consider this explicitly.

Taken together, it is clear that there are multiple potential causes of the evident time-based PM impairment in ASD. Although studies of the cognitive correlates of this impairment are potentially informative, Table 4 illustrates the “patchwork” nature of results, as well as the fact that almost no correlate has been studied systematically across studies. Future studies might consider focussing on the key candidate underlying causes of this PM impairment and conduct systematic investigations of those.

Is event-based PM really impaired in ASD? Although the conclusions drawn in parts 1 and 2 of this chapter were remarkably consistent in suggesting a large impairment of time-based PM in ASD, this consistency was not evident with regard to event-based PM. Although the meta-analysis presented in Part 1 provided evidence of a subtle (statistically small) impairment of event-based PM in ASD, the review presented in Part 2 questions the validity of the evidence from the meta-analysis. Eleven studies have investigated event-based PM among people with ASD. Five of the studies found an impairment in ASD, while six did not. There is no clear pattern with regard to age; half of the studies found an impairment in their adult/children samples while the other half did not. However, if one only considers the studies that fulfilled the aforementioned methodological guidelines necessary for studying PM in ASD, evidence points toward unimpaired event-based PM in ASD.

A careful consideration of the studies of event-based PM that were included in the meta-analysis suggest that the methodological rigour of several of the studies was not sufficiently high to draw strong conclusions from the meta-analytic data. That is, although the *results* from *across* all studies of event-based PM in ASD suggest a subtle impairment in ASD, the methods that produced those results may not be valid and/or reliable enough to allow a firm conclusion from the results to be drawn. There are also *a priori* reasons to hypothesise that event-based PM should be unimpaired (despite impaired time-based PM) in ASD. The profile of strengths and weaknesses in *retrospective* memory in ASD suggests that this ability is impaired only when tests of memory are uncued/unstructured (see Boucher et al., 2012). For example, in tests of free recall, which require *self-initiated* retrieval of information from long-term memory (paralleling the demands of *time*-based PM), adults and children with ASD tend to show diminished performance. In contrast, in tests of cued recall or recognition (where a cue/the context for retrieval is provided, paralleling the demands of *event*-based PM), adults and children with ASD tend to show *un*diminished performance. These findings have led to suggestions that only unstructured/unsupported cognitive/memory tasks will be impaired in ASD (the “task support hypothesis”; e.g., Bowler, Gardiner, & Berthollier, 2004). The analysis in Part 2 of this chapter is in line with this hypothesis.

Conclusion

PM impairments can seriously impact an individual’s everyday life and independent functioning. The above review of the existing literature indicates that time-based PM is challenging for individuals with ASD, which is consistent with self-reports (Williams et al., 2014). In contrast, the literature review indicates that evidence for an event-based PM impairment in ASD is mixed, at best. Methodological limitations with several of the existing studies of event-based PM prevent firm conclusions about the extent to which this ability is impaired in ASD. Thus, well-controlled studies need to investigate event-based PM systematically, taking into consideration the methodological guidelines outlined above. The empirical studies carried out in this thesis explore both time- and event-based PM in individuals with ASD and typically developing individuals, in an attempt to clarify the nature and mechanisms of PM abilities and how specific PM impairments could be addressed. As such, this thesis contributes to the existing literature by incorporating different theoretical approaches and employing novel methods to explore different aspects of PM in ASD.

Table 4. Overview of PM correlates

		clock checks	**DEX**	**General cognitive ability**	**Inhibition**	**Switching/ cognitive flexibility**	**Theory of mind**	**Verbal processing efficiency**	**Verbal fluency/ semantic switching**	**Working memory**	**ABAS**	**Autism severity**	**PRMQ PM-scale**
Time-based	ASD	r = .73^{*1} r = .80^{*5}		FSIQ r = .51^{*6}	Stroop r = .47^{*6}		Animations r = -.42^{*5}	r = .41^{7}	r = .30^{6}		r = .57^{*6}	Not studied	
	NT	r = .86^{*1} r = .47^{*5}				WCST r = .32^{†5}			r = .54^{*6}	Visual complex span r = .39^{7} Verbal storage span r = -.38^{7}	r = .45^{*6}		
	Both	r = .82^{*1}	r = -.38^{*4}			TMT r = -.38^{*4}				Digit ordering r = .33^{4}			
Event-based	ASD	N/A	r = -.48^{*2}	NVIQ r = .52^{*8}		DCCS r = .34^{8}	Not studied	r = .45^{*7}		Verbal complex span r = -.36^{7} Verbal storage span r = -.52^{*7} Block span r = .45^{*8}		CARS r = -.34^{†9} ADOS-SC r = -.37^{*3} ADOS-R r = -.21^{*3}	
	NT	N/A	r = -.31^{2}	NVIQ r = .34^{8}	Stroop r = .56^{*8}	TMT r = .32^{6}	Not studied		r = .43^{*6}	Visual complex span r = -.30^{7} Visual storage span r = -50^{*7}	r = .30^{6}		r = .43^{†7}
	Both		r = -.36^{*2}										

Notes. *: significant $p < 0.05$; †:marginal significant $p < 0.09$; marginal and non-significant correlations are only included in the table if at least of moderate size ($r \geq .30$); ^{1}: Altgassen et al. 2009; ^{2}: Altgassen et al. 2010; ^{3} Jones et al. 2011: FSIQ partialled out; ^{4} Altgassen et al. 2012; ^{5} Williams et al. 2013: ongoing task performance partialled out; ^{6} Henry et al. 2014; ^{7} Williams et al. 2014: ongoing task performance partialled out; ^{8} Yi et al. 2014; ^{9} Sheppard et al. 2016; No correlations were assessed in Altgassen et al. 2014, Brandimonte et al. 2011, and Kretschmer et al. 2014; ABAS: Adaptive Behavior Assessment Scale; DEX: Dysexecutive Questionnaire; PRMQ: Prospective Retrospective Memory Questionnaire; FSIQ: Full scale IQ; NVIQ: Non-verbal IQ; DCCS: Dimensional Change Card Sort task; TMT: Trail Making Task; WSCT: Wisconsin Card Sorting Task; CARS: Childhood Autism Rating Scale; ADOS-SC: Autism Diagnostic Observation Schedule social communication; ADOS-R: Autism Diagnostic Observation Schedule repetitive behaviour; N/A: not applicable

CHAPTER 2

EVENT-BASED PROSPECTIVE MEMORY IN CHILDREN WITH AUTISM: THE ROLE OF FOCAL AND NONFOCAL CUES IN TASK PERFORMANCE

Introduction

As outline in Chapter 1, researchers commonly distinguish two types of PM (Einstein & McDaniel, 1990; Kliegel, McDaniel, & Einstein, 2008; Kvavilashvili & Ellis, 1996): *time-based* PM, which requires the execution of the delayed intention at a specific time point (e.g., taking the tea bag out of the cup after three minutes), and *event-based* PM, which requires the execution of the delayed intention upon the occurrence of a particular event (e.g., turning off the oven when the timer goes off). In comparison to time-based PM, which requires more *self-initiated* monitoring, intention retrieval is *cued* in event-based PM (e.g., by the timer going off). For this reason, event-based PM is considered to involve fewer attentional/executive resources than time-based PM (Einstein, McDaniel, Richardson, Guynn, & Cunfer, 1995; Kvavilashvili & Fisher, 2007; Sellen, Louie, Harris, & Wilkins, 1997). In relation to this, studies on PM development in children have found a linear increase of both event-based PM and time-based PM across childhood, however event-based PM performance was found to be superior in comparison to time-based PM (Yang, Wang, Lin, Zheng, & Chan, 2013). Furthermore, research has clearly documented a decline in both event-based and time-based PM in older age, albeit less dramatically in the former (see the meta-analyses by Henry, MacLeod, Phillips, & Crawford, 2004 and Uttl, 2008). Typically, in laboratory event-based PM tasks, participants are engaged in an ongoing task, such as a lexical decision task (deciding whether a stimulus represents a word or not). Additionally, the PM component requires the participant to remember to carry out a specified action (e.g., a certain keypress) whenever the participant encounters a pre-specified target cue (e.g., a particular word).

According to the multiprocess framework (Einstein & McDaniel, 2005; McDaniel & Einstein, 2000), several factors influence PM retrieval processes and thus the likelihood of successful execution of one's intentions. One particularly important factor concerns "cue focality", which refers to the extent to which the PM target cue is related to the ongoing task (i.e., how easily the cue can get into the attentional focus while attending to the ongoing task). Focal PM cues have characteristics that are processed *as part of* the ongoing task, whereas nonfocal cues are not directly related to the ongoing task and hence appear outside of the immediate attentional focus. In the example of a lexical decision task, which requires semantic processing, a focal cue to carry out the PM action would be a specific word, (e.g., carry out the PM action upon encountering the word "monkey"); whereas a nonfocal cue might be a specific colour that the word is printed in (e.g., carry out the PM action upon encountering a word written in blue font; rather than any other colour). Because nonfocal cues are not processed automatically as part of ongoing task performance (i.e., one's judgement in the ongoing task is not specifically about the aspect of the task that cues the PM action), detection of them requires a higher level of attention-demanding monitoring processes than does detection of focal cues (Einstein & McDaniel, 2005; Scullin, McDaniel, Shelton, & Lee, 2010). Interestingly, not only do focal and nonfocal PM tasks differ in the degree to which they require executive resources, but they also appear to differ in the type of executive function required. Zuber, Kliegel, and Ihle (2016) found that focal PM task performance is more strongly related to inhibitory control than to shifting, whereas nonfocal PM task performance is more strongly associated with shifting than to inhibition.

Two meta-analyses have addressed the question of whether age-related declines in PM vary as a function of PM cue focality. Despite methodological and conceptual differences in the approach taken in each meta-analysis, both found larger effect sizes for age effects (i.e., decline in performance) on tasks involving nonfocal cues than tasks involving focal cues (Ihle, Hering, Mahy, Bisiacchi, & Kliegel, 2013; Kliegel, Jäger, & Phillips, 2008). This increased age-related decline in event-based PM tasks involving nonfocal cues is often explained by well-established age-related declines in the executive resources required detect PM cues (but see Uttl, 2011 for an alternative explanation). Specifically, research examining effects of ageing on inhibitory control and cognitive flexibility show a clear decline in both abilities (Adolfsdottir, Wollschlaeger, Wehling, & Lundervold, 2016; Dempster & Vegas, 1992; Salthouse, 2010), which in combination are likely to result in greater PM difficulties when nonfocal cues are involved (e.g., Schnitzspahn, Stahl, Zeintl, Kaller, & Kliegel, 2013).

These age-related declines in event-based PM in older age appear to be mirrored by age-related improvements in PM across childhood and adolescence as a result of concurrent executive function development (Mahy, Moses, & Kliegel, 2014). Only two studies have explicitly investigated focality effects on event-based PM in NT children and adolescents. L. J. Wang et al. (2011) tested a group of adolescents and a group of young adults and found a significant interaction between age and focality. This reflected non-significant between-group differences in detection of focal cues, but significantly better detection of nonfocal cues in younger adults than in adolescents. A similar interaction was found by Kliegel et al. (2013) who tested a group of 6- and 7-year olds in comparison to 9- and 10-year olds. Both these results support the idea that limited attentional and executive resources make it more difficult to a) monitor for nonfocal cues and/or to b) shift the attentional focus away from the ongoing task when a nonfocal PM cue is detected. These findings are not only relevant for our understanding of the typical development of PM, but also for helping to understand cases of PM impairment. In particular, the issue of cue focality and its influence on PM task performance may help to explain the pattern of PM strengths and difficulties observed in ASD.

On the cognitive level, research has identified a unique profile of *retrospective* memory strengths and weaknesses in ASD (Ben Shalom, 2003; Boucher & Bowler, 2008; Boucher et al., 2012; Lind, 2010). However, only a handful of studies have explored the future-oriented memory for delayed intentions in ASD. To date, research into time-based PM has unequivocally indicated deficits in ASD (see chapter 1 for a review). However, research into event-based PM has produced mixed results, with half of the studies observing no impairment (Altgassen & Koch, 2014; Altgassen, Schmitz-Hübsch, et al., 2010; Henry et al., 2014; Williams et al., 2013; Williams et al., 2014), but the other half reporting a significant deficit in ASD (Altgassen et al., 2012; Brandimonte et al., 2011; Kretschmer et al., 2014; Sheppard et al., 2016; Yi et al., 2014). As discussed in chapter 1, it may be that studies reporting event-based PM *impairments* in ASD suffer from methodological confounds, which render the results unreliable. On this view, time-based PM is, in fact, selectively impaired in ASD as a result of the high self-monitoring/executive demands inherent in time-based PM tasks (e.g., Williams et al., 2014). However, even though event-based PM has lower self-monitoring/executive demands than time-based PM *and* even if previous studies have suffered from methodological limitations, this does not preclude event-based PM deficits in ASD. Given the established cue focality effects on event-based PM task performance in NT individuals, it is clear that some event-based PM tasks rely more heavily on executive resources than others do. Therefore, it may be that individuals with ASD are especially susceptible to the contrast between cue types in event-based PM tasks and manifest impairments (relative to closely-matched NT participants) only when nonfocal cues are involved.

There are good theoretical reasons to suppose event-based PM tasks involving nonfocal cues might be difficult for people with ASD, relative to tasks involving focal cues. Parallels have been drawn between the memory profile characteristic of ASD and the pattern of memory decline in older age NT individuals (Bowler, Gaigg, & Lind, 2011; Craik & Anderson, 1999). Given that performance on nonfocal PM tasks declines more significantly than performance on focal PM tasks in older adults, one might expect to see the same in ASD. Moreover, it has been suggested recently that performance on focal PM tasks taps somewhat different executive resources than performance on nonfocal PM tasks. Zuber, Kliegel, and Ihle (2016) found that focal PM task performance is strongly related to inhibitory control, whereas nonfocal PM task performance is more strongly associated with set-/attention-shifting. This is important, because while many studies find undiminished inhibitory control in ASD, the majority report impaired set-shifting/cognitive flexibility (Hill, 2004; Kenworthy et al., 2008). This is reflected in meta-analytic findings on the executive profile in ASD (Lai et al., 2016), which report consistent moderate size impairments of cognitive flexibility but at most heterogenous and small inhibition problems. For these reasons, one might well expect difficulties with performance on nonfocal PM tasks relative to performance on focal PM tasks among individuals with ASD, if indeed any deficits in event-based PM in ASD exist.

Another interesting factor with regards to event-based PM in ASD is that so far studies have only used visual PM cues but not auditory ones. Previous research has shown that unusual sensory processing in ASD, especially in children, is highly prevalent (Suarez, 2012) and that similarly to higher-level cognitive abilities, individuals with ASD are characterised by a particular profile of perceptual strengths and weaknesses (Bakroon & Lakshminarayanan, 2016). In particular, difficulties to interpret differences and similarities of sensory input in ASD (Suarez, 2012) may be most relevant to PM performance in ASD; i.e. difficulties to discriminate stimuli within a certain domain (visual/auditory) could lead to PM failure as one would not be able to identify the appropriate cue to trigger PM retrieval. Individuals with ASD show enhanced perceptual abilities in visual search or visual discrimination tasks (Samson, Mottron, Soulières, & Zeffiro, 2012) but have difficulties to filter out task irrelevant sounds and focus on task relevant sounds (DePape, Hall, Tillmann, & Trainor, 2012). Furthermore, a recent review has found that regardless of sensory processing modality, the increasing complexity of stimuli is what leads to perceptual problems in ASD whereas relatively simple stimuli (just as those used in this study) lead to no between-group differences (Baum et al., 2015). Importantly, if auditory versus visual basic sensory processing differed in ASD this might affect processing of PM cues from different modalities. If individuals with ASD are better at processing stimuli from one domain those stimuli, this should influence their PM performance on the cue modality. Importantly, this would have practical implications when teaching children with ASD how to use memory cues in everyday life.

In the current study, an experiment was designed that aimed to whether cue focality differentially affects event-based PM in ASD in comparison to NT control participants taking into account the aspect of PM cue modality. An experiment was designed to investigate cue focality effects on event-based PM performance under two different conditions using the same ongoing task. In a *focal condition*, PM cues were an integral part of the processing demands of the ongoing task whereas in a *nonfocal condition*, PM cues were not in the attentional focus of performing the ongoing task. It was predicted that participants in both would show better performance in the focal compared to the nonfocal condition. However, it was expected that this effect would be more pronounced in individuals with ASD. Furthermore, in the nonfocal condition, the modality of the PM cue was manipulated to explore whether this would particularly impact PM performance in ASD. As the PM cues used in this study were of low complexity, we hypothesized that different cue modality would not affect children with ASD.

Methods

Power analysis

To address the issue of statistical power, G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007) was used to conduct a power analysis to determine the sample size that would have been necessary to detect between-group differences in event-based PM if they truly exist. To do this, it was necessary to estimate an effect for the hypothesised between-group difference in nonfocal PM task performance, which was not straightforward. There were several options which effect size to choose. If only considering event-based PM studies in ASD that found an impairment the mean weighted effect size would be 0.72[3]. However, it has been argued that several of the previous studies of event-based PM in ASD suffer from significant methodological confounds that render the reported study results unreliable. Therefore, basing an effect size estimate on these studies may be biased. An alternative might be to use the estimate on the average effect size associated with between-group differences in time-based PM. The rationale was that the executive demands of nonfocal event-based PM tasks are similar to those of time-based PM tasks (because both require a degree of executive inhibition and cognitive flexibility above and beyond that required to complete event-based focal PM tasks). Across the six existing studies of time-based PM in ASD, the weighted average effect size (see Chapter 1) for between-group differences in performance was 0.87.

Finally, considering the ageing analogy of memory between individuals with ASD and NT elderly, effect sizes reported by Henry et al. (2014) or Ihle et al. (2013) might also provide a good estimate of the to be expected effect size. Ihle et al. (2013) reported an effect size of 0.74 for age differences with nonfocal cues. The effect sizes reported by Henry et al. (2014) represented correlation coefficients between age and PM performance. Thus, for comparability, effect sizes were transformed, which resulted in a similar-sized effect of 0.72 for age effects in event-based PM (irrespective of cue focality) and 0.85 in time-based PM.

It was decided to conduct two power analyses using the lowest (0.72) and highest (0.87) effect size estimate reviewed above to compute a range of the required sample size. The analyses revealed that a sample of 18 to 25 participants was required to achieve the minimal recommended power of .80 (Cohen, 1992).

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[3] The mean weighted effect size for event-based PM group differences between ASD and NT was calculated following the formulae of Lipsey and Wilson (2001).

Participants

Twenty children with ASD (14 male) and 20 NT children (15 male), aged between eight to 14 years, took part in this experiment[4]. Participants in the ASD group had all received a formal diagnosis of autistic disorder (*n* = 13) or Asperger's disorder (*n* = 7), according to DSM-IV or ICD-10 criteria (American Psychiatric Association, 2000; World Health Organisation, 2006). No NT participant had a diagnosis of any developmental disorder, and no concerns were raised about any child's development by parents or teachers.

Table 5 gives an overview of the participant characteristics. Using the second edition of the Wechsler Abbreviated Scale of Intelligence (WASI-II, Wechsler, 2011), participant groups were equated for verbal IQ (VIQ), performance IQ (PIQ), and full-scale IQ (FSIQ). Groups were also equated for chronological age. All participants passed a short test of colour-blindness (Ishihara, 1951). The parents of all participants completed the Social Responsiveness Scale (SRS; Constantino and Gruber, 2005), which provided a measure of ASD/ASD-like characteristics. All participants with ASD scored above the ASD cut-off of 60 on the SRS, in keeping with their diagnosis. Eighteen of the 20 NT participants scored below 60 on the SRS. Two NT participants scored above 60 (with scores of 64 and 67, respectively). However, these two participants were attending mainstream schools and had no history of any developmental disorder. Therefore, it is unlikely that these participants had an undiagnosed ASD. However, to ensure that including these participants in the overall sample did not affect the results of the study, all experimental analyses in this chapter were re-run after excluding them. Key

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[4] Fifty participants were originally recruited to take part in this study (ASD: *n* = 30, NT: *n* = 20). However, data from 10 participants with ASD had to be excluded either because their IQ was below the cut-off of 70 (*n* = 3), because of not passing the colour-blindness test (*n* = 1), they could not remember either of the cues in the focal condition (*n* = 2), they could not recall one of the two cues in the nonfocal condition (*n* = 3), or to improve the matching with the NT group (*n* = 1).

experimental results are reported after removing these participants[5]. The results were almost identical with and without these NT participants included. The study was approved by the local ethics committee of the School of Psychology at the University of Kent and written informed consent was obtained from the participants' parents prior to the study.

Table 5. Sample characteristics

	Group means (SD)				
	ASD (*n* = 20)	**NT (*n* = 20)**	***t***	***p***	**Cohen's *d***
Age	11.65 (1.78)	11.50 (1.61)	0.28	.78	0.09
VIQ	102.20 (10.29)	102.95 (12.76)	0.21	.84	0.06
PIQ	100.35 (17.58)	108.80 (12.34)	1.76	.09	0.57
FSIQ	101.20 (14.05)	106.60 (12.22)	1.30	.20	0.41
SRS T-score	87.25 (4.81)	46.10 (8.98)	18.07	< .001	5.71

Note. ASD = autism spectrum disorder; NT = neurotypical; VIQ = verbal intelligence quotient; PIQ = performance intelligence quotient; FSIQ = Full-scale intelligence quotient; SRS = Social Responsiveness Scale

Procedure

Tasks were presented using Psychtoolbox (version 3.0.11; Brainard, 1997; Kleiner et al., 2007; Pelli, 1997) running in Matlab 2014 (The MathWorks, Inc.).

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[5] As noted on p. 52, two NT participants scored above cut-off on the SRS. When the ANOVA concerning *ongoing task performance*, reported on p. 61, was re-run with these two participants excluded, the results were almost identical. There a significant main effect of Condition, $F(1, 36) = 13.94$, $p = .001$, $\eta_p^2 = .28$ (note: in the original analysis p < 0.001, $\eta_p^2 = .29$), but no significant main effect of Group or Group × Condition interaction, all $ps \geq .40$, all $\eta_p^2 \leq .02$, note: in the original analysis all $ps \geq .71$, all $\eta_p^2 \leq .004$). Hence, the ASD and NT groups remained matched for ongoing task performance. When the ANOVA concerning *PM performance*, reported on pp. 61-63, was re-run with these two participants excluded, the results were almost identical. There was a significant main effect of Condition $F(1,36) = 9.41$, $p = .004$, $\eta_p^2 = .21$ (note: in the original analysis $p = .01$, $\eta_p^2 = .16$).The main effect of Group as well as the Group × Condition interaction remained non-significant (all $ps \geq .40$, all $\eta_p^2 \leq .02$; note: in the original analysis all $ps \geq .56$, all $\eta_p^2 \leq .01$).

PM task. The ongoing task involved making judgements about visually-presented shapes and consisted of 80 trials. Following a 2-second fixation period at the beginning of each trial, several different-coloured geometric shapes (between three and eight) were displayed on the screen in random positions. On each trial, no shape appeared twice or had the same colour (e.g., a red square, a blue triangle, an orange pentagon). Participants had to respond using the number keys (three to eight) on the keyboard, indicating the number of shapes displayed on each trial. A new trial started once a response was registered or after a 10-second time window had elapsed. This ongoing task was completed by all participants in two conditions (*focal* vs. *nonfocal* PM cues) in counterbalanced order. For an illustration of the experimental task in the two conditions see Figure 5. Participants did not complete a longer single block of only the ongoing task, which is a common strategy to explore the costs of remembering a delayed intention on top of the ongoing task using reaction time analyses (Burgess et al., 2001; R. E. Smith, 2003). This type of analysis was not the focus of the present study as previous studies of PM (time-based PM: Altgassen et al. 2009, event-based PM using nonfocal cues: Altgassen et al. 2010) did not find any indication of intention costs for both accuracy and reaction time measures. Based on these findings, we did not predict differential intention costs between groups or conditions.

Each PM condition contained two possible PM cues. Previous event-based PM studies using several PM cues partly found PM impairment in ASD (e.g., Brandimonte et al., 2011; Kretschmer et al.,2014) but did not control for retrospective memory failure. In this study it was ensure to check for retrospective memory failures after each condition.

In the focal condition, two visual PM cues were used, as they had to be part of the processing of the ongoing task which required visual processing. In contrast, in the nonfocal condition, a visual and an auditory PM cue were used. It was not possible to match conditions for cue modality due to the definition of cue focality. Cue focality indicates whether a cue is processed as part of the ongoing task (focal) or whether it is unrelated to the ongoing task (nonfocal). Hence, to implement two different modalities for focal cues, the ongoing task would have needed to involve a switch between two different tasks, sometimes focusing on visual and sometimes focusing on auditory stimuli. However, in the nonfocal condition, an ongoing task involving a switch would have meant that the auditory cue would not be nonfocal anymore. Furthermore, an ongoing task involving task-switching could have negatively impacted the ASD group due to problems when switching task across modalities (Reed & McCarthy, 2012). This might have negatively affected matching groups on ongoing task performance, which would have influenced the interpretation of group differences in PM if they had been found. Therefore, the PM cues were implanted as follows.

In a *nonfocal* condition, participants were required to judge the number of shapes on each trial of the ongoing task, as described above. On each trial, the background colour of the screen changed (possible colours: blue, green, orange, purple, or yellow). Also, while participants were completing the task, three different background tones (275Hz, 750Hz, 1012.5Hz) were played continuously in random order over the computer speakers. Tones were presented at a rate of one every two seconds and each lasted 600ms. In this condition, the *PM instruction* was to press a specific keyboard key (rather than judging numbers of shapes) every time either a) the background colour of the screen was yellow (PM background colour cue; $\text{PM}_{\text{background}}$), or b) the 750Hz tone sounded in the background (PM sound cue; PM_{sound}). In other words, participants had to interrupt their ongoing task performance and complete the PM instruction every time one of these PM cues occurred. There were 80 trials in this condition, of which eight contained a PM cue (four trials had a yellow background; four trials were accompanied by the 750Hz tone).

In a *focal condition*, participants were required to judge the number of shapes on each trial of the ongoing task. The background colour of the screen was grey on each trial. To control for background noise, background tones were presented in this condition (370Hz, 495Hz, 637.5Hz) at the same rate as in the nonfocal condition, but participants were instructed to ignore the tones. In this condition, the *PM task* was to press a specific keyboard key (rather than judging numbers of shapes) every time either a) exactly six shapes appeared on screen (PM amount cue; $\mathrm{PM}_{\mathrm{amount}}$), *or* b) a diamond shape appeared on screen (PM shape cue; $\mathrm{PM}_{\mathrm{shape}}$). In other words, participants had to interrupt their ongoing task performance and complete the PM instruction every time one of these PM cues occurred. There were 80 trials in this condition, of which eight contained a PM cue (four trials contained six shapes; four trials contained a diamond).

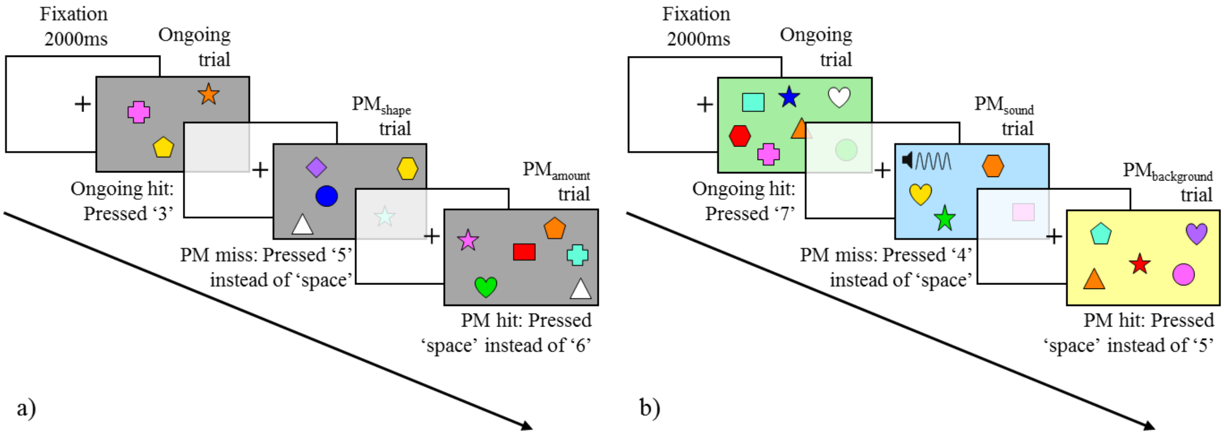

Figure 5. Depiction of possible trials and outcomes a) during the focal PM condition and b) during the nonfocal PM condition.

Prior to the start of each condition, participants were instructed verbally about the ongoing task, followed by five practice trials to familiarise them with the ongoing task and the sounds in the background, before they were given the PM instructions. Moreover, it was ensured that the participants could discriminate between the three beep sounds used in the nonfocal condition using a short discrimination task. Participants were instructed to listen carefully to each sound, which sounded three times, so that they could get a general understanding of the sounds. Subsequently, the sounds were played in random order (nine trials) and participants had to indicate which of the three sounds they heard. Participants had to correctly identify each sound in at least seven out of the nine trials to pass the discrimination task. If participants had identified fewer sounds correctly (which was the case for two participants from each group), they completed another set of practice trials. All participants in the second set of practice trial had at most one error and completed the nonfocal PM condition afterwards. After the completion of each condition, participants' memory for the PM instruction was verified; participants were asked to tell the experimenter what they had to remember to do while doing the ongoing task. In order to pass participants had to name *both* cues and the pre-specified keyboard key. If participants were unable to remember the instructions spontaneously, they were prompted by the experimenter who stated that a certain keyboard key should have been pressed on specific occasions during the task. Participants were then asked to recall what the key was and on what occasions it should have been pressed. No participant failed to recall the PM instructions after prompting and there were no group differences in rates of spontaneous remembering of the instruction in either focal ($\chi^2(1) = 0.36$ $p = .55$, $\varphi = .10$), or nonfocal ($\chi^2(1) = 0.23$ $p = .63$, $\varphi = .08$), conditions (see Table 6).

Table 6. Number of participants in each group passing the PM instruction memory check spontaneously vs. needing a general prompt in order to pass

	Focal condition		**Nonfocal condition**	
	ASD	NT	ASD	NT
Spontaneously remembered	18	19	18	17
Remembered after prompted	2	1	2	3

Scoring and statistical analysis

The reported performance on the PM task components represent the proportion of times that participants correctly carried out the PM action. A score of one was awarded for correctly pressing the pre-specified key on each respective PM trial (*PM hit*), and the total number of hits was divided by the total number of PM trials for each cue type respectively (*PM proportion hit*). For all different cue types, each cue type appeared four times in their respective condition.

However, for the $\text{PM}_{\text{amount}}$ cue noticing of the cue was dependent on participants counting the number of shapes correctly. If participants accidentally counted wrongly on trials that showed six shapes, the PM amount cue (six shapes on the screen) would not be "delivered" to the participant because they responded wrongly to the ongoing task. Given this, the $\text{PM}_{\text{amount}}$ proportion score does not include PM failures that were due to ongoing task failure; a PM failure (score of zero) was *only* given if participants responded correctly to the ongoing trials but failed to carry out the PM task (i.e., they recognised there were exactly six shapes, but nonetheless forgot to carry out the PM action). For example, if six shapes were on the screen but participants counted five instead, then no PM failure was given and the total number of PM trials in their proportion score was adjusted respectively (if this happened once then the proportion score would be calculated as the number of hits divided by three). PM performance was collapsed across cue types for each condition. In each condition, ongoing task performance was calculated as the proportion of correct responses on the ongoing trials and correct responses on a maximum of eight PM failure trials (*ongoing task proportion hits*). If there was a PM failure but participants responded correctly to the ongoing task they receive a score of one; for example, if there were two PM failures but each time a correct response to the ongoing task, ongoing task accuracy would be calculated as the proportion of correct responses out of 74 trials (72 pure ongoing plus two PM failure trials).To assess associations between ASD symptoms as measured with the SRS, non-parametric Spearman-Rho correlation analyses were performed due to non-normal distribution of the SRS total score (Kolmogorov-Smirnov test; ASD: $D(20) = .37, p \leq .001$, NT: $D(20) = .20, p \leq .03$).

Throughout this thesis, an alpha level of .05 was used to determine statistical significance. All reported significance values were two-tailed, unless otherwise indicated. Greenhouse-Geisser corrections were used where the assumption of sphericity was violated. Where ANOVAs were used, partial eta squared (η_p^2) is reported as a measure of effect size ($\geq$

.01 = small effect, ≥ .06 = moderate effect, ≥. 14 = large effect; Cohen, 1988). Where *t*-tests were used, Cohen's *d* is reported as a measure of effect size (≥.0.20 = small effect, ≥ 0.50 = moderate effect; ≥ 0.80 = large effect; Cohen, 1988). Where categorical (Chi-square) analyses were conducted, phi (φ) is reported as a measure of effect size (≥ .10 = small effect, ≥.30 = moderate effect, ≥.50 = large effect; Cohen, 1988). Where correlation analyses were conducted, Spearman rho (r) is reported as a measure of effect size (r ≤ .10 = small effect, r ≤ .30 = moderate effect, r ≤ .50 = large effect; Cohen, 1988)

Bayes factor analysis

An increasingly used alternative to power calculations is to calculate a Bayes factor associated with the critical result of interest. According to standard statistical conventions, if a *p*-value for a specific analysis is > .05 then it can be concluded that the result is null and does not support the alternative hypothesis. However, treating *p*-values in this way assumes they are categorical and absolute, rather than "a convenient reference point along the possibility-probability continuum'' (Cohen, 1990, p. 1311). Bayes factors overcome this issue by estimating the relative strength of a finding for one theory over another theory, allowing a more graded interpretation of the data (e.g., Rouder et al., 2009). Thus, they are especially useful for interpreting null results, because they provide an estimate of the degree to which findings are supportive of the null hypothesis (H_0) *over* the alternative hypothesis (H_1) (Dienes, 2014). According to Lee and Wagenmakers (2013) adjusted criteria of Jeffreys' (1961) original criteria for interpreting Bayes factors, values larger than 10 provide strong evidence for H_1, values between three and 10 provide moderate evidence for H_1, and values between one and three provide anecdotal evidence for H_1. A Bayes factor of one does not provide any evidence in favour of either the H_1, or H_0. Values between one-third and one provide anecdotal, between one-tenth and one-third moderate, and smaller than one-tenth strong evidence for H_0. Thus, Bayes factors between one-third and three provide inconsistent evidence for the respective hypothesis.

Therefore, additionally to the traditional null hypothesis significance testing approach, Bayes factors are reported for the respective analyses throughout this thesis. Bayesian analyses were computed using the software JASP using the recommended default objective prior for the respective analysis (JASP Team, 2017; Wagenmakers, Love, et al., 2017; Wagenmakers, Marsman, et al., 2017). Where ANOVAs where employed, Bayesian t-tests were used to explore significant interaction effects. However, at present, Bayesian post-hoc tests are yet to be developed to correct multiple comparisons. For this study, the data were submitted to Bayesian repeated measures mixed ANOVAs to obtain the BF_{10}, the Bayes factor in support of the alternative hypothesis over the null hypothesis. Bayes factors for ANOVAs with more than one factor are conceptualised as Bayes factors for the different possible models (null model, model of main effect one, model of main effect two, additive model of both main effects, and the full model including both main effects and the interaction effect). Bayes factors for the interaction effect are not computed in JASP by default but can easily be obtained. It can be computed by dividing the Bayes factor of the full model by the Bayes factor of the additive model. Importantly for the interpretation of the data one has to consider that the Bayes factor for the interaction effect represents whether the evidence is stronger in favour of the full model in comparison to a model only containing both main effects. If one wished to obtain the Bayes factor favouring the additive model over the full model one would reverse the above calculation by dividing the Bayes factor of the additive model by the Bayes factor of the full model

Results

Ongoing task performance

The mean proportion of ongoing trials in which the number of shapes was correctly identified for each condition is shown in Table 7. These data were analysed using a mixed ANOVA with group (ASD/NT) as between-subjects factor and condition (Focal/nonfocal) as the within-subjects factor. Results revealed a main effect of focality, $F(1,38) = 15.55$, $p < .001$, $\eta_p^2 = .29$, $BF_{10} = 80.13$, which reflected superior ongoing task performance in the focal condition compared to the nonfocal condition across groups. The Bayes factor provides strong evidence for this hypothesis. Crucially, however, neither the main effect of group, $F(1,38) = 0.10$, $p = .75$, $\eta_p^2 < .01$, $BF_{10} = 0.33$ nor the interaction between Group and Condition, $F(1,38) = 0.15$, $p = .71$, $\eta_p^2 <.01$, $BF_{10} = 0.31$, were significant. The BF_{10} for the additive model was 29.16 and for the full model 8.98, thus the model that outperformed all other models was the one containing the main effect of focality. Hence, the two diagnostic groups did not differ from each other in terms of either level of overall ongoing task performance, or patterns of ongoing task performance across conditions. Thus, any between-group differences in PM performance in each condition cannot be attributed to between-group differences in the execution of the ongoing task. The Bayes factor analysis supports this conclusion

PM task performance

Table 7 shows the mean proportion of trials on which PM instructions were correctly carried out (proportion of PM hits) for each condition. For the purpose of data analyses, cue types were collapsed. However, for completeness, PM performance is reported in Table 7 for each cue type separately[6], as well as collapsed.

Table 7. Event-based PM task performance (collapsed across cues and for each cue type), as well as ongoing performance by condition (Means and SDs)

		Group means (SD)		
		ASD	**NT**	**Cohens' *d***
Focal condition	Proportion of PM hits (collapsed across cues)	.70 (0.26)	.70 (0.24)	0
	Proportion of PM hits (PM_{amount})	.80 (0.29)	.82 (0.22)	-0.08
	Proportion of PM hits (PM_{shape})	.60 (0.37)	.59 (0.38)	0.03
	Ongoing task hits proportion score	.96 (0.08)	.96 (0.05)	0
Nonfocal condition	Proportion of PM hits (collapsed across cues)	.53 (0.25)	.59 (0.29)	-0.22
	Proportion of PM hits (PM_{sound})	.56 (0.41)	.64 (0.38)	-0.21
	Proportion of PM hits ($PM_{background}$)	.49 (0.34)	.54 (0.39)	-0.14
	Ongoing task hits proportion score	.90 (0.07)	.91 (0.12)	-0.10

A 2 (Group: ASD/NT) × 2 (Condition: Focal/Nonfocal) mixed ANOVA was used to analyse the PM performance. It revealed a significant main effect of condition, reflecting superior PM performance in the focal condition than the nonfocal condition across groups, *F*(1,

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[6] A 2 (Group: ASD/NT) × 4 (Cue type: PM_{shape}, PM_{amount}, PM_{sound}, $PM_{background}$) was performed to confirm that different cues did not differentially affect PM performance between groups. It revealed a significant main effect of cue type $F(3,114) = 5.73$ $p = .001$, $\eta_p^2 = .13$, $BF_{10} = 50.34$. Post-hoc pairwise multiple comparisons (Bonferroni corrected) revealed significant PM performance differences between the following cue types: $PM_{amount} > PM_{shape}$, ($p = .01$), $PM_{amount} > PM_{sound}$ ($p = .05$), $PM_{amount} > PM_{background}$ ($p < .001$). This indicates that the PM_{amount} cue resulted in the highest PM performance compared to all other cues and that performance did not differ between the other cue types. No main effect of group $F(1,38) = 0.26$, $p = .61$, $\eta_p^2 < .01$, $BF_{10} = 0.24$, or Group x Cue type interaction $F(3,11) = 0.13$, $p = .94$, $\eta_p^2 = .003$, $BF_{10} = 0.08$ was found. The BF_{10} for the additive model was 12.96 and for the full model 0.98, thus the model that outperformed all other models was the one containing the main effect of cue type. Hence, the ASD and NT groups performed equally well on the PM task overall and were equally affected by cue type.

38) = 7.45, p = .01, η_p^2 = .16, BF$_{10}$ = 7.34. However, there was no significant main effect of group, F(1, 38) = 0.24, p = .63, η_p^2 < .01, BF$_{10}$ = 0.31. Likewise, there was no Group × Condition interaction, F(1, 38) = 0.35, p = .56, η_p^2 .= .01, BF$_{10}$ = 0.37. The BF$_{10}$ for the additive model was 2.40 and for the full model 0.89, thus the model that outperformed all other models was the one containing the main effect of focality. Thus, the ASD and NT groups performed equally well on the PM task overall and were similarly affected by cue focality. The Bayes factor analysis supports this conclusion

Categorical analysis

In addition to analysing mean levels of performance, categorical variables were also created and analysed[7]. Occasionally, group-level means obscure underlying differences at the individual level. For example, differences between ASD and NT groups in mean levels of task performance can be driven by a few poorly-performing individuals in the case group (Williams, Peng, & Wallace, 2016). Equally, when no between-group differences are observed in mean levels of performance – as in the current study – it does not rule out the possibility that some

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[7] The categorical analysis was also performed using White et al.'s (2006) criterion of classifying any individual as outlier if their performance was below 1.65SDs of the control group mean (which represents the bottom 5% of the sample). Using this cut-off, White et al. (2006) previously were able identify cases of domain-specific impairments in dyslexic participants. This analysis identified 4 NT and 2 ASD participants in the focal condition, $\chi^2(1)$ = 0.78, p = .38, φ = .14, BF$_{10}$ = 0.60, and 4 NT and 3 ASD in the nonfocal condition, $\chi^2(1)$ = 0.17, p = .68, φ = .07, BF$_{10}$ = 0.42, who fell in this category. Furthermore, a cut-off of performance below 2SDs of the control group mean (which represents the bottom 2.28% of the sample) was explored as this could have revealed a very small but nonetheless clinically relevant number of ASD participants with a specific PM impairment. This analysis identified not one NT and only 1 ASD participant in the focal condition, $\chi^2(1)$ = 1.03, p = .31, φ = .16, BF$_{10}$ = 1.00, and only 1 NT and not one ASD in the nonfocal condition, $\chi^2(1)$ = 1.03, p = .31, φ = .16, BF$_{10}$ = 1.00, who fell in this category. Thus, even when applying a stricter criterion, the same results were obtained.

individuals in the case group manifest an impairment (White et al., 2006). To investigate this possibility, the number of individuals in each group who scored below the mean PM performance of the NT group was explored (i.e., the number of individuals who scored correctly at or below 70% for the focal and at or below 59% for the nonfocal condition, see Table 8). No between-group differences were observed in either the focal condition, $\chi^2(1) = 0.40$, $p = .53$, $\varphi = .10$, $BF_{10} = 0.26$, or the nonfocal condition, $\chi^2(1) = 0.92$, $p = .38$, $\varphi = .15$, $BF_{10} = 0.34$. The same was true when analysing the data after a median-split instead of splitting in the sample based on the NT mean (see Table 8); focal condition, $\chi^2(1) = 0.10$, $p = .75$, $\varphi = .05$, $BF_{10} = 0.21$ or the nonfocal condition, $\chi^2(1) = 0.92$, $p = .38$, $\varphi = .15$, $BF_{10} = 0.34$.

Table 8. Categorical analysis: number of participants scoring above or below mean (left) and median (right) PM task performance of the NT group for each condition

		Group (split using NT mean)			**Group (split using NT median)**	
		ASD	**NT**		**ASD**	**NT**
Focal condition	Above NT mean	10	12	Above NT median	10	11
	Below NT mean	10	8	Below NT median	10	9
Nonfocal condition	Above NT mean	7	10	Above NT median	7	10
	Below NT mean	13	10	Below NT median	13	10

Correlations with ASD symptoms

Non-parametric Spearman-Rho correlation analyses revealed no significant correlations between the SRS total score and behavioural performance (ongoing task and PM) when analysing the data collapsed across both groups (all *r*s ≤ -.28, all *p*s ≥ .08). When analysing groups separately, there were no significant correlations in the ASD group (all *r*s ≤ -.34, all *p*s ≥ .14) and for the NT group (all *r*s ≤ -.30, all *p*s ≥ .19), apart from one marginally significant correlation between overall PM accuracy in the nonfocal condition and the SRS total score (r = -.45, p = .05). This indicates that NT children scoring higher on the SRS (although still below the clinical cut-off), performed less well in the nonfocal PM condition.

Discussion

Previous studies of event-based PM in ASD have produced mixed findings, with some studies reporting event-based PM impairments in ASD, but others reporting that this ability is undiminished in ASD (see Chapter 1). Until now, no study has explored the effect of cue focality on event-based PM in ASD. Given that PM tasks involving nonfocal cues (that are not processed directly as part of ongoing task completion) require greater executive control than do PM tasks that involve focal cues (that are processed directly as part of ongoing task completion), it was speculated that individuals with ASD might show diminished performance in a task that involved nonfocal cues, but not in a comparable task that involved focal cues. In that case, it might have partially explained discrepant results regarding event-based PM abilities in the literature to date. On the contrary, however, participants with ASD in the current study showed no hint of impairment on either focal or nonfocal PM tasks, relative to age-, sex- and IQ-matched comparison participants. Both groups of participants performed significantly better (i.e., remembered to carry out the PM action) when cues were focal than when they were nonfocal, and there were no group differences in the extent to which cue focality influenced performance. Importantly, the Bayesian analyses strongly favoured the alternative hypothesis that focal task performance was superior to nonfocal task performance, but supported the null hypothesis that there were no between-groups differences in levels of patterns of performance on the PM task. Furthermore, categorical analyses indicated that the number of participants performing below the mean level of performance of the control group was similar between groups. Thus, it did not identify cases of individuals with ASD who performed abnormally low relative to control participants in either condition. This indicates that the analysis of PM performance at group level did not mask a specific impairment with nonfocal PM cues in individual cases with ASD. These results suggest that school-aged children and young adolescents with ASD with intellectual abilities in the typical range do not manifest an event-based PM deficit even when task demands (and executive load) are relatively high. Therefore, these current results provide further support for the view that event-based PM task performance is undiminished in ASD. This finding is particularly striking because the tasks used in the current study were demanding in a number of ways. Both tasks involved complex PM instructions that required participants to carry out a PM action upon the occurrence of either one of two cues. Remembering to carry out an intended action in such circumstances is not straightforward. Hence, the fact that participants with ASD showed almost identical levels of PM performance overall suggests that their PM abilities are as good as those of NT individuals even when task demands are high. Moreover, the executive load of carrying out the PM action in the nonfocal task was especially high and resulted in a decrease in PM performance relative to PM performance in the focal task. The fact that the ASD group was equally affected by cue focality as NT comparison participants suggests that the underlying system responsible for PM works similarly in each population.

If these findings are reliable it still leaves unanswered a question about why some previous studies have reported event-based PM deficits in ASD. One possible explanation are methodological limitations of previous research as outlined by Williams et al. (2014). For example, of the five studies that report an event-based PM impairment in ASD, two did not equate groups for ongoing task performance (Altgassen et al., 2012; Brandimonte et al., 2011); three did not rule out forgetting of the PM instruction as reason for poor PM performance in the ASD group (Altgassen et al., 2012; Brandimonte et al., 2011; Yi et al., 2014); and three studies did not equate groups for baseline characteristics (Brandimonte et al., 2011; Sheppard et al., 2016; Yi et al., 2014)). In the current study, participant groups were equated for baseline characteristics, showed no differences in ongoing task performance, and recalled PM task instructions equivalently. This suggests that under controlled conditions, among appropriately-matched groups, event-based PM is unimpaired in ASD.

An important previous finding is Williams et al. (2014)'s suggestions, that children in the ASD group may use inner rehearsal strategies to maintain the PM instruction constantly in mind while performing the ongoing task. That is, although on a behavioural level no impairment may be apparent, the underlying PM mechanisms in ASD may be supported by compensatory strategies, and hence the actual PM competence would be limited. It is impossible to know whether this could have been the case for this study. However, the ongoing task used in this study inherently involved verbal/subvocal processes (counting). Research has shown that counting taps into verbal working memory capacity and can be disrupted by secondary verbal task (Healy & Nairne, 1985; Logie, Gilhooly, & Wynn, 1994). Thus, this may have prevented the use of verbal rehearsal strategies to support PM at least to some extent. Nevertheless, future studies should address this hypothesis more directly, which will be the focus of Chapter 3.

With regard to the ageing hypothesis of memory in ASD (Bowler et al., 2011; Craik & Anderson, 1999), the current results failed to provide support for the assumption that not only retrospective but also prospective memory in ASD compares to memory in healthy ageing. Individuals with ASD showed similar performance in both conditions whereas typically healthy older adults usually perform worse on nonfocal tasks under laboratory conditions (Ihle et al., 2013). The age-paradox of prospective memory (Rendell & Craik, 2000; Schnitzspahn, Ihle, Henry, Rendell, & Kliegel, 2011) might provide an explanation for this discrepant finding. The age-paradox reflects the phenomenon that in comparison to younger adults, older adults show age deficits when PM tasks have to be carried out under laboratory conditions but show an age advantage when PM tasks have to be carried out in the context of everyday life demands. It has been suggested that older adults struggle with the rigid dual-task character of laboratory PM tasks, which are particularly challenging attentional control resources (Schnitzspahn et al., 2011). In contrast, individuals with ASD might benefit from the structured laboratory environment and circumscribed PM cues, in line with the task support hypothesis that cued memory retrieval is undiminished in ASD (Bowler, Gardiner, & Grice, 2000).

Finally, with regard to research on PM development, the study results are in line with the predictions of the multiprocess framework (Einstein & McDaniel, 2005; McDaniel & Einstein, 2000) and other studies demonstrating an advantage of focal in comparison to nonfocal cues (Cona, Bisiacchi, & Moscovitch, 2014; Scullin et al., 2010; L. J. Wang et al., 2011). Importantly, the sensory domain of the PM cue did not differentially influence PM in either group. The PM_{amount} cue turned out to be the easiest cue to respond to (resulting in the highest PM performance of all four cue types) since it was directly dependent on the correct response to the ongoing task and thus in maximal attentional focus. However, performance did not differ for any of the other three PM cues, irrespective of being visual or auditory. This indicates that the auditory PM cue was not significantly more difficult for the ASD group to process compared to the NT group as no Group × Cue type interaction emerged. Thus, cue modality did not negatively affect PM performance in the ASD group. As this study used relatively simple cues, this is line with the conclusions of Baum et al. (2015) who predicted sensory processing problems in ASD with more complex stimuli. Therefore, even if there were higher order auditory/visual sensory processing differences in ASD, these did not play a role in this study.

In sum, this study provides further evidence for undiminished event-based PM in ASD independent of cue focality. Importantly it was found that children with ASD are able to detect both focal and nonfocal cues to the same extent as NT comparison children while being engaged in a demanding ongoing activity. These findings imply that use of cues by individuals with ASD should be a particularly effective approach to supporting PM in everyday life.

CHAPTER 3

THE ROLES OF VERBAL AND VISUOSPATIAL PROCESSING IN EVENT-BASED PROSPECTIVE MEMORY: POSSIBLE COMPENSATORY STRATEGIES BY CHILDREN WITH AUTISM

Introduction

The previous chapter explored whether specific characteristics of the PM cue, namely its focality in relation to the ongoing task, affect PM retrieval in ASD. The following chapter will report a study exploring event-based PM in children with ASD under different processing demands during the intention maintenance phase.

Event-based PM involves remembering to carry out a delayed intention at the appropriate point in the future, upon the occurrence of a certain trigger or cue (e.g., taking the food out of the oven when the timer goes off; the timer being the event or cue to complete the prospective action; Einstein & McDaniel, 1990; McDaniel & Einstein, 2007). Importantly, PM is a process divided into different phases: *intention formation or encoding, retention interval, intention retrieval and execution,* and *outcome evaluation* (Ellis, 1996). During intention formation, the intention or plan is formed and its content (when to do what) encoded into memory. This information needs to be stored over a delay period until the appropriate retrieval context occurs (i.e., the timer going off in the example above). At this point, a person has to retrieve the content of their intention and execute it accordingly. Based on the outcome, an intention is either flagged as completed, or failed and requiring a reattempt. As such, PM failure can occur due to: a) failure to remember the retrieval context, thus the characteristics of the appropriate moment to carry out the delayed intention, which is equivalent to forgetting of the PM cue; b) failure to remember the intended action one was supposed to carry out in the future; or c) failure to remember that one had a delayed intention in the first place. According to the multiprocess framework (Einstein & McDaniel, 2005; McDaniel & Einstein, 2000), event-based PM failure depends on a variety of factors (e.g., PM cue and task characteristics), which can affect processing during the different PM phases. Specifically, this framework suggests that, in relatively simple event-based PM tasks, intention retrieval can be facilitated to a great extent through automatic, non-attention-demanding processes. However, as task complexity increases, so does the need for attention-demanding strategic monitoring of the environment for the appropriate cue/event to signal that one's prospective action should be carried out. Thus, studies aiming to identify causes for event-based PM failure have focused on these factors and the associated memory and executive control functions (Mahy et al., 2014; M. Martin et al., 2003).

In laboratory studies of event-based PM, manipulation of ongoing task demands affects the ease with which one can inhibit attending to the ongoing task and switch flexibly to carry out the target PM action at the appropriate time. The nature of ongoing task demands dependent on the task's difficulty level or load on memory and/or executive resources (Meier & Zimmermann, 2015) and thus determines the extent to which it is perceived as absorbing and engaging. As a result, these demands play a substantial role in how much attentional capacity a participant has to devote to the task of detecting the event that signals the PM action should be carried out. While the multiprocess framework assumes that thinking about a delayed intention is exhibited as external monitoring for PM cues (Einstein & McDaniel, 2005), the intention monitoring hypothesis additionally suggests that individuals periodically will think about what they have to do in the future; i.e., refresh their intention in their mind, to support PM (Mahy & Moses, 2015).

Hence, considering these ongoing task aspects and their influence leading up to PM retrieval is critical for our understanding of PM processes/failures. Of particular interest, working memory capacity is crucially involved in the intention maintenance phase during the execution of the ongoing task, serving as a bridge between intention encoding and the delay until the intention retrieval (Mahy et al., 2014). The availability of working memory resources determines whether incoming information can be processed or is dismissed due to capacity limitations (Hiebel & Zimmer, 2015). In the context of a PM task, the working memory demands of the ongoing task influence attentional processes supporting readiness to respond to a PM cue (R. E. Smith & Bayen, 2005). Thus, it is unsurprising that increases in working memory capacity from toddlerhood to childhood are linked to the ability to maintain an intention over a delay (Mahy & Moses, 2011), or that positive relationships have been found between working memory capacity and PM among NT adults (R. E. Smith, 2003; Y. Wang, Cao, Cui, Shum, & Chan, 2013). Importantly, different levels of load on working memory components differentially affect concurrent event-based PM processing. In experiments with NT adults, it has been found that high demands on executive processing and visuospatial storage negatively affect event-based PM, whereas verbal working memory demands have little influence (Marsh & Hicks, 1998). This suggests that in NT adults, intention retention (which is required for successful intention retrieval, of course) is not primarily verbally mediated (but see Mahy, Mohun, Müller, & Moses, 2016).

A possible explanation for the link between visuospatial capacity and PM might be the relevance of visuospatial processing for episodic future thinking (Atance & O'Neill, 2001). Episodic future thinking, also known as “prospection”, is the ability to project one-self into the future and plan, imagine and pre-experience future events. Clearly, this form of future-oriented cognition is relevant during the encoding of a delayed intention in a PM task, and it has been suggested that an individual might mentally simulate the execution of a PM task as a mental encounter with the specified retrieval context (G. A. Brewer & Marsh, 2010). This form of mental simulation must be related to one’s ability to generate and manipulate mental images. Visual mental imagery encompasses the mental simulation and transformation of perceptual information from memory (Kosslyn, Ganis, & Thompson, 2001), which is facilitated by visuospatial working memory (Keogh & Pearson, 2011; Tong, 2013). This imagination process is thought to be beneficial for strengthening the association between the retrieval context and the intended PM action, and thus reduces demands on intention maintenance in favour of more spontaneous automatic-associative intention retrieval and execution (G. A. Brewer et al., 2011; Terrett et al., 2016). For example, when forming the intention to pick up a parcel after work, one might imagine the route to take and the particular junction where one needs to turn right to go to the post office (including the change of lane, indicating right, etc.) instead of going straight home. Later, when driving up to this junction, the previous mental simulation of the environment might facilitate the retrieval and execution of the PM action. Exploration of these processes is potentially important to extend our understanding of event-based PM in ASD.

It is clear from results in Chapters 1 and 2 that controversy remains about whether, or the extent to which, event-based PM is impaired in ASD. It is possible that event-based PM is genuinely unimpaired in this disorder; studies may report diminished event-based PM in ASD only because of methodological limitations that confound the study results. However, an alternative possibility is that individuals with ASD might use compensatory strategies to perform well on event-based PM tasks, but in the absence of typical underlying competence (see e.g., Williams et al., 2014). Specifically, their evidence implied that despite apparently intact performance the underlying competence of event-based PM in ASD may differ from typical development. This would mean that they might accomplish similar event-based PM task performance to NT individuals, despite engaging different underlying cognitive processes to succeed. In this context, it is interesting that Williams et al. (2014) found alternative cognitive correlates of successful event-based PM in participants with and without ASD. Specifically, they found that verbal working memory span was associated with event-based

PM success in ASD (*r* = .52), whereas visuospatial working memory span was associated with event-based PM success in NT controls (*r* = .50). This finding suggests that event-based PM in ASD may be verbally mediated; i.e., they might use inner speech or rehearsal to maintain the type of cue they would need to react to (in this case words representing musical instruments). In contrast, NT participants might have used mental simulation to imagine encountering the PM cue. In this study, the PM cue was categorical, so participants might have imagined different objects of this particular category (common musical instruments), which may have helped later PM retrieval.

Somewhat related to this is the study of Altgassen, Schmitz-Hübsch, et al. (2010) who studied event-based PM in the context of an ongoing task requiring visuospatial working memory. No group differences were found by Altgassen and colleagues for either PM accuracy or ongoing task performance. Their finding might indirectly imply that the visuospatial working memory demands of the ongoing task did not affect event-based PM performance in ASD, which would be in line with Williams et al. (2014). No other research has explicitly addressed working memory components/processes in investigations of event-based PM in ASD.

There is mixed evidence whether individuals with ASD engage in inner speech or verbal processes to support different aspects of cognition in a similar fashion as NT individuals (Williams, Peng, et al., 2016). In their review, Williams, Peng, et al. (2016) summarise that evidence indicates that individuals with ASD either use inner speech in a typical fashion to support certain aspects of cognition or do not use inner speech but without an obvious cost for the respective task. In contrast, episodic future thinking which is thought to play a supportive role in event-based PM has consistently been found impaired in ASD (Hanson & Atance, 2014; Lind, Williams, Raber, Peel, & Bowler, 2013; Terrett et al., 2013).

Therefore, the current study aimed to explore whether event-based PM is facilitated by the use of compensatory strategies in ASD. An experiment was designed to tested event-based PM under two conditions of ongoing task demands. In one condition, the ongoing task placed strong demands on verbal working memory/processing for success, whereas in the other condition the ongoing task tapped visuospatial working memory/processing. The logic of the design was as follows. If NT participants rely predominantly on visuospatial processing/mental simulation to succeed on PM tasks, then an ongoing task that specifically requires mental imagery should impair their performance by placing higher demands on visuospatial processing resources. In contrast, if participants with ASD employ verbal rehearsal strategies to facilitate event-based PM then an ongoing task that inherently requires verbal processing resources should prevent inner speech use to facilitate event-based PM. Thus, it was predicted that the ASD group would perform significantly worse on the event-based PM task in the verbal ongoing task condition in comparison to the NT group, and vice versa that the NT group would show decreased event-based PM performance relative to the ASD group in the visuospatial task condition (Group × Task interaction).

Methods

Power analysis

The issue of statistical power was addressed in a similar way as in chapter 2. An a priori power analysis using G*Power 3 (Faul et al., 2007) was conducted to determine the sample size that would have been required to detect between group difference in event-based PM on the verbal task if they truly existed. Deriving an effect size for this analysis was not straightforward. If event-based PM was indeed supported by verbally-mediated strategies in ASD, impeding such strategy use should result in a similar size impairment of time-based PM in ASD, which does not lend itself to strategy use. Thus, for the purpose of this power analysis, the mean weighted effect size for between-group differences in time-based PM (*d* = 0.87, see Chapter 1) was used resulting in a required sample size of 18 participants per group.

Participants

Participants were 20 children with ASD (15 male) and 20 typically developing children (16 male) aged between eight to 14 years old[8]. Thirty-four (17 ASD and 17 NT) of these participants took part in the study described in Chapter 2. All participants with ASD had a formal diagnosis of autistic disorder (*n = 13)* or Asperger's disorder (*n* = 7) in accordance with established criteria (DSM-IV, American Psychiatric Association, 2000; ICD-10, World Health Organisation, 2006). No NT participant had a diagnosis of any developmental disorder, and no concerns were raised about any child's development by parents or teachers.

Sample characteristics are shown in Table 9. Experimental groups were equated closely for chronological age, as well as for verbal and nonverbal ability using the Wechsler Abbreviated Scale of Intelligence second edition (WASI-II; Wechsler, 2011). For all participants, parents completed the Social Responsiveness Scale (Constantino & Gruber, 2005) to assess autistic/ASD-like characteristics. All participants with ASD scored above the ASD cut-off of 60 on the SRS, in line with their diagnosis. Three TD participants scored above 60 (with scores of 62, 64, and 67, respectively). However, these participants attended mainstream schools and had no history of any developmental disorder. Therefore, it is unlikely that these participants had an undiagnosed ASD. Nevertheless, to ensure that the inclusion of these

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[8] Fifty-nine participants were originally recruited to take part in this study (ASD: *n* = 30, NT: *n* = 29). However, data from 10 participants with ASD due to their IQ being below the cut-off of 70 (*n* = 3), not being able to remember the PM instruction in the visuospatial condition (*n* = 5), or to improve the matching with the NT group (*n* = 2), as well as data from nine NT children due to not being able to remember the PM instruction in the verbal (*n* = 1) or visuospatial condition (*n* = 4), or to improve matching with the ASD group (*n* = 4) was excluded from the final data analysis.

participants did not affect the results of the study, all experimental analyses presented were rerun after excluding them. Key experimental results after removing these participants are reported[9]. The results were almost identical with and without these NT participants included. The study was approved by the local ethics committee of the School of Psychology at the University of Kent and written informed consent was obtained from the participants' parents prior to the study.

Table 9. Sample characteristics

	Group means (SD)				
	ASD (n = 20)	**NT (n = 20)**	t	p	**Cohen's d**
Age	11.64 (1.82)	11.23 (1.69)	0.74	.47	-0.23
VIQ	101.90 (10.38)	101.75 (10.76)	0.05	.96	-0.01
PIQ	99.75 (17.28)	106.00 (8.62)	-1.45	0.16	0.46
FSIQ	100.85 (13.74)	104.50 (9.55)	-0.98	0.34	0.31
SRS total T-score	86.30 (5.98)	47.30 (9.37)	15.70	< .001	-4.97

Note: VIQ = verbal intelligence quotient; PIQ = performance intelligence quotient; FSIQ = Full-scale intelligence quotient; SRS = Social Responsiveness Scale

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[9] As noted on p. 75, three NT participants scored above cut-off on the SRS. Groups remained equated for baseline characteristics after excluding their data from the analyses (all ts ≤ 0.65, all ps ≥ .10, all ds ≤ 0.55). When the ANOVA concerning ongoing task performance, reported on pp. 80-81, was re-run with these three participants excluded, the results were almost identical. There was a significant main effect of task, $F(1, 35) = 91.32$, $p \leq .001$, $\eta_p^2 = .72$ (note: in the original analysis, $p \leq .001$, $\eta_p^2 = .73$), but no significant main effect of group or Group × Task interaction, all ps ≥ .40, all $\eta_p^2 \leq .02$, note: in the original analysis all ps ≥ .35, all $\eta_p^2 \leq .03$). Hence, the ASD and NT groups remained matched for ongoing task performance. When the ANOVA concerning PM performance, reported on p. 81, was re-run with these three participants excluded, the results were almost identical. There was no significant main effect of group or task, as well as no Group × Task interaction (all Fs ≤ 1.21, all ps ≥ .28, $\eta_p^2 \leq .03$).

Procedure

Tasks were presented using Psychtoolbox (version 3.0.11; Brainard, 1997; Kleiner et al., 2007; Pelli, 1997) running in Matlab 2014 (The MathWorks, Inc.). Participants completed two different PM tasks in counterbalanced order. One task required verbal working memory resources whereas the other tapped into visuospatial working memory (see Figure 6 for an illustration). Each task contained 48 trials in total, 44 ongoing trials and four PM trials. As a rule of thumb, PM cues usually appear in five to 10% of the total number of trials in a standard PM experiment (West, 2008). Four PM trials out of 48 total trials resulted in 8.3% of the trials being PM trials in this study. This method was adopted to prevent that the experimental becomes a vigilance task where participants maintain the intention through active rehearsal.

The ongoing tasks were specifically chosen to tap into specific resources from the respective working memory domain (verbal versus visual) which was under investigation in this study, even though this resulted in different task durations.

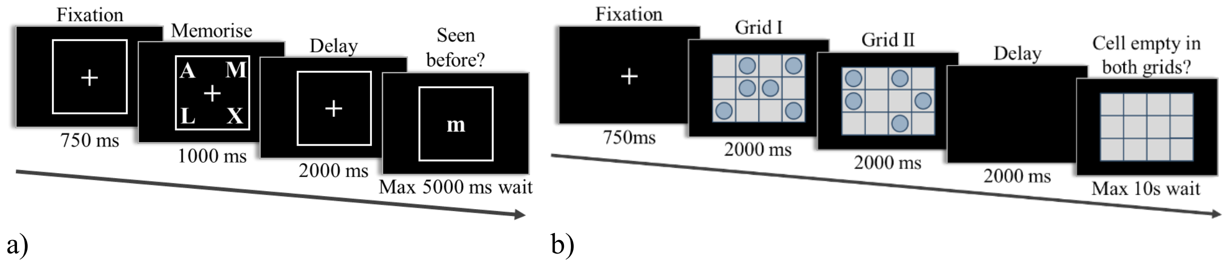

Figure 6. Illustration of the structure of an ongoing trial for a) the verbal working memory task, and b) the visuospatial working memory task

Verbal working memory condition. The ongoing task consisted of a letter memorisation task (see Figure 6a). This task was similar to the one used in Experiment 1 in a study by Awh et al. (1996) but event durations were adjusted after piloting durations to adjust task difficulty for the child sample in this study. The task was chosen as Awh et al. (1996) had shown that task performance significantly decreased when participants had to perform concurrent articulatory suppression. Thus, successful performance in this task strongly relied verbal rehearsal. During a study phase, participants were presented with four different letters, which they had to retain over a brief delay. Subsequently, during a recognition phase, participants had to respond to one single letter that appeared in the middle of the screen. Their task was to indicate whether this letter was one of four letters previously presented (yes/no decision) by pressing the respective keyboard key. There was an equal number of match (letter was one of the old four letters that had to be memorised) and mismatch (letter was new) trials. The PM task required the participants to press a pre-specified key whenever encountering the letter ‘n’. This letter only appeared during the recognition phase, however this was not known to the participants. Participants completed 10 practice trials of the ongoing task before being instructed about the PM task. There was a total of 44 experimental ongoing trials and four PM trials.

Visuospatial working memory condition. The ongoing task was a mental synthesis task (for an illustration of the trial structure see Figure 6b); adapted from Brockmole, Wang, & Irwin, 2002). This task was chosen as it had been identified as a task that tapped into visual imagery and memory involving the generation, maintenance, and transformation/manipulation of a mental image (Pearson, Deeprose, Wallace-Hadrill, Burnett Heyes, & Holmes, 2013), processes which are thought to be relevant for episodic future thinking. Participants saw two grids of three by four cells in brief succession for two seconds respectively (the original task used four by four grids however this number was reduced to decrease the task difficulty for the child sample in this study). Stimuli durations were chosen based on Brockmole et al.’s (2002) results that memory capacity for the first grid was highest when there was virtually no delay between its offset and the onset of the second grid, and for the second grid memory capacity was highest with a duration of 2000ms. In each grid, some cells contained a dot while other cells remained empty. The circles were placed in such a way that if there was a dot in a specific position in the first grid, this cell position would be empty in the second grid. According to this rule, five dots were randomly placed in either the first or second grid and six into the other one. To solve the task, participants had to memorise the dots' positions to identify the cell that would be empty in each grid when mentally overlaying/combining both grids. To respond, participants had to select/click a cell in an empty grid using the left mouse key that they thought was the empty one. The PM task required participants to respond with the right mouse key instead of the left one if a specific cell in the grid was empty (which was the second cell from the bottom left). As such, noticing the PM cue was dependent on the correct response to an ongoing trial; i.e., the PM cue was 'delivered' only if a person correctly identified the pre-specified cell as the solution to the ongoing task. Hence, a wrong response during an actual ongoing trial could deliver a PM cue. Before instructing the PM task, participants completed 10 practice trials of the ongoing task. There were 44 ongoing trials and four PM trials in total.

Scoring and data analysis

Verbal working memory condition. Ongoing task performance was collapsed across match and mismatch trials. On each trial, participants received a score of one for a correct response (*ongoing hit*). Ongoing performance scores represent the proportion of ongoing hits across all trials relative to the total number of ongoing trials (*ongoing task proportion hits*). For each correctly carried out PM action, a score of one was awarded (*PM hit*). PM performance scores represent the proportion of PM hits relative to the total number of PM trials (*PM proportion hits*).

Visuospatial working memory condition. Ongoing performance scores represent the proportion of ongoing hits (i.e., a score of one was awarded if the correct empty cell was identified and the left mouse key was used to select it) relative to the total number of ongoing trials (*ongoing task proportion hits*). PM performance was operationalised as the proportion of correct PM responses out of all total delivered PM cues irrespective whether those cues occurred during ongoing or actual PM trials; i.e., the total number of PM hits relative to the total number of trials that delivered a PM cue (*PM proportion hit*)[10].

An alpha level of .05 was used to determine statistical significance. Greenhouse-Geisser corrections were used where the assumption of sphericity was violated. Where ANOVAs were used, partial eta squared (η_p^2) is reported as a measure of effect size (≥ .01 = small effect, ≥ .06 = moderate effect, ≥. 14 = large effect; Cohen, 1988). Where *t*-tests were used, Cohen's *d* is reported as a measure of effect size (≥.0.20 = small effect, ≥ 0.50 = moderate effect; ≥ 0.80 = large effect; Cohen, 1988). Where categorical (Chi-square) analyses were conducted, phi (φ) is reported as a measure of effect size (≥ .10 = small effect, ≥.30 = moderate effect, ≥.50 = large effect, Cohen 1988).

Bayes factors (BF_{10}) in support of the alternative (H_1) over the null hypothesis (H_0) were computed for all relevant effects by submitting the data to the respective Bayesian analyses. Bayes factors were interpreted according to Lee and Wagenmakers (2013) classification (see Chapter 2).

Results

Ongoing task performance

Table 10 shows mean ongoing performance for each group and task. Between-group differences in ongoing task performance were explored using a Group (ASD/NT) × Task (verbal/visuospatial) mixed ANOVA. No significant main effect of group emerged, *F*(1,38) =

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[10] In the visuospatial task, the number of times, a PM cue appeared was dependent on the ongoing task. Independent sample t-tests were used to confirm that groups did not differ on the number of PM cues delivered during PM (ASD: *M* = 2.55, *SD* = 1.15, NT: *M* = 2.35 *SD* = 1.27) and ongoing (ASD: *M* = 2.20, *SD* = 1.77, NT: *M* = 2.55, *SD* = 1.79) trials (all *t*s ≤ 0.53, all *p*s ≥ .54). Thus, the combined PM proportion hit score for the visuospatial task is comparable between both groups.

0.20, p = .65, η_p^2 = .01, BF_{10} = 0.32. However, there was a significant main effect of task, F(1,38) = 104.12, $p \leq .001$, η_p^2 = .73, BF_{10} = 9.25*10^{10}. Finally, the Group × Task interaction was not significant, F(1,38) = 0.01, p = .93, $\eta_p^2 \leq .001$, BF_{10} = 0.31. The BF_{10} for the additive model was 2.9*10^{10} and for the full model 8.92*10^9. Therefore, the model with the highest Bayes factor was the on containing the main effect of task. Thus, crucially, there were no differences between the groups in terms of either levels of ongoing task performance. The visuospatial task appeared to be more demanding than the verbal task in both groups.

PM performance

Table 10 shows mean PM performance for each group and task. PM proportion hit scores were analysed using a 2 × 2 mixed ANOVA with group (ASD/NT) as between-subject factor and task (verbal/visuospatial) as within-subject factor. For PM proportion hits, there were no significant main effects of group, F(1,38) = 0.09, p = .78, η_p^2 = .002, BF_{10} = 0.28, and task F(1,38) = 1.01, p = .32, η_p^2 = .03, BF_{10} = 0.43. The Group × Task interaction was also not significant, F(1,38) = 0.85, p = 0.36, η_p^2 = .02, BF_{10} = 0.50. The BF_{10} for the additive model was 0.10 and for the full model 0.05. This indicates that the pattern of results (no main or interaction effects) is 20 times (1 divided by 0.05) more likely under the null hypothesis. Thus, there were clearly no differences between groups in terms of levels or patterns of accuracy across PM tasks.

Table 10. Means (SDs) of proportion hit scores and mean hit RTs for ongoing and PM performance by task condition

		Group means (SD)		
		ASD	**NT**	**Cohens' *d***
Verbal working memory condition	PM proportion hits	.85 (0.25)	.81 (0.28)	-0.15
	Ongoing task proportion hits	.79 (0.10)	.82 (0.15)	0.24
Visuospatial working memory condition	PM proportion hits	.74 (0.29)	.81 (0.19)	0.29
	Ongoing task proportion hits	.47 (0.22)	.50 (0.28)	0.12

Categorical analysis

In keeping with the approach taken in Chapter 2, categorical variables were created and analysed in addition to analysing mean levels of performance. This was to investigate whether some individuals with ASD might be employing compensatory strategies and thus should be particularly impaired in the verbal working memory condition. Thus, the number of individuals in each group who scored below the mean PM performance of the NT group was explored (i.e., the number of individuals who scored correctly at or below 81% for the verbal working memory condition and at or below 81% for the visuospatial working memory condition, see Table 11)[11]. No between-group differences were observed in either the verbal condition, $\chi^2(1) = 0.42$, $p = .52$, $\varphi = .10$, $BF_{10} =$,28 or the visuospatial working memory condition, $\chi^2(1) = 0.40$, $p = .53$, $\varphi = .10$, $BF_{10} = 0.26$. Results were identical when analysing the data after a median-split instead of splitting in the sample based on the NT mean.

Table 11. Categorical analysis: number of participants scoring above or below mean (left) and median (right) PM task performance of the NT group for each condition

		Group (split using NT mean)			**Group (split using NT median)**	
		ASD	**NT**		**ASD**	**NT**
Verbal	Above NT mean	13	11	Above NT median	13	11
condition	Below NT mean	7	9	Below NT median	7	9
Visuospatial	Above NT mean	8	10	Above NT median	8	10
condition	Below NT mean	12	10	Below NT median	12	10

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[11] The categorical analysis was also performed using White et al.'s (2006) criterion of classifying any individual as outlier if their performance was below 1.65SDs of the control group mean. This analysis identified 2 NT and 2 ASD participants in the verbal working memory, $\chi^2(1) = 0$, $p = 1$, $\varphi = 0$, $BF_{10} = 0.51$, and 2 NT and 3 ASD in the visuospatial working memory condition, $\chi^2(1) = 0.23$, $p = .63$, $\varphi = .08$, $BF_{10} = 0.51$, who fell in this category. Thus, even when applying a stricter criterion, the same results were obtained.

Discussion

The debate on event-based PM abilities in ASD has led to the suggestion that individuals with ASD may use compensatory strategies to attain similar levels of performance on event-based PM tasks as NT individuals. This study sought to investigate this hypothesis by manipulating demands on processing resources that individuals with ASD might use to maintain delayed intentions while performing an ongoing task. Specifically, it was explored whether verbal or visuospatial ongoing processing demands might play differential roles in event-based PM in ASD in comparison to NT development. The results of this study align with findings of unimpaired event-based PM in ASD and provide initial evidence that this is not achieved through verbally mediated strategy use in ASD.

Verbally mediated event-based PM in ASD?

Contrary to what was predicted, demands of the verbal ongoing task did not have detrimental effects on event-based PM in the ASD group compared to an ongoing task with visuospatial processing demands. In fact, the results revealed that the ASD group was not impaired on either of the event-based PM tasks in comparison to the NT control group. Importantly, the Bayes factor analyses supported this null finding. Additionally, the categorical analysis did not identify a subgroup of individuals with ASD who were particularly impaired in the verbal working memory condition This adds to the existing evidence that found intact event-based PM in ASD (Altgassen & Koch, 2014; Altgassen, Schmitz-Hübsch, et al., 2010; Henry et al., 2014; Williams et al., 2013; Williams et al., 2014) and challenges the hypothesis that event-based PM may be verbally mediated as suggested by Williams et al.'s (2014).

The absence of verbal strategy use in ASD when completing event-based intentions, aligns with research indicating that event-based PM in NTs is not verbally mediated (Marsh & Hicks, 1998). This suggests, that inner speech use in ASD is not atypical in PM tasks, which also fits with Williams, Peng, et al.'s (2016) conclusion that individuals with ASD manifest typical use of inner speech, at least in some domains. However, it contradicts research suggesting that verbal processing in ASD is associated to a significantly greater degree than in typical development with performance on tasks in other cognitive domains. In particular, it has been put forward that individuals with ASD "hack out" solutions to mind reading tasks using verbal abilities despite having diminished underlying conceptual competence in that domain, supported by evidence that verbal abilities contribute to theory of mind/mindreading task performance significantly more in individuals with than without ASD (Durrleman & Franck, 2015; Kimhi, 2014; Williams & Happé, 2009). It seems that this strategic approach does not apply to event-based PM abilities in ASD.

However, next some potential explanations why this study might have failed to find evidence to support verbal strategy use in ASD are considered. Based on finding a correlation between event-based PM and verbal working memory span in the ASD, and visuospatial working memory span in the NT group, Williams et al. (2014) proposed that individuals with ASD might use compensatory verbal strategies to support event-based PM. An alternative explanation, however, would be that participants in each group used different strategies and/or processing resources to perform the ongoing task in their study, which affected their PM performance. Participants had to memorise a series of sequentially presented words (study phase) before making a recognition judgement about a list of words (test phase: are the memorised words identical to the words in the list). The PM task required a response upon noticing words that were musical instruments. In case of the ASD group, verbal working memory may have facilitated event-based PM because it enabled participants in this group to remember more word stimuli, which would have been crucial to detect the PM cue. NT participants on the other hand may have used a pattern matching strategy to perform the ongoing task, meaning that irregularities in the visual pattern may have led to the detection of

PM cue. Although, Williams et al. (2014) reported partial correlations for the association between event-based PM and working memory controlling for ongoing task accuracy, they did not report the zero-order correlations between measures of working memory, event-based PM, and ongoing task performance. Therefore, it is not clear whether associations between working memory and ongoing task accuracy could offer a different explanation of results in the light of lack of support for the compensatory strategy hypothesis in ASD.

Furthermore, methodological differences between this and Williams and colleagues' study need to be considered. Williams et al. (2014) used nonfocal PM cues compared to focal ones in this study. The use of nonfocal cues usually requires a greater degree of monitoring for the PM cue in the environment than a focal cue (Scullin et al., 2010). This usually results in better PM performance with focal in comparison to nonfocal cues, especially when the complexity of the to be remembered intention is relatively low (as it was the case in this study; Ballhausen, Schnitzspahn, Horn, & Kliegel, 2017) . Thus, it may be that this study did not find an indication for strategy use due to a performance advantage with focal cues.

Finally, the sample in this study were children aged between eight and 14 years old whereas Williams et al. (2014) tested adults aged 17 to 58 years covering a wide age range. It may be a possibility that adults with ASD have acquired verbal strategies to solve a variety of cognitive tasks that enable an independent everyday life, however, this use of strategy may not yet be present in children with ASD. If this was a viable hypothesis, one would expect to find a pattern of consistently impaired event-based PM in children but not adults with ASD. Previous evidence however, does not reveal such a pattern of age-related event-based PM impairment in ASD (see Chapter 1 for a review). Thus, this strengthens the idea that event-based PM in ASD is indeed unimpaired and unaided by verbal strategies regardless of age group.

One limitation of this study was that the ongoing tasks were not equivalent in difficulty. Based on the ongoing task performance (proportion hit rates), the verbal task was easier in comparison to the visuospatial task. Thus, it is unclear whether the division of attentional resources between ongoing and PM task was comparable between tasks. This might have biased the results. Therefore, a more systematic manipulation of ongoing task load (low vs high verbal and visuospatial working memory demands) would be necessary to ensure that the level of processing demands does not play a role in ASD using ongoing tasks that are comparable in difficulty. Nonetheless, this study does not provide strong evidence to uphold the idea of verbal strategy use in ASD to support event-based PM.

Role of visuospatial processes/episodic future thinking for event-based PM in NT

The intention monitoring hypothesis (Mahy & Moses, 2015) suggests that participants might intermittently think about their intentions at various points before the appropriate moment for retrieval has arrived. Thus, according to the assumption that NT participants might use mental imagery to support event-based PM by accessing or refreshing the mental image of the delayed intention, it was predicted that the visuospatial processing demands of the ongoing task might disrupt this process. However, the NT group performed equally well on the visuospatial task in comparison to the verbal task. This indicates that episodic future thinking did not play a major role to facilitate event-based PM in this study.

Previous studies have found positive links among children and adults between episodic future thinking and event-based PM involving both focal (Altgassen et al., 2015; Nigro, Brandimonte, Cicogna, & Cosenza, 2014) and nonfocal (Atance & Jackson, 2009; G. A. Brewer & Marsh, 2010; Neroni, Gamboz, & Brandimonte, 2014; Terrett et al., 2016) cues. Thus, mental simulation of the future retrieval context at the intention encoding stage should occur automatically and independently of the type of PM cue. Therefore, the use of focal PM cues in this study should not have had an impact on the results. However, the visuospatial ongoing task demands may not have tapped enough into resources relevant for episodic future thinking. de Vito, Buonocore, Bonnefon, and Della Sala (2015) have outlined that episodic future thinking is facilitated through a mix of visual and spatial imagery. The visuospatial ongoing task in this study involved the mental transformation of visual images and required spatial imagery to some extent (i.e., memorising the spatial relations/spatial layout of the dot/grid stimuli). As, episodic future thinking seems to rely much more on spatial rather than visual imagery (de Vito et al., 2015), it may be that the load imposed on spatial imagery was not large enough to negatively affect event-based PM in this study. Therefore, future studies into the link between PM and episodic future thinking should explore whether only a specific component of imagery, visual or spatial, is involved in facilitating PM. Furthermore, to increase the certainty in these results, it may be interesting, to explore whether a manipulation that interferes with episodic future thinking during intention encoding leads to similar results.

One caveat is necessary with regards to statistical power. For the power calculation, the size of impairment in time-based PM was used since one would expect a similar size impairment in the ASD group if the ongoing verbal task interfered with PM in ASD. However, this effect size may not be applicable to the NT group. It may have been more appropriate to use the effect size found by Marsh and Hicks (1998) who reported visuospatial interference effects on event-based PM. Using this effect size ($d = 0.69$) 27 participants per group would have been required to detect this effect. Thus, this study's sample size may have been too small to reliably detect group differences in the PM task.

Conclusion

In the current study, participant groups were equated for baseline characteristics, showed no differences in ongoing task performance, and recalled PM task instructions equivalently. In sum results from both Chapter 2 and 3 suggest that under controlled conditions, among appropriately-matched groups, event-based PM is unimpaired in children with ASD. In the following Chapter 4, time-based PM will be explored in adults with ASD rather than with children with ASD. It has been shown that there is both continuity and change in the developmental trajectories of children with ASD (McGovern & Sigman, 2005). This is especially important for abilities that are thought to underpin time-based PM, e.g. executive functions. It is thought that developmental trajectories of executive functions differ in neurotypical in comparison to autistic individuals (Demetriou et al., 2017). In neurotypical children, a study has found that age-related variance in time-based PM performance was due to variability in underlying cognitive resources such as planning and switching, (Mackinlay, Kliegel, & Mäntylä, 2009), abilities which have been shown to be impaired in ASD (Lai et al., 2016). Thus, time-based PM was investigated in adults with ASD to exclude varying developmental trajectories/individual differences of/in abilities that underpin time-based PM.

CHAPTER 4

THE ROLE OF EXTRINSIC MOTIVATION ON TIME-BASED PROSPECTIVE MEMORY IN ADULTS WITH AUTISM: RELATIONS TO EXECUTIVE FUNCTIONING AND MINDREADING

Introduction

The previous two chapters explored event-based PM in ASD and both added to the evidence that the ability to fulfil event-based delayed intentions is undiminished in ASD. Therefore, this chapter will turn to the investigation of what might underpin time-based PM impairments in ASD.

When PM requires to be carried out at a particular future time point, it is referred to as time-based PM (Kliegel, McDaniel, et al., 2008; Kvavilashvili & Ellis, 1996). Time-based PM encompasses both remembering to carry out an action after a certain time delay (e.g., taking medication 30 minutes after eating), or at a specific time point (e.g., taking medication at 7pm). As such, time-based PM facilitates successful completion of tasks on a daily basis, although PM failures are not uncommon in the general population (Terry, 1988) and can have adverse consequences (Woods et al., 2015).

Mechanisms of time-based PM

Carrying out a time-based delayed intention is a process consisting of different stages (intention encoding, maintenance, retrieval, and execution; Ellis 1996), and involves both executive control processes and time perception (M. Martin et al., 2003; Mioni & Stablum, 2014). In a laboratory setting, participants have to divide their attention between an ongoing task (e.g., rating words on different dimensions) and the time-based PM task, which usually requires participants to carry out the intended action at the appropriate point (e.g., to press a specific keyboard key after every 2 minutes). To keep track of the elapsed time, a timer or clock is available on demand (e.g., by pressing another pre-specified keyboard key). Thus, clock-checking plays a crucial role for successful PM. Specifically, a J-shaped function of time checks has been found to reflect strategic time monitoring processes (Mäntylä & Carelli, 2006). This means that at the beginning of any interval preceding a time-based PM task, an individual will only occasionally pay attention to how much time has elapsed since forming the intention. The frequency of time checks will steadily increase and reach its peak prior to the respective target time. Thus, in comparison to cued PM retrieval in event-based PM task, time-based PM involves a series of self-initiated processes to enable PM retrieval (Einstein et al., 1995). An interplay of several cognitive processes supports this process. Updating of information in working memory supports the intermittent maintenance of the content of a time-based intention while engaging in the ongoing task and tracking the passage of time (Mioni & Stablum, 2014; Voigt et al., 2014). Inhibitory control, as well as cognitive flexibility are required to interrupt attending to the ongoing task (Kerns, 2000) and subsequently to either initiate a check of how much time has elapsed (Mioni & Stablum, 2014; Mioni, Stablum, McClintock, & Cantagallo, 2012; Vanneste, Baudouin, Bouazzaoui, & Taconnat, 2016) or to execute the PM task (Kliegel et al., 2002; Kliegel, Ramuschkat, & Martin, 2003; Mackinlay et al., 2009). Finally, mindreading/mentalizing ability (the ability to represent one's own and others' mental states; Frith, 2005) has also been implicated in time-based PM (e.g., Williams et al., 2013). First, carrying out a delayed intention involves recognising and responding to one's own mental state (i.e., one's intention) in the first place, which of course requires mindreading (Williams et al., 2013). There may be a second way in which mindreading might contribute to successful time-based PM, however, and this relates to understanding the demands of *others* when they give time-based PM instructions. This possibility is considered in the context of the following discussion of PM encoding.

Aspects of PM encoding

Kvavilashvili and Ellis (1996) discussed different types of intentions and how this might affect PM performance. Of particular interest is the level of priority/importance an intention is assigned during its initial encoding. Naturally, subjective importance of an intention will vary in everyday life depending on personal (e.g., desires, goals, other intentions) and social (e.g., self- or other-generated intentions) factors. However, during laboratory experiments, perceived importance might rely more strongly on how a particular task is instructed. Usually a time-based PM instruction of the form, "please try to remember to do press this button in 2-minute intervals", is given to the participant by the experimenter. As with many PM instructions given by others in everyday life, this form is somewhat vague and unstructured. Hence, participants are given no benchmark on how important the PM task is *relative to* the ongoing task using this standardised task instruction. In this context, participants need to infer the experimenter's intention about the relative importance of the tasks they are being set, which may well require mindreading.

In a recent review Walter and Meier (2014) underlined the role of an intention's importance for PM. They suggested that different types of importance instruction either increase intrinsic motivation (doing something out of natural interest or other internally motivating factors) or extrinsic motivation (doing something for external incentives/driving factors), which in turn are differently linked to PM performance. According to their framework, the manipulation of an intention's *social importance* (i.e., the experimenter informs the participant that an intention is important for someone else) might lead to deeper encoding of the intention and facilitate spontaneous retrieval processes associated with intrinsic motivation. In contrast, emphasizing the *relative importance* of the intention (i.e., the importance of one intention relative to another) affects PM performance by increasing extrinsic motivation mediated by changes in the allocation of attentional resources. For example, when travelling by airplane, the intention not to miss the flight back home is more important than the intention to buy a souvenir at the airport. Thus, one will make sure to arrive in time at the airport, and to regularly check the information boards for updates on the gate, boarding etc. Only a few studies have studied such importance effects on time-based PM.

Social importance. An early time-based PM study by Cicogna and Nigro (1998) manipulated the social motive associated with the delayed intention. Specifically, participants were either told to put the receiver back on the phone after five minutes either because the experimenter expected a very important phone call (high social importance) or because he was expecting a call from a colleague (low social importance). Stressing social importance resulted in a higher rate of fulfilling the delayed intention as well as a higher subjective rating of intention importance. This is in line with findings by Penningroth, Scott, and Freuen (2011). In a first experiment, they asked participants to list important or less important past intentions and whether they had been completed. Subsequently intentions were categorised as social or not by two independent raters. Their analyses found that intentions classified as social were important intentions and that those intentions were fulfilled to a significantly greater extent than non-social intentions. In their second experiment Penningroth et al. (2011) found that participants assigned greater importance to social in comparison to non-social PM tasks. Furthermore, Altgassen, Kliegel, Brandimonte, and Filippello (2010) manipulated social importance in a standard time-based PM task where participants were required to press a specific keyboard in 2-minute intervals while performing a concurrent ongoing task (see chapter 1, Table 1, Altgassen et al. 2009). The time-based PM was either instructed as doing a favour to the experimenter (high social importance) or without additional social context. The social importance instruction had a beneficial effect on time-based PM in older adults compared to performance under standard task instructions. Younger adults performed similarly under both types of instructions. However, the within-group performance increase in older adults did not lead to equivalent performance compared to the younger adults.

Relative importance. For time-based PM, only one study has so far explicitly explored the effect on task performance of stressing the relative importance of an intention (Kliegel, Martin, McDaniel, & Einstein, 2001). Participants had to remember to press a pre-specified key in 2-minute intervals (time-based PM task) while completing a word rating task (ongoing task). Half of the participants were told that the time-based PM task was more important than the ongoing task (PM high importance condition) and half were told the opposite, namely that the ongoing task was more important than the time-based PM task (PM low importance condition). Results revealed that the PM high-importance condition positively affected the PM hit rate (d = 1.14), as well as the timeliness of the PM responses (d = 1.11). Furthermore, participants monitored the time more frequently when PM was emphasised (d = 0.75) indicating a strategic allocation of attentional resources in favour of PM. Interestingly, the costs of high PM importance on the ongoing task were restricted to trials prior and after a PM target time, instead of having an overall effect on word rating performance. This is in line with research on interference effects of nontemporal tasks on concurrent temporal tasks. For instance in a dual-task study by Brown (1997) the nontemporal task (which would be the equivalent of the ongoing task in a prospective memory paradigm) negatively affected time perception performance but not vice versa due to the two tasks competing for attentional resources. This effect however seems reversible as studies that explicitly instructed to attend more to the timing task (e.g., 75% vs. 25%) showed an improved accuracy in time judgements (Macar, Grondin, & Casini, 1994). Other studies into the effects of relative importance on event-based PM (Loft, Kearney, & Remington, 2008; R. E. Smith & Bayen, 2004) further support beneficial effects of emphasizing the PM over the ongoing task. However, in line with the multiprocess framework (McDaniel & Einstein, 2000), the effects of importance instructions were dependent on ongoing task demands and characteristics of the PM cue (saliency, focality) suggesting that if PM is mediated by automatic processes, the importance instructions should not make a difference (Kliegel, Martin, McDaniel, & Einstein, 2004).

In sum, although mediated through different processes both relative and social importance instructions seem to be promising means to enhance time-based PM. This opportunity is particularly relevant for people with developmental or neuropsychological disorders that involve diminished time-based PM ability, such as ASD.

Time-based PM impairments in ASD

Research has established time-based PM problems in ASD (see Chapter 1) and these problems arguably contribute to reduced everyday functioning and quality of life (van Heijst & Geurts, 2015). However, despite agreement about the existence of time-based PM difficulties in ASD, the underlying mechanism(s) for this impairment still remain(s) unclear. Despite problems with executive functions in ASD (Hill, 2004; Kenworthy et al., 2008), only inconsistent associations have been found between time-based PM and measures of inhibition and cognitive flexibility (Henry et al., 2014; Williams et al., 2013), as well as no association with working memory (Williams et al., 2014).

Furthermore, an interesting correlation between mindreading and time-based PM has been reported (Williams et al., 2013). The Triple I hypothesis (White, 2013) proposes that mindreading impairments in ASD result in problems to infer implicit information. Therefore, tasks that are unstructured, open-ended, or that require the inference of the experimenter’s implicit expectations will result in difficulties for individuals with ASD. White (2013) have made this case specifically to explain the variability of performance on executive function tasks in ASD. However, the Triple I concept does equally apply to time-based PM tasks where participants are not explicitly told about the importance of PM task. Mindreading problems in ASD might result in difficulties to form a clear representation of the experimenter’s implicit expectation that carrying out the time-based PM is a crucial part of completing the task, and thus result in time-based PM impairments in ASD. Williams et al. (2013) provide tentative evidence for this idea.

The current study

In sum, both executive and social-cognitive processes have been implicated in successful retrieval and execution of time-based intentions in ASD. However, the processes involved in the *encoding* of time-based intentions have so far received only very limited attention. Their exploration could extend our understanding of diminished time-based PM in ASD. As outlined above, the level of importance of an intention can have a positive impact on PM, but this effect has not yet been explored in ASD. The current study investigated this effect by manipulating the relative importance of the intended action to be completed. Participants with and without ASD completed two versions of a time-based PM task previously employed by Williams et al. (2014), once emphasizing the importance of the PM task and once emphasizing the importance of the ongoing task. For the NT control group, a replication of the overall findings reported by Kliegel et al. (2001) was expected. Specifically, the following effects were predicted: a) significantly more completions of intended actions (time-based PM hits) in the PM high compared to the PM low importance condition; b) facilitated by strategic time-monitoring especially in the time interval prior to target time; and c) worse ongoing task performance when emphasizing the importance of the PM task as compared to when emphasizing the ongoing task.

For the ASD group, it was predicted that there would be *enhanced* beneficial effects of emphasising importance of the PM task, relative to the benefits experienced by the control participants (who usually perform well on time-based PM tasks anyway). Thus, the increase in PM performance in the high in comparison to a low importance condition was expected to be significantly larger in the ASD group in comparison to the NT group. Furthermore, it was hypothesized that the high importance instruction should have a positive effect on the allocation of attentional resources, which should be reflected in increased time-monitoring behaviour in the *PM high importance* condition, especially in the critical time interval prior to target time.

Importantly, the second aim of this study was to establish possible correlates of time-based PM improvements in the PM high vs low importance condition. As reviewed above, executive functions play a key role in facilitating time-based PM and individuals with ASD show a particular pattern of executive dysfunction (characterised by impairments in cognitive flexibility and working memory, and relatively unimpaired inhibitory control; Hill, 2004; Kenworthy et al., 2008; Kercood et al., 2014; Lai et al, 2016; Landry & Al-Taie, 2016). Therefore, it was explored whether self-report and behavioural measures of inhibition and cognitive flexibility were related to changes in time-based PM outcome measures. Inhibitory control was assessed due to its critical involvement in time-monitoring to facilitate PM. As changes in time monitoring are expected to result in increases in PM performance, it was explored whether this was related to individual differences in inhibitory control. Cognitive flexibility was examined as it is consistently impaired in ASD and due to its pivotal role for the execution of time-based intentions. It was predicted that ASD participants with lower executive function indices would benefit more from the structure-enhancing importance instruction. Associations between change in time-based PM outcome measures and self-report measures of inhibition, cognitive flexibility and PM were additionally explored. These self-report indices provide greater ecological validity, reflecting everyday life problems in the respective executive domain, and are associated with independent adaptive functioning and quality of life (de Vries & Geurts, 2015; Pugliese et al., 2016; Woods, Weinborn, Velnoweth, Rooney, & Bucks, 2012) which PM is important for. Therefore, the aim was to assess whether individuals who report poorer executive function and PM in everyday life are those who will benefit most from the importance manipulation or whether the manipulation has (positive) effects regardless of how individuals perceive their own abilities. Furthermore, there is some theoretical and empirical support for the idea that difficulties with mindreading might be involved in how individuals with ASD perceive the importance of a given task. Therefore, the association between mindreading ability and changes in performance from the PM low to the PM high importance condition was analysed.

Methods

Power analysis

G*Power 3 (Faul et al., 2007) was used to conduct a power analysis to determine the required sample size to detect the predicted improvement in time-based PM performance in the ASD group. Kliegel et al. (2001) found a large effect sizes of $d = 1.14$ for improvement in PM hit rates from the low to the high importance condition. Thus, assuming this effect size and $\alpha = .05$, it was established that a total sample size of $n = 14$ participants per group would achieve Cohen's (1992) recommended power of .80. Given the actual sample size of 48 in this study, an actual power of 0.97 was achieved assuming $\alpha = .05$, and $d = 1.14$.

Participants

Twenty-five participants with ASD (21 male) and 23 NT control participants (19 male) were recruited for this study. The study was approved by the ethics committee of the School of Psychology at the University of Kent and participants gave written informed consent before taking part. All participants in the ASD group had a confirmed diagnosis of ASD according to standard diagnostic criteria (ICD-10, DSM-IV or DSM-5) (American Psychiatric Association, 2000, 2013; World Health Organization, 2006). Additionally, all participants with ASD undertook the Autism Diagnostic Observation Schedule, second edition (ADOS-2, Lord et al., 2012), scores on which provide an indication of ASD severity. All participants completed the Autism Spectrum Quotient, a self-report measure of ASD traits (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). Groups were matched closely for chronological age and gender, as well as for verbal IQ, performance IQ, and full-scale IQ using the Wechsler Abbreviated Scale of Intelligence (WASI-II, second edition, Wechsler, 2011; see Table 12).

Table 12. Sample characteristics

	Group means (SD)					
	ASD (***n*** **= 25)**	**NT** (***n*** **=23)**	***t***	***df***	***p***	**Cohen's *d***
Age	34.84 (11.42)	38.24 (13.19)	-0.958	46	0.34	-0.28
VIQ	105.20 (13.64)	104.35 (9.60)	0.248	46	0.81	0.07
PIQ	102.92 (19.39)	104.65 (10.81)	-0.378	46	0.71	-0.11
FSIQ	104.32 (16.44)	104.87 (9.39)	-0.141	46	0.89	-0.04
AQ	31.00 (9.06)	16.91 (6.75)	-6.068	46	< .001	1.76
ADOS	8.80 (4.09)					

Materials and procedures

Autism Diagnostic Observation Schedule 2 (ADOS-2, Lord et al. 2012): The ADOS-2 is a very widely-used, “gold standard” observational/interview assessment of communication, social interaction, and imagination. It is designed to provide an estimate of the severity of ASD diagnostic features. For those participants with ASD who did not have record of an existing/recent (within 2 years) ADOS assessment, Module 4 (i.e., the module appropriate for verbally fluent individuals, which all the participants were) was administered.

Self-report measures.

Autism-spectrum Quotient (AQ): The AQ is a 50-item questionnaire assessing autistic characteristics. Participants rate their level of agreement on a 4-level scale (‘Definitely agree’, ‘Slightly agree’, ‘Slightly disagree’, ‘Definitely disagree’). It provides a total score of autistic features (range 0 to 50) with higher scores indicating the presence of more autistic features. It has good psychometric properties with regards to test-retest reliability, internal consistency (Baron-Cohen et al., 2001), as well as discriminant validity (Woodbury-Smith, Robinson, Wheelwright, & Baron-Cohen, 2005). The established screening cut-off for ASD is a total score of 26 (Woodbury-Smith et al., 2005).

Behaviour Rating Inventory of Executive Function - Adult version (BRIEF-A; Roth, Isquith, & Gioia, 2005): The BRIEF-A was administered to assess self-reported everyday executive functioning. The BRIEF-A consists of 75 statements describing specific behaviours and participants have to rate how often a certain behaviour has been a problem within the past month on a 3-point scale ('Never', 'Sometimes', 'Often'). Several subscales (Inhibit, Shift, Emotional control, Self-monitor, Initiate, Working memory, Plan/organise, Task monitor, and Organisation of materials) and summary scores (Behaviour regulation index, Metacognition index, and Global composite score) can be calculated. Of particular interest for this study are the Inhibit subscale (measuring the ability to control prepotent responses/inhibitory control) and Shift subscale (measuring the ability to switch flexibly between activities or situations, to switch attentional focus; and to tolerate change). The BRIEF-A has a good reliability for both internal consistency (global indices .93 to .96, clinical scales .73 to .90) and test-retest reliability (global indices .93 to .94, subscales .82 to.93) and good convergent validity with other self-report measures of executive functioning. Raw scores were converted to age-normed T-scores (with a mean of 50 and a SD of 10) with higher scores indicating greater executive problems. Scores above a T-score of 65 are considered as potentially clinical relevant.

Prospective Retrospective Memory Questionnaire (PRMQ, Crawford, Smith, Maylor, Della Sala, & Logie, 2000; G. Smith, Della Sala, Logie, & Maylor, 2000): The PRMQ is a self-report measure of everyday memory slips. It is composed of 16 items probing for both retrospective and prospective memory difficulties. Participants have to rate the frequency of described memory slips on a 5-point scale ('Very often', 'Quite often', 'Sometimes', 'Rarely', 'Never'). Sum scores provide a general memory factor, as well as a prospective and retrospective memory score. The scales have good internal consistency (Cronbach's alpha 0.80 to 0.89). Raw scores were converted to standardised T-scores (Crawford et al., 2003), with higher T-scores indicating better memory.

Behavioural measures. Computer tasks were presented using Psychtoolbox (version 3.0.11; Brainard, 1997; Kleiner et al., 2007; Pelli, 1997) running in Matlab 2014 (The MathWorks, Inc.), PsychoPy2 (version 1.84.2; Peirce, 2007), and E-Prime (version 2.0.10.252; Schneider, Eschman, & Zuccolotto, 2002).

The Stroop and WCST tests were chosen as established standard behavioural tests of executive functions in neurodevelopmental disorders (Ozonoff & Jensen, 1999). The Stroop task is thought to be a classic measure of the ability to inhibit prepotent responses (Miyake et al., 2000). Using structural equation modelling, Miyake et al. (2000) have found that set shifting/cognitive flexibility is the crucial component which underpins performance on the main outcome variable of the WCST (perseverative errors). Furthermore, the WCST perseverative errors reliably distinguish ASD from neurotypical individuals (Landry & Al-Taie, 2016). As the WCST has been widely used in ASD research, it was thought that it was the right task to use in this study although some researchers have raised concerns about its psychological validity (Geurts, Corbett, & Solomon, 2009). Importantly, both cognitive flexibility as measured by the WCST and response inhibition as measured by the Stroop task have been associated with restricted repetitive behaviours and motor stereotypies in ASD (Lemonda, Holtzer, & Goldman, 2012; Lopez, Lincoln, Ozonoff, & Lai, 2005; Mostert-Kerckhoffs, Staal, Houben, & de Jonge, 2015). Furthermore, tasks were also chosen based on associations with time-based prospective memory. Both the WCST and Stroop tests have been linked to performance on time-based PM tasks in neurotypical individuals and/or individuals with ASD (Henry et al., 2014; Kliegel, Martin, McDaniel, & Einstein, 2002; Kliegel, Ramuschkat, & Martin, 2003; Mioni & Stablum, 2014; Vanneste, Baudouin, Bouazzaoui, & Taconnat, 2016; Williams, Boucher, Lind, & Jarrold, 2013). Therefore, it was thought that these tasks would be suitable to investigate whether performance changes in prospective memory from the PM low importance to the PM high importance condition were associated with executive function abilities.

A computerised version of the *Stroop task* (Stroop, 1935) was used as a standard measure of inhibitory control/the ability to inhibit prepotent responses (Miyake et al., 2000). Participants were required to respond to a series of single words of different ink colours (blue, green, red, and yellow) on the screen. The task was to indicate as quickly as possible the respective ink colour of each word via keypress. There were 150 trials, which contained either neutral, congruent, or incongruent word stimuli. In the *neutral trials*, participants had to respond to one of four neutral non-colour words (CHIEF, MEET, PLENTY, TAX). The four colour words corresponding to the four ink colours were used in the two non-neutral conditions. In c*ongruent trials,* the colour word and its ink colour were identical, whereas in i*ncongruent trials* the colour word was printed in a different ink colour. Participants completed a short practice at the beginning to familiarise themselves with the response options (which key corresponds to which ink colour). As measure of inhibitory control, the reaction time difference between correct responses on incongruent versus congruent trials was calculated. Trials with reaction times faster than 200ms (anticipatory) or slower than 2.5SDs above the individual mean reaction time across all trials were excluded from the analysis.

A computerised version of the *Wisconsin Card Sorting Task* (WCST; Berg, 1948; Nelson, 1976) was used as an established measure of cognitive flexibility/set shifting (Miyake et al., 2000). It consisted of four stimulus cards and 128 response cards which varied on three dimensions: number of shapes (1 to 4), type of shape (circle, cross, star, triangle), and colour of shapes (blue, green, red, yellow) with each card showing a different, shape, colour, and number of shape. The participant's task was to sort each response card presented below the stimulus cards into categories according to an unknown rule. Participants had to determine what the rule was (sorting by type of shape, number of shape, or colour) and received feedback after each response whether they responded correctly or not. The card that needed to be categorized never matched on more than one feature with each of the four stimulus cards (e.g., shape and colour). The sorting rule changed unbeknown to the participant after 10 cards were sorted correctly. The number of perseverative errors was used as an index of cognitive inflexibility (i.e., a tendency to become stuck in set). A perseverative error was defined as a) persisting to sort a card into the same category as the previous one, after they had received feedback of their previous sort being incorrect (see Cianchetti, Corona, Foscoliano, Contu, and Sannio-Fancello, 2007).

As a measure of mindreading, the *Animations task* (Abell, Happé, & Frith, 2000) was administered. This task involved watching four short video clips in pseudorandom order. Each clip showed the interaction between a small blue and a big red triangle moving around the screen. Participants had to describe what was happening in each clip. An accurate description of each scene required the attribution of mental states to the triangles (coaxing or surprising). Participants watched each clip twice and gave a running commentary during the second viewing. Descriptions were recorded, and later transcribed and coded by two independent raters who were unaware of the hypotheses of the study or to group membership. Transcripts were awarded a score of two, one, or zero based on how accurately the descriptions reflected each clip following the coding guidelines provided by Abell et al. (2000). Hence, mindreading sum scores ranged from zero to eight. Inter-rater reliability was good according to established criteria (Fleiss, Levin, & Paik, 2003; Landis & Koch, 1977), weighted $\kappa = 0.63$, $p < .001$.

PM experiment. Participants completed two conditions of a time-based PM experiment in counter-balanced order to explore effects of importance instructions. The same ongoing and PM task were used for both conditions. Each condition lasted for approximately 11 minutes and contained 40 ongoing trials and five PM trials. The conditions differed only in how their importance was instructed. In the *PM low importance condition*, participants were told that the ongoing task was more important than the prospective memory task, whereas in the *PM high importance condition* instructions were reversed, i.e., the prospective memory task was instructed to be more important than the ongoing task. Between the two conditions, there was a 45-minute gap during which participants completed several filler tasks.

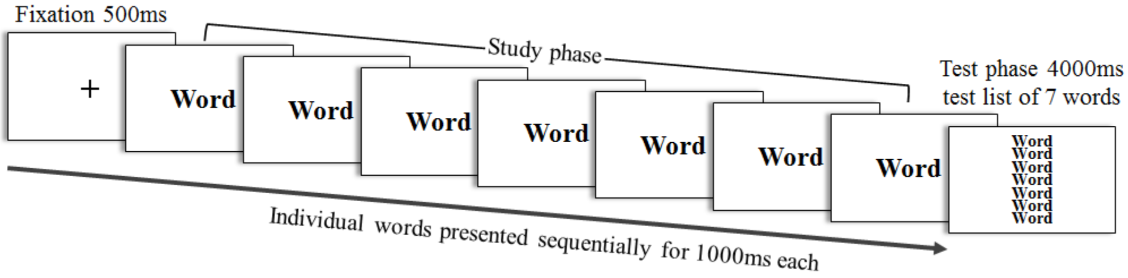

Figure 7. Schematic depiction of the trial structure of the ongoing task

The *ongoing task* (see Figure 7) followed the procedure previously used by Williams et al. (2014). Participants had to memorise seven sequentially presented words (study phase), followed by a test list of seven words (test phase). In the test phase, participants had four seconds to respond whether the list of words matched the words presented during the study phase or not and press a respective keyboard key. In half of the trials the test phase were identical to those during the study phase and for the other half of the trials, one word was replaced with a lure item that had to be found to be identified as a mismatch trial. To ensure understanding of task instructions, participants had to complete five practice trials. A score of one was awarded for each correct response and a proportion score (*ongoing task proportion hits*) was calculated, as the total number of hits relative to the total number of ongoing trials. For the analysis of performance changes between the two conditions a difference score was computed by subtracting performance in the PM high importance condition from the performance in the PM low importance condition. A positive difference score indicates better ongoing performance in the PM low importance condition.

Two sets of 300 words were used as stimuli counter-balanced across conditions (280 word stimuli plus 20 lure stimuli). Both sets were equated for frequency and syllable length according to Kucera and Francis (1967) guidelines and derived from the MRC Psycholinguistic Database (Coltheart, 1981). The matching of the sets was confirmed using multivariate analyses finding a nonsignificant main effect of set, Wilk's criterion, $F(2,557) = 0.14$, $p = .87$.

For the embedded *PM task*, participants were instructed to press a pre-specified keyboard key in 2-minute intervals (PM target times at minutes 2, 4, 6, 8, and 10) to carry out the prospective memory instruction. The use of 2-minute intervals is a standard procedure which is widely accepted and used in previous research that explored time-based PM (Einstein, Smith, McDaniel, & Shaw, 1997; Kliegel et al., 2001; Mackinlay et al., 2009). As time-based PM impairments in ASD have clearly been shown using this interval length (Altgassen et al. ,2009; Williams et al., 2013; Williams et al., 2014), this study employed the same interval length to explore whether the relative importance manipulation would improve time-based PM abilities in ASD. To keep track of the time, they could bring up a digital clock on the screen lasting for 1.5 seconds before disappearing by pressing a pre-specified keyboard key.

The scoring followed the procedure employed by Williams et al. (2014), which this experiment was based on. A score of one was awarded for each PM hit. A PM hit was defined as pressing the pre-specified key within a 15 second time window around each target time (± 7.5 seconds, see Figure 8). This scoring criterion ensured that a participant would have had enough time to respond to both the ongoing and PM task on any trial if the PM target time fell in the middle of a trial (see Williams et al. 2014). A proportion score (*PM proportion hit*) *was* calculated as the number of PM hits out of five PM trials. Additionally, *PM target accuracy* was calculated as the mean of the absolute difference between the time of remembering the PM task (i.e., pressing the pre-specified key) and the target time across all PM hit trials. For example, a PM hit at 2 minutes and 5 seconds (125 seconds) would result in a negative PM target accuracy for that trial of minus 5 seconds. When averaging across all PM hit trials, the absolute value is used; e.g., $|120s - 125s| = 5s$ for each trial because otherwise one would distort the mean by averaging across positive and negative values. A value of zero would indicate perfect accuracy (i.e., pressing exactly on the target time), and hence the bigger the value the further from target time the PM press happened (max 7.5 seconds, see Figure 8 for an illustration). For the analysis of time-monitoring behaviour, the five 2-minute periods prior to each target times were each broken down into 30-second segments and the mean number of time checks in each time interval (0-30, 31-60, 61-90, 91-120 seconds) across all five PM trials was calculated, as is standard in studies of time-based PM (see e.g., Kliegel et al., 2001; Mackinlay et al., 2009).

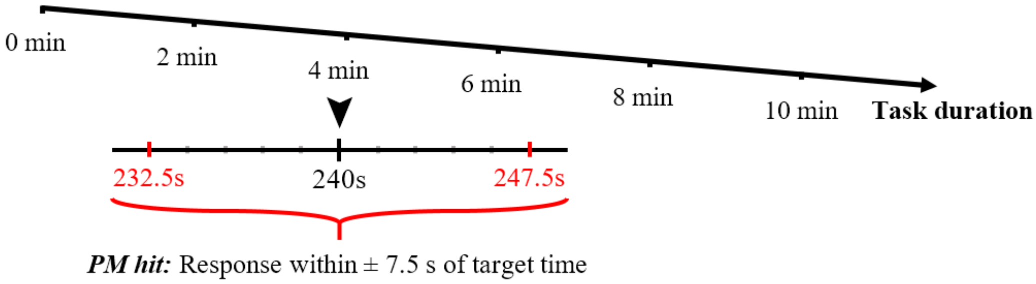

Figure 8. Overview and example timeline on how a PM hit was scored and how PM target accuracy was calculated

To assess correlates of change in time-based PM performance from one condition to the other, *difference scores* were computed for each of the dependent variables (proportion hit scores, target accuracy, and mean number of time checks in the critical fourth interval prior to target time) by subtracting performance in the PM low condition from performance in the PM high condition. Positive difference scores for proportion accuracy and mean number of time checks indicate increased performance in the high importance condition (i.e., higher number of hits/more time checks in the PM high condition). Negative difference scores for target accuracy indicate that participants responded closer to target time in the PM high importance condition.

Retrospective memory for task instructions was checked after each condition, specifically participants had to correctly recall which of the two tasks the more important one was. All participants successfully retrieved the PM instruction.

Statistical analysis

An alpha level of .05 was used to determine statistical significance. Greenhouse-Geisser corrections were used where the assumption of sphericity was violated. Where

ANOVAs were used, partial eta squared (η_p^2) is reported as a measure of effect size (≥ .01 = small effect, ≥ .06 = moderate effect, ≥. 14 = large effect; Cohen, 1988). Where *t*-tests were used, Cohen's *d* is reported as a measure of effect size (≥.0.20 = small effect, ≥ 0.50 = moderate effect; ≥ 0.80 = large effect; Cohen, 1988).

Bayes factors (BF_{10}) in support of the alternative (H_1) over the null hypothesis (H_0) were computed for all relevant effects by submitting the data to Bayesian repeated measures mixed ANOVA. Additionally, Bayesian correlation analyses were performed. For the correlations reported in Table 15 two-tailed tests were used. For the partial correlations, one-tailed tests were used. JASP does not provide Bayesian partial correlations per se. However, partial correlations represent the correlations of the residuals after regressing the to be controlled variable onto the variables of interest. Thus, the respective regression analyses were conducted saving the residuals and subsequently performed Bayesian correlation analyses on the residuals. Bayes factors were interpreted according to Lee and Wagenmakers (2013) classification (see Chapter 2).

Results

Sample description

Means and standard deviations for the self-report and behavioural measures of mindreading and executive functions are displayed in Table 13. Individuals with ASD did not show diminished mindreading performance in the Animations task. On the self-report measures, the ASD group reported significantly more executive function and memory problems relative to the NT group, with large associated effect sizes. Furthermore, the ASD group shower poorer cognitive flexibility on the Wisconsin Card Sorting Task indexed by a greater number of perseverative errors, but no significant diminution of inhibitory control on the Stroop task.

Table 13. Sample characteristics for behavioural and self-report measures of mind reading, PM, and executive functions

	Group means (SD)					
	ASD	**Neurotypical**	***T***	***df***	***p***	**Cohen's *d***
Mindreading (Animations task)	4.64 (1.82)	5.30 (1.82)	1.26	46	.21	-0.36
PRMQ prospective memory scale	40.60 (12.43)	50.96 (10.39)	3.12	46	.003	-1.14
PRMQ retrospective memory scale	45.56 (9.16)	53.61 (8.85)	3.09	46	.003	-1.11
BRIEF Inhibit	63.40 (12.47)	51.82 (9.81)	-3.50	45	.001	1.17
BRIEF Shift	72.04 (13.82)	50.59 (8.16)	-6.37	45	<.001	2.07
WCST perseverative errors	13.52 (10.98)	5.62 (4.40)	3.06	40	.004	0.87
Stroop inhibitory control	105.71 (88.14)	84.66 (134.47)	0.60	39	.56	0.13

Notes. There was some missing data for executive function measures. Only 22 NT participants completed the BRIEF-A, 21 participants in each group completed the WCST, and finally, 21 ASD participants and 20 NT participants completed the Stroop task. Participants in the experimental groups remained matched for baseline characteristics for all correlational analyses. Sample characteristics for the remaining scales of the BRIEF-A can be found in Appendix 1, Table A1.

Table 14. Ongoing and PM performance scores by group and condition

		Group means (SD)		
Condition		**ASD (*n* = 25)**	**NT (*n* = 23)**	**Cohen's *d***
PM low importance	Ongoing proportion hits	.65 (0.15)	.78 (0.10)	-1.02
	PM proportion hits	.69 (0.34)	.95 (0.09)	-1.05
	PM target accuracy	2.24 (1.60)	1.37 (1.05)	0.64
	# PM inaccurate	1.04 (1.21)	0.43 (0.90)	-0.57
	Time checks 4th interval	1.70 (0.92)	2.17 (1.27)	0.42
PM high importance	Ongoing proportion hits	.63 (0.12)	.74 (0.13)	-0.88
	PM proportion hits	.91 (0.21)	.99 (0.04)	-0.53
	PM target accuracy	1.66 (1.00)	1.02 (0.85)	0.69
	# PM inaccurate	1.48 (4.05)	0.04 (0.21)	-0.50
	Time checks 4th interval	2.26 (1.02)	3.21 (1.67)	0.69

Ongoing task

Ongoing task performance (see Table 14) was subjected to a 2 × 2 mixed ANOVA with Group (ASD/NT) as between-subject factor and Condition (PM low/high importance) as within-subject factor. Main effects of group, $F(1,46) = 12.63$, $p = .001$, $\eta_p^2 = .22$, $\text{BF}_{10} = 33.33$, and condition, $F(1,46) = 5.30$, $p = .03$, $\eta_p^2 = .10$, $BF_{10} = 1.94$, were significant. The NT group performed better overall in comparison to the ASD group[12], and both groups showed better ongoing performance in the *PM low importance condition*. No significant interaction effect emerged $F(1,46) = 0.17$, $p = .68$, $\eta_p^2 = .004$, $BF_{10} = 0.33$. The BF_{10} for the additive model was 63.88 and for the full model 21.04. This means that the additive model provided the greatest evidence for the present data.

PM task

PM hits. PM proportion hit scores were used as the dependent variable in a 2 × 2 mixed ANOVA with Group (ASD/NT) as between-subjects factor and Condition (PM low/high importance) as within-subject factor. There was a main effect of group, $F(1,46) = 10.95$, $p =$

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[12] Due to the dual-task nature of PM tasks, attentional resources are divided between ongoing and PM task. As a result, between-group differences in ongoing task performance might reflect that fewer resources were available to perform the PM task. Thus, to interpret PM performance in the ASD group, it is important that their ongoing task performance is matched with the NT group (see Chapter 1 for a detailed discussion). Therefore, prior to the analysis of PM task performance, the group difference in proportion of hits on the ongoing task was analysed. For this purpose, ongoing task performance was collapsed across conditions and entered into an independent-samples t-test with group as the independent variable. This analysis revealed that the ASD group ($M = 0.64$, $SD = 0.13$) performed significantly worse than the control group ($M = 0.76$, $SD = 0.11$), $t(46) = 3.55$, $p = .001$, $d = 0.99$. Since these group differences could have influenced PM performance in the different conditions, all analyses were repeated among a subsample that was matched for ongoing task performance as well as baseline characteristics. In order to achieve this matching, the NT participant with the highest ongoing task performance and the ASD participant with the lowest ongoing task performance were excluded sequentially. This process continued until the effect size for the between-group difference in ongoing task performance was small ($d < 0.50$). This resulted in groups of 19 participants in each group who were matched for age and IQ ($d \leq 0.53$). Crucially, the results concerning PM performance were not substantially different in this subsample (matched for ongoing task performance) and in the full sample (unmatched for ongoing task performance. Therefore, the results from the full sample are reported here. The full details of the subsample analyses can be found in Appendix 2.

.002, η_p^2 = .19, BF_{10} = 16.95 with the ASD group performing worse overall than the NT group, and a main effect of condition, $F(1,46) = 18.09$, $p < .001$, η_p^2 = .28, BF_{10} = 147.26, indicating better PM performance in the PM high importance condition. More importantly, however, there was a significant interaction between group and condition, $F(1,46) = 8.18$, $p = .006$, η_p^2 = .15, BF_{10} = 6.76 (see Figure 9a and 9b). The BF_{10} for the additive model was 2689.84 and for the full model 18188.69. This means that the full model provided the greatest evidence for the present data. Tests of simple effects comparing PM performance within groups revealed that only the ASD group significantly increased their PM proportion scores from the PM low to the PM high importance condition (ASD: $F(1,46) = 26.40$, $p < .001$, η_p^2 = .37, d = -0.86; BF_{10} = 52.74; NT: $F(1,46) = 0.93$, p =.34, η_p^2 = .02, d = -0.44, BF_{10} = 1.20). Tests of simple effects of between group differences indicated that ASD participants performed significantly less well than comparison participants in the PM low importance condition, with a large associated effect size, $F(1,46) = 12.81$, $p = .001$ η_p^2 = .22, d = -1.05, BF_{10} = 36.53. In the PM high importance condition, the ASD group again performed less well that the NT group, although the difference only approached significance and was associated with a moderate effect size, $F(1,46) = 3.32$, $p = .08$, η_p^2 = .07, d = -0.53, BF_{10} = 1.09 (see Table 14 for means and standard deviations). However, the Bayes factor did not support evidence for either the null or alternative hypothesis and the NT group performed at ceiling in the PM high importance condition, $t(22) = -1.00$, $p = .33$, BF_{10} = 0.34; thus cautious interpretation of the interaction effect is required.

PM target accuracy. Among participants who had a minimum of one PM hit in each condition, PM target accuracy was analysed (ASD n = 23, NT n = 23). In a 2 × 2 mixed ANOVA, with group (ASD/NT) as between-subjects factor and condition (PM low/high importance) as within-subject factor, a main effect of group emerged indicating that NT group overall responded closer to target time than the ASD group, $F(1,44) = 6.94$, $p = .01$, η_p^2 = .14,

BF_{10} = 4.47. Furthermore, a significant main effect of condition indicated that both groups responded closer to target time in the PM high importance condition than in the PM low importance condition, $F(1,44) = 6.36$, $p = .02$, $\eta_p^2 = .13$, $BF_{10} = 3.35$. However, the Group × Condition interaction did not approach significance, $F(1,44) = 0.38$ $p = .54$, $\eta_p^2 = .01$, $BF_{10} = 0.33$. The BF_{10} for the additive model was 14.25 and for the full model 4.72. This means that the additive model provided the greatest evidence for the present data. (see Figure 9 and Table 14).

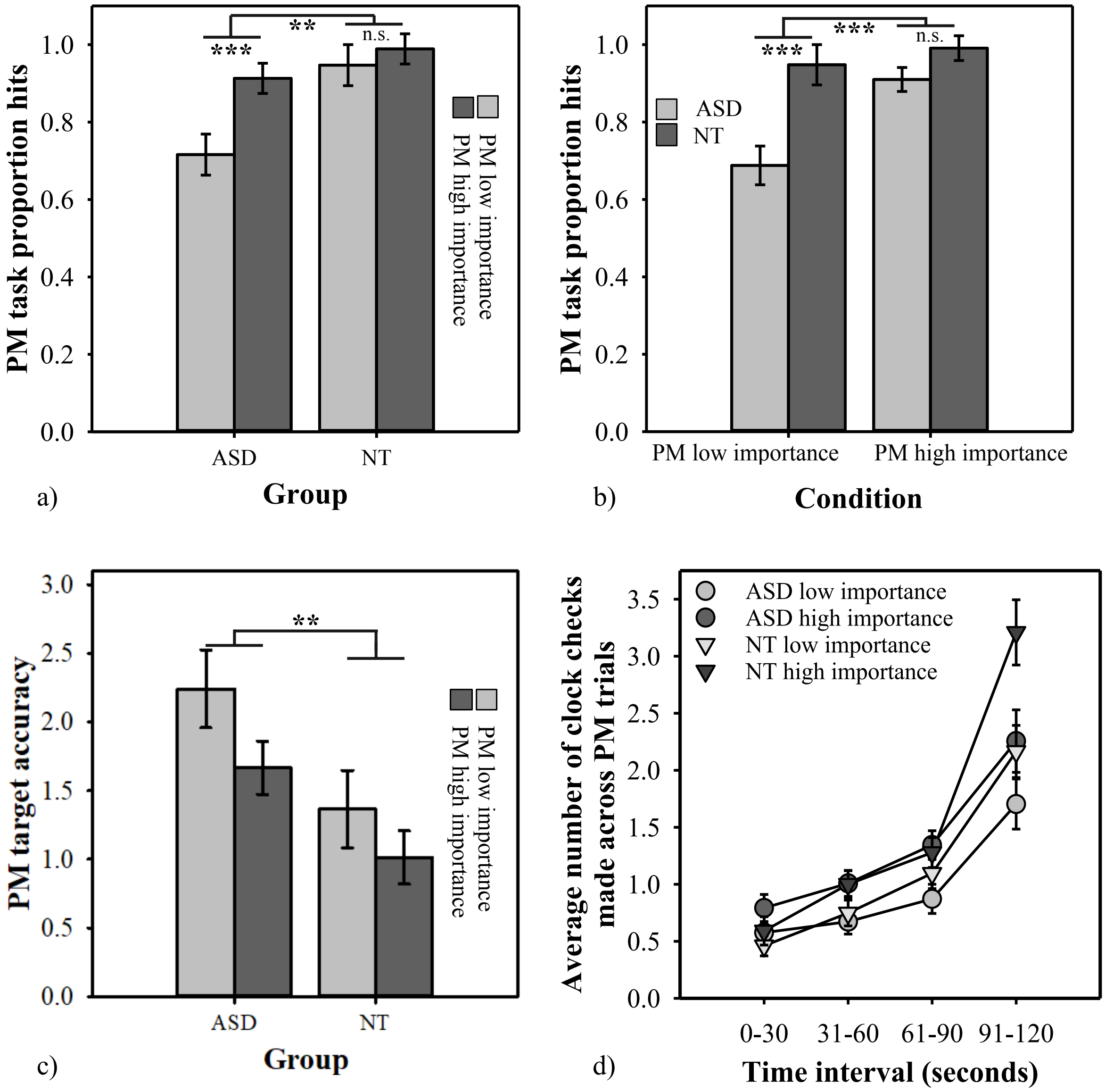

Figure 9. *PM performance: a) Main effect of group and within-group comparison by condition for PM proportion hits; b) Main effect of condition and between-group comparison for PM proportion hits; c) Main effect of group for PM target accuracy; and d) Time-monitoring pattern by interval in the ASD and NT group by importance condition. Error bars represent standard errors of the means. **: $p \leq .01$, ***: $p \leq .001$, n.s.: not significant.*

Time-monitoring. Figure 9d) shows the mean number of time checks carried out for each condition during each of the four time periods among ASD and comparison participants. A 2 × 2 × 4 mixed ANOVA was conducted on this data with Group (ASD/NT) as between-subjects factor, and Condition (PM low/high importance) and Time interval (0-30, 31-60, 61-90, 91-120 seconds) as within-subject factors. The main effect of group was non-significant, $F(1,46) = 1.08$, $p = .30$, $\eta_p^2 = .02$, $\mathrm{BF}_{10} = 0.29$. There were significant main effects of condition, $F(1,46) = 23.01$, $p < .001$, $\eta_p^2 = .33$, $\mathrm{BF}_{10} = 339.89$, and interval $F(1.39,63.75) = 122.23$, $p < .001$, $\eta_p^2 = .73$, $\mathrm{BF}_{10} = 2.01 * 10^{49}$. The Group × Importance interaction was non-significant, $F(1,46) = .002$, $p = .96$, $\eta_p^2 < .001$, $\mathrm{BF}_{10} = 0.16$, but there were significant two-way interactions between group and interval, $F(1.39,63.75)$, $p < .004$, $\eta_p^2 = .14$, $\mathrm{BF}_{10} = 1206.48$, and condition and interval, $F(2.11,97.19) =9.09$, $p < .001$, $\eta_p^2 = .17$, $\mathrm{BF}_{10} = 5.03$. Most importantly, all these effects were qualified by a significant three-way Group × Importance × Interval interaction $F(2.11,97.19) = 3.41$, $p = .04$, $\eta_p^2 = .07$, $\mathrm{BF}_{10} = 0.39$. Of all the different models possible the of the two main effects and two-way interactions described above attained the largest Bayes factor[13], $\mathrm{BF}_{10} = 5.43 * 10^{59}$. Tests of simple effects revealed a significant group difference for the crucial interval immediately prior to target time (91-120 seconds) in the PM high importance condition only; in this condition, significantly more time checks were made in the NT group ($M = 3.21$, $SE = 29$) than in the ASD group ($M = 2.26$, $SE = .27$), $F(1,46) = 5.79$, $p = .02$, $\eta_p^2 = .11$, $\mathrm{BF}_{10} = 2.83$. Furthermore, the comparison of time checks per interval within conditions showed that the ASD group checked the time

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[13] It is not possible within JASP to calculate the BF_{10} for the model which is indicated based on traditional null hypothesis significance testing: main effects of condition and interval, two-way interactions between Group × Interval, and Importance × Interval, and the three-way interaction Group × Importance × Interval of Importance. Therefore, it is difficult to estimate what the additional three-way interaction adds to the model in comparison to a model without it.

significantly more often for three intervals (31-60, 61-90, 91-120 seconds) in the PM high importance condition (all Fs $\geq$ 5.39, all ps $\leq$ .03, all η_p^2 $\geq$ .11, all $BF_{10} \geq 5.05$), whereas the NT group only checked the time more often in intervals 31-60 and 91-120 (all Fs $\geq$ 4.48, all ps $\leq$ .04, all $\eta_p^2 \geq .09$, interval 31-60 $BF_{10} = 1.15$, interval 91-120 $BF_{10} = 24.39$).

Cognitive correlates

Ongoing task. Ongoing task performance was collapsed across conditions for each group before being entered into correlation analyses. Additionally, to explore correlates of change in ongoing task hits between conditions, a difference score was computed (positive values indicating better ongoing performance in the PM low importance condition). No relations between executive functions measures (indexed by self-reported executive function problems on the BRIEF-A, as well as performance on the WCST and Stroop) and ongoing task performance or the change in performance were found in either group. The only significant correlation was found between mindreading and ongoing task performance in the ASD group (see Table 15). Therefore, ongoing task performance was partialled out when investigating the correlation between mindreading and change in PM performance.

PM task. Difference scores were computed for proportion hit scores, target accuracy, and time checks in the critical last interval. Subsequently, a series of planned correlations was performed between indices of time-based PM performance change and a) time monitoring; b) self-report and behavioural measures of executive functions; c) a self-report measure of memory; and d) self-report and behavioural measures of mindreading. Furthermore, correlations explored whether modulation of time monitoring frequency was associated with any of these measures (see Table 15 for all the results of the correlation analyses and the associated Bayes factors).

Table 15. Correlates of change (Δ) in PM and ongoing performance, and ongoing performance overall

	Group		**Δ proportion hit**	**Δ target accuracy**	**Ongoing proportion hits (collapsed)**	**Δ proportion hits**
Δ I4 time monitoring	*ASD*	*r*	.40*	-.45*	.05	-.12
		BF$_{10}$	1.62	2.21	0.57	0.39
	NT	*r*	-0.27	-.34	.23	.32
		BF$_{10}$	0.53	0.86	0.27	1.43
BRIEF inhibition scale	*ASD*	*r*	.23	-.66***	-.15	.02
		BF$_{10}$	0.45	58.02	0.32	0.25
	NT	*r*	-.16	-.12	-.24	-.23
		BF$_{10}$	0.33	0.30	0.46	0.44
BRIEF shifting scale	*ASD*	*r*	.01	-.24	-.12	-.11
		BF$_{10}$	0.25	0.46	0.29	0.28
	NT	*r*	-.25	.11	.07	-.31
		BF$_{10}$	0.49	0.29	0.28	0.67
WCST perseverative errors	*ASD*	*r*	.61**	-.19	-.25	.02
		BF$_{10}$	14.93	0.37	0.46	0.27
	NT	*r*	.28	-.15	.22	.26
		BF$_{10}$	0.54	0.33	0.42	0.50
Stroop inhibition index	*ASD*	*r*	<.01	-.26	< .01	-.17
		BF$_{10}$	0.27	0.49	0.27	0.35
	NT	*r*	-.06	.04	-.20	-.30
		BF$_{10}$	0.28	0.28	0.38	0.58
Mindreading score (Animations task)	*ASD*	*r*	-.27	-.15	.48*	-.15
		BF$_{10}$	0.55	0.33	3.95	0.31
	NT	*r*	.22	.35	.28	.33
		BF$_{10}$	0.41	0.95	0.58	0.78
PRMQ prospective memory scale	*ASD*	*r*	-.10	.39†	-.21	.18
		BF$_{10}$	0.28	1.32	0.40	0.35
	NT	*r*	.08	-.12	-.03	-.07
		BF$_{10}$	0.27	0.27	0.26	0.27
PRMQ retrospective memory scale	*ASD*	*r*	-.05	.46*	-.09	.19
		BF$_{10}$	0.26	2.68	0.27	0.36
	NT	*r*	.09	-.37	.02	-.08
		BF$_{10}$	0.29	0.28	0.26	0.27

Correlations significant two-tailed † $p \le .06$, * $p \le .05$, *** $p \le .001$

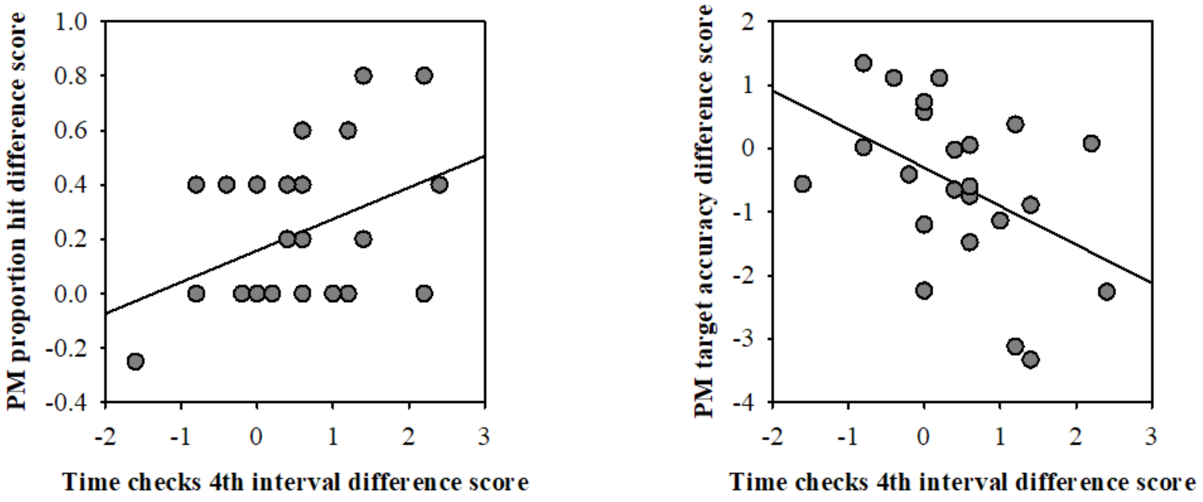

Figure 10. *Scatterplots illustrating the relationship between the change in time-checks in the critical fourth interval and PM performance in the ASD group.*

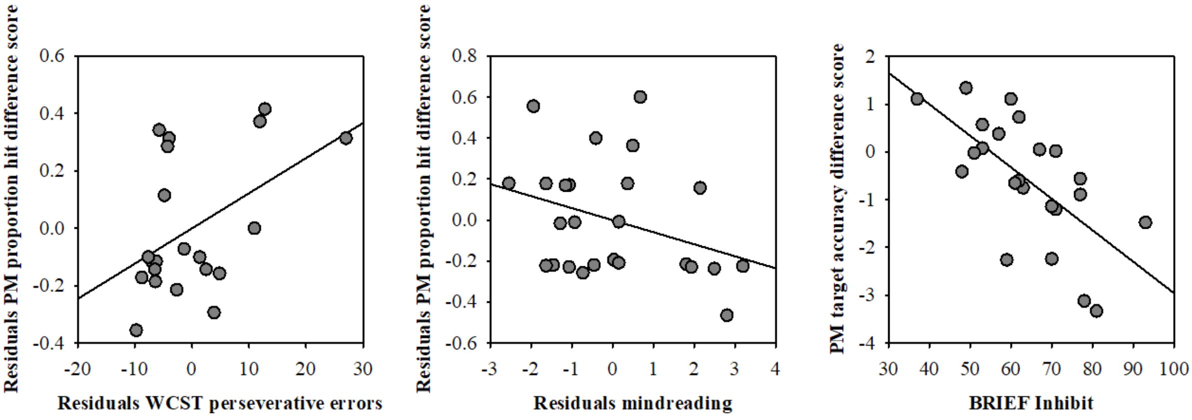

Figure 11. *(Partial) correlations scatterplots depicting correlations for cognitive correlates of interest in the ASD group.*

The partial correlation between change in PM proportion hits and perseverative errors on the WCST controlling for non-perseverative errors was significant in the ASD (r = .47, p = .04, BF_{10} = 2.36) but not in the NT group (r = .25, p = .29, BF_{10} = 0.47). However, a Fisher z-test revealed that the size of the correlation in the ASD group was not significantly different from the one in the NT group (z = 0.76, p = .45). The partial correlation between change in PM proportion hits and mindreading controlling (Animations task theory of mind score) for overall ongoing task performance was not significant in either group (ASD: r = -.33, p = .11, BF_{10} = 0.88; NT: r = .16, p = .47, BF_{10} = 0.34). Finally, self-report problems of executive functions on the several clinical scales of the BRIEF-A correlated with PM target accuracy in the ASD group but not the NT group (see Figure 11 for scatterplots of the above correlations in the ASD group). Additionally, PM target accuracy in the ASD group correlated with self-rated PM (although only marginally) as well as self-rated retrospective memory.

Discussion

Time-based PM has consistently been found to be impaired in individuals with ASD. However, only little evidence exists tackling the question of how this impairment could be alleviated. Only one previous study (Kretschmer et al., 2014) has explored whether the use of implementation intentions as an explicit encoding strategy might improve time-based PM in ASD. However, beneficial effects on time-based PM in ASD could not be observed (see Chapter 1 for a detailed discussion). To address this issue further, this study investigated how instructions of relative importance affected time-based PM in ASD and how changes in performance related to standard self-report and objective measures of executive functions, memory and mindreading. There were several key findings.

Beneficial effects of importance instruction on time-based PM

Emphasising the importance of the time-based PM over the ongoing task (PM high importance condition) had, as predicted, significantly greater beneficial effects in the ASD group than in the NT control group. The Bayes factor analysis supported this conclusion. This increase in PM performance in ASD shrunk the between-group differences in PM hits from a large to a medium sized effect. Indeed, performance among ASD participants in the *high* importance condition was equivalent to performance among NT participants during the *low* importance condition.

However, conclusions about the improvement PM proportion hit rate in the ASD group *relative to* the NT control group should be interpreted with a degree of caution, given the fact that the NT group did not perform significantly below ceiling in the PM high importance condition. Had the PM high importance condition been more demanding, NT participants may have shown a larger improvement across conditions than they were able to demonstrate in the current task. Having stated this, however, the finding that performance among ASD participants in the *high* importance condition was equivalent to performance among NT participants during the *low* importance condition is still highly important and not affected by the issue of ceiling effects among NT participants. Moreover, the ceiling effect in the NT group only emerged for PM hits but not PM target accuracy.

With regards to PM target accuracy, beneficial effects of emphasising the PM task had been predicted, especially in the ASD group. Previous research had shown that individuals with ASD responded less accurately under standard instructions (Williams et al., 2014). In this study, although overall, both groups responded closer to target time in the PM high importance condition, the ASD group responded less accurately in comparison to the NT group. Thus, the importance instruction did not enhance the accuracy of PM responses in individuals with ASD, so that it equalled that of the comparison group.

This study did not include a baseline time-based PM condition where neither ongoing nor PM task were differentially emphasized. As this study employed the same task as Williams et al. (2014), task performance was compared across studies[14]. In their study, the PM hits rates (ASD: M = 0.79, NT: M = 0.95) were similar to PM performance in this study's PM low importance condition (ASD: M = 0.69, NT: M = 0.95). One sample t-tests comparing performance for each group indicated that the PM low importance condition was comparable to standard time-based PM task instructions in the ASD group ($t(40) = 0.96$, $p = .34$) and identical in the NT group. This is crucial as in most everyday situations a time-based task instruction/delayed intention is given informally without explicit emphasis on its importance relative to other tasks that need to be completed. This may well contribute to communication

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[14] The ASD sample in Williams et al.'s (2014) study featured higher intellectual abilities in comparison to the sample reported in this chapter.

and interactional difficulties (understanding directions or “reading between the lines”) of individuals with ASD, especially in a work setting (Hendricks, 2010). Therefore, the above results provide promising evidence that, importance instructions might be a simple strategy in everyday life for individuals with ASD to compensate for general time-based PM deficits. This extends existing research into importance instructions effects and is in line with results from other studies that found beneficial effects of explicit task instructions in ASD (Bowler et al., 2000). It may be that the explicit importance instruction provides useful structure and scaffolding in managing dual task demands for participants with ASD leading to improved performance. This could be particularly useful in employment settings for individuals with ASD to manage multi-tasking demands; e.g., finishing a work report and being on time for a work group meeting. It would be interesting to investigate whether an additional instruction with regards to the PM importance, (e.g., it is more important to press the pre-specified key within 5 seconds of the target time) might result in further performance benefits in the ASD group.

The ASD group exhibited adaptive time-monitoring and modulated their time checking frequency for different time intervals depending on the experimental condition. However, the NT group checked the time significantly more often in the critical time interval prior to target time in the PM high importance condition in comparison to the ASD group. Hence, the importance instruction did not lead to a large enough increase in monitoring in the critical interval in the ASD relative to the NT group. The between-group differences in strategic time-monitoring in the high importance condition likely played a key role to explain this lack of an interaction effect for PM target accuracy. Nonetheless, significantly increasing time-monitoring in the critical period before target time seems to be crucial for time-based PM success in ASD. The present results indicated that a positive increase in time-monitoring in this interval from the low to the high importance condition was associated with a positive change in PM hits and more accurate responses. These results are generally in line with other studies that found positive correlations between the total number of time checks prior to target time and PM success (Altgassen et al., 2009; Williams et al., 2013) as well as the assumption that relative importance instruction results in changes of strategic monitoring (Walter & Meier 2014).

Interestingly, there is a clear discrepancy between what previous studies concluded on the role of time monitoring in time-based PM in ASD in comparison to this study. Using standard task instructions Williams and colleagues (2013, 2014) found equivalent patterns of time checks between groups. Thus, they concluded that time-monitoring performance cannot explain impaired time-based PM in ASD. This study found similar results in the low importance condition. Here, the ASD group does not significantly differ to the control group in the mean number of time checks prior to target time, however time-based PM is poorer in the ASD group. Despite this, a clear relationship between the increase in time checks and the increase in PM hits in the ASD group across conditions was found in this study. Thus, time monitoring seems to be important to alleviate time-based PM impairments even if it may not cause them in the first place. It may be that the distribution of time checks within the critical time interval might have differed between groups. It may be that the ASD group checked the time further away from target time than the NT group leading to less accurate PM responses and hence fewer hits in the low importance condition, and thus despite time checks being of similar quantity they were not of similar quality. This might have masked the importance of time-monitoring for PM success under standard conditions. To assess the role of time perception for time-based PM, it would be crucial to explore how timing abilities *independent* of the experimental task are contributing to time-based PM in ASD.

Finally, it is important to explore whether the ongoing task costs outweighed the benefits of the PM high importance condition. For ongoing task performance, the main effect of condition was of moderate size across groups. Thus, explicit task instruction may be a simple strategy to alleviate time-based PM in ASD in everyday life *without* a large negative impact on other activities. Of course, it would be useful to further explore this issue in everyday settings, but the clear implication from the current results is that providing instructions regarding importance would provide a useful strategy for enhancing time-based PM functioning in ASD.

Correlates of performance change with background measures

With regard to what underpins changes in performance, this study explored three different factors: time-monitoring, executive functions, and mindreading. This discussion will focus on correlates of ASD performance as, due to ceiling effects, the NT group did not significantly improve their performance from the PM low to high importance condition. Therefore, the reported correlation coefficients in the NT group should be interpreted with caution and regarded as exploratory with the need for further investigation.

In the ASD group, PM performance change was associated with two of three factors: time-monitoring (see discussion above) and executive functions. The results revealed that greater self-reported difficulties with inhibitory control were strongly associated with a positive change in PM target accuracy (more accurate responses in the PM high importance condition). Thus, individuals reporting more inhibitory control problems did benefit from the importance instruction. Self-report executive problems have been linked to poorer adaptive behaviour and daily living skills (Pugliese et al., 2016). Thus, elevated scores on this scale above the clinically interesting cut-off might be a tool to identify individuals with ASD who need more support with time-based PM. This outcome maps onto Henry et al.'s (2014) finding that poorer time-based PM is associated with smaller levels of functional independence in everyday life. This finding was not reflected in a similar correlation with the Stroop inhibition index. It may be that the self-report measure picked up on everyday relevant inhibitory control problems in ASD that do not become evident in a structured lab-based inhibition task (and on which the ASD group was not impaired on in this study).

With respect to cognitive flexibility, the BRIEF-shifting self-report score was not significantly associated with PM performance. In contrast, perseverative errors on the Wisconsin Card Sorting Task, a task that is difficult for people with ASD (Landry & Al-Taie, 2016), were positively associated with an increase in PM hits from the low to high importance condition, even when controlling for other executive demands. Confirming the study's prediction, this indicates that individuals with lower cognitive flexibility benefitted most from the importance instruction. This supports the idea that the explicit instruction enhances the structure of the task and hence individuals with ASD who are less flexible to adjust to changing demands are more aware of what task to focus on and how to allocate their resources. This might resolve switching problems in ASD. This finding aligns with evidence from Henry et al.'s (2014) study that found better time-based PM related to better switching. Yet, Williams et al. (2013) had found no associations with cognitive flexibility and time-based PM in ASD, although Fisher *z*-tests indicate that the size of their correlation was not significantly different from the one found in this study ($z = 1.08$, $p = .28$). Another way in which the current results differed from Williams et al. (2013) and contrary to what was predicted, mindreading was not associated with changes in time-based PM performance. This finding is contrary to the predictions of the Triple I hypothesis (White, 2013) as mindreading ability did not relate to PM in ASD or increase in PM performance whereas executive function problems did. Importantly, the ASD group did not show reduced mindreading ability in the Animations task. This suggests a dissociation between mindreading (which was not impaired in the current sample) and time-based PM (which was impaired in the current sample), implying that mindreading deficits are not what drives time-based PM impairment in adults with ASD.

These findings on associations with cognitive flexibility and mindreading are directly opposite to the correlations found by Williams et al. (2013). One major difference to Williams and colleagues' study is that they studied time-based PM in children. It may be that mindreading plays a role alongside executive functions during PM development given the overlapping brain network involving prospection and mindreading (Buckner & Carroll, 2007; Spreng & Grady, 2009) but loses relevance in later life. A recent study has found both cognitive flexibility and mindreading predicting event-based PM in adolescents but not adults (Altgassen, Vetter, et al., 2014), which may provide tentative support for this claim.

Conclusion and future directions

Altogether, the results of this study provide initial evidence that the explicit instruction of the importance of a delayed intention plays a key role in time-based PM success in ASD, facilitated through executive and strategic monitoring processes. Future research should explore this finding in several ways. The current study found beneficial effects of explicit importance instruction under controlled laboratory conditions. However, a previous study (Altgassen et al., 2012) found strong PM impairments during a naturalistic breakfast preparation task. Thus, it is crucial to further investigate whether the effect of importance instructions equally applies under real-life/naturalistic task demands in ASD when time delays and situational demands are more complex. If such a study would find similar beneficial effects to this study, the usage of explicit importance instruction as a minimal intervention strategy could prove very useful to employers, families, or care takers to facilitate a higher level of independent functioning in both adults and children with ASD.

Furthermore, it may be worth investigating the roles of social and personal importance of delayed intentions in ASD. It would be interesting to explore whether individuals with ASD respond to manipulations of social importance despite their social-communicative and mindreading problems and other evidence that reports reduced responsiveness to social rewards (Delmonte et al., 2012; Stavropoulos & Carver, 2014). Equally, it would be important to explore whether fulfilling self-generated compared to other-generated (family, work colleague, experimenter) intentions differs in ASD, as well as how self-rated (personal) importance of intentions (Ihle, Schnitzspahn, Rendell, Luong, & Kliegel, 2012; Niedźwieńska, Janik, & Jarczyńska, 2013) affects PM performance. Exploration of these factors would provide a greater insight into how to tailor task instructions for the needs of individuals with ASD.

CHAPTER 5

ASSESSING THE COGNITIVE COMPONENTS OF TIME- AND EVENT-BASED PROSPECTIVE MEMORY AMONG PEOPLE WITH AUTISM AND THE GENERAL POPULATION: RELATIONS WITH INTEROCEPTION, ALEXITHYMIA, AND AUTISM TRAITS

Introduction

In the previous chapters, the nature of event- and time-based PM impairments in individuals with ASD was investigated in comparison to typically developing participants. The aim of this chapter was to investigate PM in typical development in the light of emerging theories on the links between autism, alexithymia, and interoception. Clarifying these links will extend our understanding of whether associations with interoception and alexithymia provide a new perspective on PM research in ASD.

Several theories attempt to capture the processes and mechanisms underpinning PM (see Chapter 1). Whereas the multiprocess framework (McDaniel & Einstein, 2000, 2007), as well as the PAM theory (R. E. Smith, 2003; R. E. Smith & Bayen, 2004), focus on event-based PM, the attentional gate model (Block & Zakay, 2006) provides a specific account of time-based PM. Regardless of what aspect/type of PM is under consideration, there is agreement that executive functions play a crucial role in PM development (Mahy et al., 2014). On a neural level, neuroimaging studies have identified shared, as well as distinct, regions of the rPFC that are engaged when an individual is engaged in one of the two PM types (Burgess et al., 2011; Gonneaud et al., 2014; Okuda et al., 2007). This evidence supports the need for separate theoretical accounts of event-based PM and time-based PM and further exploration how behavioural observation of PM translate into distinct patterns of brain activation. The exploration of autonomous and psychophysiological processes may therefore provide further insight into PM mechanisms.

Relatively little is known about the potential influence of psychophysiological processes involved in PM. A few studies have reported a role for autonomous responses in attention, response inhibition, or target detection which are relevant for PM (e.g., Jennings, 1992; Jennings, van der Molen, Brock, & Somsen, 1991; Ramírez, Ortega, & Reyes Del Paso, 2015). Furthermore, Kliegel, Guynn, and Zimmer (2007) have found that skin conductance response as a measure of autonomous arousal increases in response to the detection of PM cues, regardless of PM hit rate per se. This was interpreted to reflect the noticing a PM cue without necessarily triggering the retrieval of the content of an intention from retrospective memory. Importantly, the role of "interoception" has gained recent interest as a mediator in the effect of physiological arousal on cognition (Craig, 2003; Tsakiris & Critchley, 2016). Interoception refers to the perception of internal bodily states (thus the conscious perception of afferent autonomous reactions), such as hunger, thirst, heartbeat etc. Interoceptive processes are commonly classified into three partially distinct components (Garfinkel, Seth, Barrett, Suzuki, & Critchley, 2015). Interoceptive sensitivity represents the subjective experience of autonomous processes and is usually measured using self-report assessments. Interoceptive accuracy was defined as the ability to correctly detect and track measurable indicators of bodily sensations, e.g., heart rate. It is most frequently measured objectively using a heartbeat detection task (Schandry, 1981). In this task participants have to silently count their heartbeats without feeling their own pulse during different time intervals. Finally, interoceptive awareness was defined as the ability to reflect on one's own accuracy to correctly perceive interoceptive signals and can be operationalised as how strongly subjective interoceptive sensitivity and objective interoceptive accuracy match.

Interoceptive signals represent salient information about the current bodily state, which are integrated together with information on environmentally salient stimuli, as well as motivational, social, and cognitive conditions into a higher-order re-representation of the current state of self, influencing cognitive processes and behaviour (Craig, 2009; Critchley & Garfinkel, 2018). A few studies have implicated interoception in memory processes in general, and recently also in PM in particular. It has been suggested that bodily signals might act as facilitating cues for memory retrieval; thus greater interoceptive accuracy would enable better use of these cues leading to better memory performance (Critchley & Harrison, 2013). This is supported by evidence that greater interoceptive accuracy was related to better word memory when tested in a surprise free recall test (Garfinkel et al., 2013) or during an implicit memory test (Werner, Peres, Duschek, & Schandry, 2010). Furthermore, a recent study has found the first evidence for associations between interoception as well as heart rate variability (the variation in the time interval between consecutive heartbeats) and event-based PM (Umeda, Tochizawa, Shibata, & Terasawa, 2016). In their study, they explored how interoceptive accuracy (measured using the heart rate detection task) as well as cardiac activity recorded during the performance of an event-based PM task related to PM accuracy. They found that better PM performance was associated with greater interoceptive accuracy (r = .35) and accompanied by a greater increase in heart rate during the onset of a PM cue (r = -.42). The findings of Kliegel et al. (2007) and Umeda et al. (2016) indicate that physiological processes might mediate PM performance by being associated with the noticing of PM target cues. Therefore, greater interoceptive accuracy might lead to a significantly greater amount of noticing PM cues and hence a higher probability of engaging in retrieving the associated intention content from memory.

Importantly, physiological and interoceptive processes should also be relevant for time-based PM, although no study has so far explored this link. Originally it was proposed that physiological processes might influence time perception mediated through arousal effects (Mella, Conty, & Pouthas, 2011; Pollatos, Laubrock, & Wittmann, 2014; Wittmann, 2009). The common finding is that increased arousal modulates attention to time processing biasing time perception (usually resulting in overestimation of time). Craig (2009) has suggested that time perception may be directly related to physiological processes due to shared neural representations in the insular cortex. Using the pace-maker or attentional gate models of time perception/prospective timing (see Chapter 1), bodily signals may have a time-keeping function themselves, encoding duration by serving as direct input/beats into the pacemaker when timing an interval (Wittmann, 2009, 2013). Since then, several studies have explored how physiological signals (heart rate variability or skin conductance) as well as interoception relate to the perception of time. Several studies have reported positive associations between heart rate variability and time perception (Cellini et al., 2015; Fung, Crone, Bode, & Murawski, 2017; Pollatos, Laubrock, et al., 2014). Importantly there is also some evidence supporting a link between interoceptive accuracy and prospective timing estimates involved in time-based PM. For instance, Meissner and Wittmann (2011) found that greater interoceptive accuracy was associated with higher accuracy in a time reproduction task, which required participants to reproduce durations by indicating when a comparison tone was the same length as an initially presented first tone ($r = .45$). Furthermore, Pollatos, Yeldesbay, Pikovsky, and Rosenblum (2014) found heart rate variability associated with both interoceptive accuracy and time reproduction. In sum, the above evidence supports the idea that interoception may not only be associated with event-based PM but also time-based PM processes.

A personality trait that is thought to be inversely associated with interoception is alexithymia. Alexithymia is characterised by difficulties in describing and identifying emotions, distinguishing between emotions and physiological sensations of emotional arousal, as well as problems in thinking about one’s own emotional state resulting in an externally oriented cognitive style (Larsen, Brand, Bermond, & Hijman, 2003; Taylor, 2000). As reviewed by Taylor (2000), individuals high in alexithymic traits show deficits in the cognitive processing and regulation of emotions, as evidenced by poorer emotion regulation, low "emotional intelligence", and reduced emotional awareness. Importantly, the interpretation of bodily signals is involved in the identification of one's emotions and emotional awareness (Craig, 2009); e.g., NT individuals with better interoceptive accuracy seem to experience more intense emotional experiences (Critchley, Wiens, Rotshtein, Öhman, & Dolan, 2004; Pollatos, Traut-Mattausch, Schroeder, & Schandry, 2007). Consequently, it seems plausible that reduced cognitive-affective processing in alexithymia should be accompanied by decreased interoceptive processing. Based on associations found between interoceptive sensibility (R. Brewer, Cook, & Bird, 2016), as well as interoceptive accuracy (Herbert, Herbert, & Pollatos, 2011), and levels alexithymia, researchers have suggested that alexithymia is characterised by a generalised impairment of interoception.

These findings might further inform our understanding of PM both in typical and atypical development. If interoceptive abilities drive the level of alexithymic traits, then one would expect that alexithymia is linked to cognitive abilities that are associated with interoception. For the study of PM, the association between alexithymia and interoception suggests that difficulties with PM might be the result of high alexithymia traits mediating the effective use of interoceptive signals to influence the detection of and readiness to respond to PM cues. Importantly, a neurodevelopmental disorder which is characterised by specific impairments of PM (impaired time-based but undiminished event-based PM, see Chapter 1) and a high prevalence of alexithymia (Berthoz & Hill, 2005; Hill, Berthoz, & Frith, 2004) is ASD. A recently emerging view is that many social-affective difficulties (difficulties with empathy and emotion processing) observed in ASD are not core features of ASD, but rather the result of high levels of alexithymia (the "alexithymia hypothesis"; Bird & Cook, 2013; Bird et al, 2010; Cook, Brewer, Shah, & Bird, 2013; Milosavljevic et al. 2016). Furthermore, there is tentative evidence for diminished interoceptive accuracy in ASD (for a review DuBois, Ameis, Lai, Casanova, & Desarkar, 2016). However, there is some debate whether interoceptive difficulties are specific to ASD or due to alexithymia (Shah, Hall, et al., 2016). In their study, Shah et al. (2016) asked participants to count their own heartbeats using Schandry's (1981) heartbeat detection task. Crucially, NT and ASD participants were matched on alexithymia, which means that the study did not actually assess interoceptive accuracy in a representative group of autistic individuals who had high levels of alexithymia. No differences in interoceptive accuracy were found between groups, which was interpreted as supporting the alexithymia hypothesis. Based on this alexithymia account of ASD, PM problems might not be ASD-specific. For the study of PM in ASD it could mean that conflicting findings on event-based PM might be the result of biased samples. That is, previous studies (including those reported in Chapters 2 and 3) might have failed to find event-based PM problems in ASD because the sample might have consisted of an unrepresentative group of individuals with ASD who had low levels of alexithymia.

Despite, the emerging evidence in support of the alexithymia hypothesis of interoception in autism, it is incompatible with findings on self-awareness in ASD. These suggest that the physical self-knowledge (the awareness of one's own bodily states, appearance, and actions) in ASD is intact whereas the psychological self-knowledge (the awareness of one's own mental states, knowledge of one's personality, and autobiographical memory) is reduced (Lind, 2010; Uddin, 2011; Williams, 2010). This view would predict that ASD traits are not associated with deficits in interoception, thus an association between interoceptive accuracy and PM should be found regardless of autism traits. Furthermore, intact physical self-awareness in ASD would also question the association between alexithymia and interoception itself; according to this account people with ASD/high ASD traits should have difficulties interpreting their physiological states (alexithymia), basic detection of states (interoceptive accuracy) should not be diminished. Based on the above described association between interoception and PM, interoceptive signals require merely detection to serve as cues for PM; thus, alexithymia should not be involved in the relationship between interoceptive accuracy and PM.

Therefore, the current study aimed to investigate specific associations between both types of PM, interoception, ASD traits and alexithymia traits in typically developing individuals using an individual differences approach. Autism traits are thought to be normally distributed in the general population (Nishiyama et al., 2014), thus one cannot divide individuals in two categories reflecting the presence/absence of autism traits. Instead, all individuals in the general population can be characterised in terms of their behaviour along a continuum of autism traits (Baron-Cohen et al., 2001). For instance, family members of individuals diagnosed with ASD might show difficulties in social cognition but not executive functions (Losh et al., 2009). Equally, neurotypical individuals might be characterised by isolated autistic traits in a specific domain which are higher than the population average but nonetheless are not clinically significant. Thus, given that ASD features are likely to be distributed continuously throughout the general population (Frazier et al., 2014), investigating how autism traits in the general population relate to PM, alexithymia, and interoception can further extend our understanding what underpins PM difficulties in ASD itself. Additionally, in Appendix 4 we will report results from a pilot study which collected interoceptive accuracy and alexithymia data from a subsample of participants reported in Chapter 4.

The first aim of this study was to establish the associations between PM and interoceptive accuracy. It was predicted that interoceptive accuracy would positively correlate with event-based PM, replicating Umeda et al.'s (2016) findings. Furthermore, based on the associations between time perception and interoception, it was predicted that interoceptive accuracy would correlate with time-based PM. Specifically, greater interoceptive accuracy might be predictive of the accuracy of PM responses (one might imagine that individuals who can keep accurately track of their bodily signals, can better use the autonomic feedback to keep track of time and thus respond more accurately in the PM response interval) rather than PM hits per se. The second aim of this study was to clarify the role of ASD and alexithymic traits in this relationship. In line with the view of intact physical self-awareness in ASD, it was predicted that autism traits would not be associated with interoceptive accuracy. Furthermore, due to scepticism with regard to the alexithymia hypothesis of ASD, in combination with the specific pattern of PM impairment in ASD, it was predicted that associations between PM and interoceptive accuracy would be found regardless of the level of alexithymic traits. Furthermore, it was predicted that ASD traits would be correlated with time-based PM but not event-based PM performance, independently of alexithymia traits or interoceptive ability. Finally, the role of top-down cognitive control was explored. The importance of executive functions for PM functioning is widely agreed upon (see Chapter 1 and results from Chapter 4). Critchley and Garfinkel (2017) proposed that executive processes can be viewed as a higher-order dimension of interoception. Specifically, it could be argued that the concept of cognitive flexibility might be applicable to shifts of attention between salient interoceptive signals and exteroceptive stimuli. Therefore, cognitive flexibility might influence the efficient use of interoceptive signals when responding to external stimuli. This aligns with the idea that the detection of salient stimuli (facilitated through interoception) guides the allocation of attention and flexible responding (Dajani & Uddin, 2015). Therefore, cognitive flexibility might have a mediating role in relationship between interoceptive accuracy and PM.

Methods

Participants

Sixty participants were recruited to take part in this study. All participants were students at the University of Kent and participated via the Research Participation Scheme in exchange of course credits. The study was approved by the ethics committee of the University of Kent and all participants gave written informed consent prior to taking part in the study. Five participants were excluded from further data analyses after data collection was complete due to a) misunderstanding task instructions in the key experimental PM condition ($n = 2$), or b) being identified as influential cases ($n = 3$, see Statistical analysis section). Thus, the final sample comprised of 55 participants. Participants were randomly assigned to one of two conditions completing either a time-based ($n = 27$) or an event-based ($n = 28$) PM task. Participants in the two conditions were matched on chronological age, $t(53) = .83$, $p = .41$, $d = 0.23$, $\mathrm{BF}_{10} = 0.36$ (event-based PM: $M = 21.37$, $SD = 5.44$, time-based PM: $M = 20.40$, $SD = 2.69$).

Tests and procedures

PM task. Participants were randomly assigned to one of two conditions at the beginning of the experiment. Half the participants completed an event-based PM task whereas the other half completed a time-based PM task. Each condition lasted approximately 11 minutes. The experimental design of the ongoing on PM task replicated the design and procedure of Umeda et al. (2016) who were the first to demonstrate the association between interoceptive accuracy and event-based PM. As the first aim of this study was to replicate this finding and to extend it to explore it with regards to time-based PM, the present procedure and stimuli closely matched those of Umeda et al. (2016).

The ongoing task consisted of a n-back task (2-back version) originally developed by Kirchner (1958) as widely used updating/working memory paradigm. Each trial consisted of a lower-case letter (one of 10 consonant letters: b, c, d, f, g, h, k, m, n, or p) presented in the centre of the screen for 500ms followed by a variable inter-stimulus interval (ISI, between 2 and 3s) during which the screen was left blank. Participants had to respond for each trial as quickly as possible whether or not the letter on-screen matched the letter that had been presented two trials previously (yes/no forced-choice response; see Figure 12). There were 204 ongoing trials in total; 30 % of the trials were n-back matches and 70% were mismatches. The task did not contain any lure 1-back or 3-back trials. Prior to instructing participants about the PM task, participants completed a short, 18-trial, practice block. Responses on each ongoing trial received a score of one if they were correctly classified as 2-back match or mismatch (*ongoing hit*). The proportion accuracy of hit trials relative to the total number of ongoing trials was computed (*ongoing hit proportion*) across match and mismatch trials.

For each condition, five PM trials were embedded into the above ongoing task. Incorrect responses to PM trials were not counted towards the ongoing hit proportion score. In the *event-based PM condition*, participants had to remember to press a pre-specified keyboard key whenever noticing a letter on screen that was a vowel. On each PM trial, a different vowel was used as PM target. The order of the vowels was random across participants. If participants remembered correctly to press the pre-specified key upon encountering a vowel they received a score of one (*PM hit*). PM performance was measured as the proportion of PM hits relative to the total number of PM trials.

In the *time-based PM condition*, participants had to remember to press a pre-specified keyboard key in 2-minute intervals while performing the ongoing task (thus after 2, 4, 6, 8, and 10 minutes). They were able to check the elapsed time by pressing another keyboard key which would trigger a digital clock to briefly appear. Responses within a 5-second interval (target time ± 2.5seconds) received a score of one (*PM hit*). PM performance was measured as the proportion of PM hits relative to the total number of PM trials (*PM proportion hits*).

Furthermore, the accuracy of the PM response (*PM target accuracy*) was analysed as the absolute reaction time difference between target time and the time of the PM response. A value of zero would indicate perfect accuracy (i.e., pressing exactly on the target time), and hence the bigger the value the further from target time the PM press happened (max 2.5 seconds). Time monitoring was assessed as the mean number of time checks within 30-second segments leading up to each target time (0-30, 31-60, 61-90, 91-120 seconds) across all five PM trials. Once participants had completed the respective PM condition retrospective memory for task instructions was verified. All participants were able to correctly recount the PM task instruction.

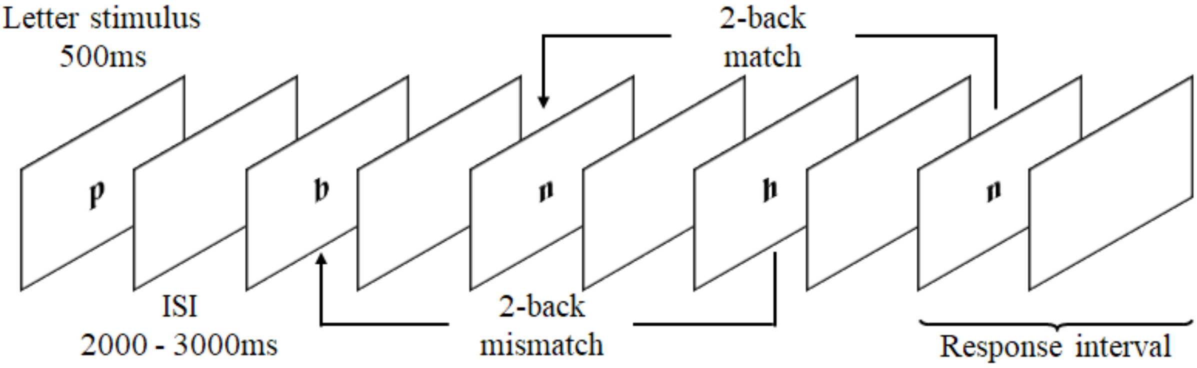

Figure 12. Schematic illustration of the 2-back ongoing task

Self-report measures.

Autism-spectrum Quotient (AQ, Baron-Cohen et al., 2001). The AQ questionnaire was used to assess autistic features in the present sample (see Chapter 4, page 92 for a description).

Toronto Alexithymia Scale (TAS). The TAS (Bagby, Parker, & Taylor, 1994) is a 20-item self-report measure concerning people's awareness and understanding of, and ability to describe, their own bodily sensations and feelings. Participants have to rate their agreement with each of the 20 statements on a 5-point scale ('Strongly Disagree', 'Moderately Disagree', 'Neither Disagree or Agree', 'Moderately Agree', 'Strongly Agree'). It is widely used

(Kooiman, Spinhoven, & Trijsburg, 2002) and has good reliability (internal consistency 0.86; Parker, Taylor, & Bagby, 2003). Higher scores indicate higher levels of alexithymia.

Behavioural measures.

A computerised version of the Wisconsin Card Sorting Task (WCST; Berg, 1948; Nelson, 1976) was used as an established measure of cognitive flexibility/set shifting (Miyake et al., 2000). The procedure was the same as described in Chapter 4 (pp. 101-102). Performance was again determined following the criteria by Cianchetti et al. (2007) and the number of perseverative errors was used as a measure of cognitive flexibility. A perseverative error was defined as a) persisting to sort a card into the same category as the previous one, after they had received feedback of their previous sort being incorrect

A heartbeat detection task (Schandry, 1981) was employed as a widely used measure of one's interoceptive ability (ability to monitor one's own physiological states). Following the procedure of Shah, Catmur, and Bird (2016), we assessed participants' interoceptive ability and compared it to their actual heart rate as acquire using a finger pulse oximeter (Contec Systems CMS-50D; Qinhuangdao, China) attached to the index finger. Participant were sat in a quiet room with closed eyes and count their heart beats using no other means than concentrating on their heart beating. This task was completed for four intervals of varying duration (25, 35, 45, and 100 seconds). The interoceptive accuracy score was calculated separately for each interval using the following formula:

$$\left(1 - \frac{|recorded\ no\ of\ heartbeats - counted\ no\ of\ heartbeats|}{recorded\ no\ of\ heartbeats}\right) * 100.$$

Subsequently, the mean across the four intervals was computed to obtain a global index of interoceptive accuracy with higher scores indicating better interoceptive accuracy.

Power analysis

Umeda et al. (2016) found a significant correlation between event-based PM and interoceptive accuracy of 0.35 with 36 participants in total. A power analysis using G*Power 3 (Faul et al., 2007) indicated that a sample size of 46 participants would be required to detect a positive correlation of similar size to achieve the recommended power of .80 (Cohen, 1992).

Statistical analysis

Differences in performance on the ongoing and PM task as well as scores on secondary measures between conditions were analysed using independent sample t-tests. Cook's distance was used to identify possible influential cases[15] in the relationship between interoceptive accuracy and PM (PM accuracy in the case of event-based PM and PM target accuracy in the case of time-based PM). An influential case was defined as a case with a Cook's distance greater than $\frac{4}{N-k-1}$ with *N* being the sample size and k being the number of predictors (Hair, Anderson, Tatham, & Black, 1998). Thus, the sample size in each condition being $N = 29$, the cut-off value was 0.15. This resulted in the exclusion of two participants in the time-based PM condition (Cook's distance being 0.25 and 0.27) and one participant in the event-based PM condition (Cook's distance being 0.21). This, procedure was also confirmed when graphically exploring Cook's distance within each condition examining any point that was much greater in comparison to all the others (Chatterjee & Hadi, 2012; see

Figure 13). Thus, the final sample consisted of $n = 28$ in the event-based PM condition and $n = 27$ in the time-based PM condition.

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[15] This method was not used in the previous chapter as it would have required the use of dimensional approaches or multivariate regression analyses, which would have been underpowered given the sample size in combination with a large number of predictors.

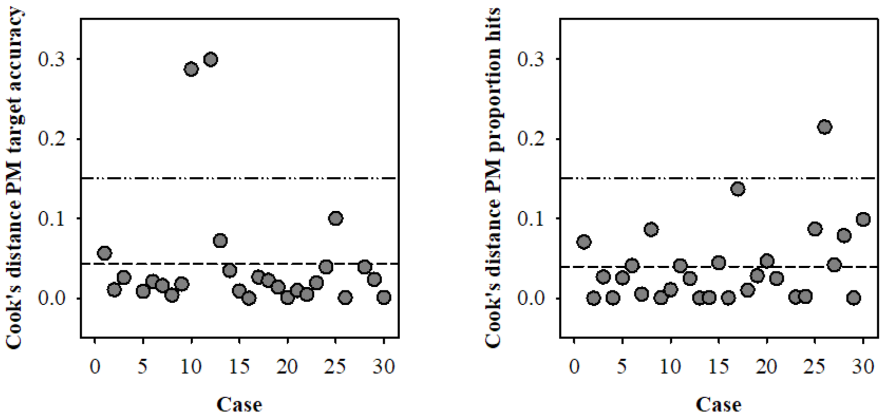

Figure 13. *Distribution of Cook's distance values in the time-based PM (left) and event-based PM (right) condition. The dotted-dashed line marks the cut-off point above which participants were excluded. The dash line marks the mean Cook's distance in each sample.*

Subsequently, Pearson's correlation analyses and partial correlation analyses were conducted to investigate associations between variables. Correlation coefficients were classified as small when r ≤ .10, moderate when r ≤ .30, and large when r ≤ .50 (Cohen, 1988). Fisher *z*-tests were used to assess whether correlation coefficients significantly differed between the two PM conditions. Furthermore, it was assessed whether the associations found between PM and interoceptive accuracy in this study significantly differed between PM condition and from those reported by Umeda et al. (2016). For comparisons of correlation coefficients involving accuracy of PM responses, the correlation coefficient was recoded such as that positive correlations were recoded as negative and vice versa. This is because a smaller value in PM target accuracy indicates better performance whereas it is the opposite for PM proportion hits. Furthermore, Bayesian correlation analyses were conducted. For the bivariate correlations reported in Table 17 two-tailed tests were used, thus the BF_{10} in support of the alternative (H_1) over the null hypothesis (H_o) indicates evidence in favour of a correlation to be existent regardless of its direction. For the partial correlations reported, one-tailed or two-tailed tests were used based on the a priori predictions, thus $BF_{10\ \mathrm{correlation}}$ indicates support in favour of the correlation to exist, $BF_{10\ \mathrm{positive}}$ indicate support in favour of a positive and $BF_{10\ \mathrm{negative}}$ indicates support in favour of a negative correlation. Bayesian partial correlations were computed using the same procedure as described in Chapter 4. Classification of Bayes factors was as described in Chapter 2 according to the guidelines of Lee and Wagenmakers (2013).

Results

Sample description

Groups did not significantly differ on measures of autistic traits, alexithymia traits, or interoceptive accuracy, although participants in the event-based PM condition made significantly more perseveration errors in the WCST than participants in the time-based PM condition (see Table 16).

Table 16. Descriptives (mean, SD) and results of independent sample t-tests of all outcome variables

	Event-based PM condition (*n* = 28)	**Time-based PM condition (*n* =27)**	***t***	***df***	***p***	**Cohen's *d***
PM proportion hits	.46 (0.29)	.59 (0.32)	-1.47	53	.15	-0.43
Ongoing hit proportion	.82 (0.14)	.80 (0.13)	0.38	53	.71	0.15
AQ total score	18.64 (4.76)	17.81 (6.05)	0.57	53	.57	0.15
TAS total score	50.57 (12.22)	52.30 (10.55)	-0.56	53	.58	-0.15
WCST perseverative errors	8.18 (5.07)	4.85 (5.48)	2.34	53	.02	0.63
Interoceptive accuracy	66.95 (13.90)	68.54 (14.32)	-0.42	53	.68	-0.11

Ongoing and PM task performance

Both groups performed equally well on the ongoing 2-back task. With regard to PM performance, participants in the time-based PM condition showed significantly more PM hits compared to those in the event-based PM condition (see Table 16). A repeated-measures ANOVA was used to assess time-monitoring in the time-based PM condition. There was a significant main effect of interval, $F(1.72, 44.72) = 43.58$, $p < .001$, $\eta_p^2 = .63$, $\mathrm{BF}_{10} = 2.14*10^{10}$. Participants in the time-based PM condition exhibited the typical J-shaped pattern of time checks with few checks at the beginning of each 2-minute interval, increasing the frequency of checks closer to target time (see Figure 14). The frequency of time checks significantly differed between each interval (all *p*s < .01, all $BF_{10} > 66.45$), except for comparison between the first and second interval. For those participants who achieved a minimum of one PM hit ($n = 25$), PM target accuracy was computed ($M = 0.67$, $SD = 0.43$, range: 0.11-1.61 seconds).

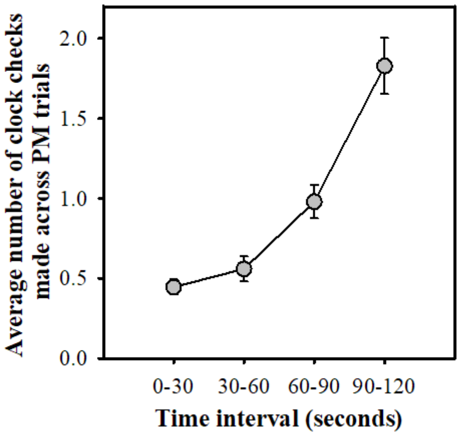

Figure 14. Illustration of the time monitoring pattern in the time-based PM condition

Correlates of PM

Table 17 displays the intercorrelations between all variables of interest, as well as associated *p* and BF_{10} values (coefficients below the diagonal in light grey shading reflect the results for the time-based PM condition, coefficients above the diagonal in dark grey shading reflect the results for the event-based PM condition). No significant associations between interoceptive accuracy and event- or time-based PM were found. Fisher *z*-tests revealed that the association between PM and interoceptive accuracy in two conditions did not significantly differ from each other, nor did they significantly differ from the one reported by Umeda et al. (2016), see Appendix 3, Table A4, all *p*s ≥ .41. Moreover, interoceptive accuracy also was not associated with autism traits or alexithymia in either condition (see Table 17), nor across the whole sample (correlation with AQ $r = .04$, $p = .76$, $BF_{10} = 0.18$, correlation with TAS $r = .13$, $p = .33$, $BF_{10} = 0.27$), with Bayes factors providing evidence for the null hypothesis. Neither time-nor event-based PM hits were associated with traits of autism or alexithymia. Time-based PM target accuracy, however, correlated significantly with autism traits, indicating that more autism traits were associated with less accurate PM responses (larger values for PM responses represent a greater time difference). A similar trend was found for alexithymia traits. Furthermore, time-based but not event-based PM hits were associated with fewer perseverative errors on the WCST. Finally, there was a trend for an association between interoceptive accuracy and cognitive flexibility in the event-based condition, indicating that individuals with higher interoceptive accuracy committed more perseverative errors. Fisher *z*-tests revealed no significant differences in these correlation coefficients between conditions (all *p*s $\geq$ .12), except for the correlation between AQ and interoceptive accuracy ($z = -2.28$, $p = 0.02$; see Appendix 3, Table A5). Based on the outcome of the bivariate correlations and the a priori predictions, the following partial correlations were conducted (see Figure 15 for scatterplots of the key partial correlations).

Table 17. Intercorrelations of variables for event-based PM (n = 28, dark grey) and time-based PM (n = 27, light grey)

		PM$_{\text{target accuracy}}$	**PM$_{\text{proportion hits}}$**	**Interoceptive accuracy**	**AQ$_{\text{traits}}$**	**TAS$_{\text{traits}}$**	**WCST$_{\text{perseverative errors}}$**	**Ongoing task hits**
PM$_{\text{proportion hits}}$	Pearson's *r*	-.16		.26	-.09	-.10	-.20	**.34**
	p-value	.46		.18	.18	.62	.31	**.08**
	BF$_{10}$	0.32		0.55	0.26	0.26	0.38	**1.00**
Interoceptive accuracy	Pearson's *r*	-.29	.03		.14	.33	**.35**	.09
	p-value	.16	.89		.49	.09	**.07**	.67
	BF$_{10}$	0.62	0.24		0.30	0.92	**1.19**	0.26
AQ$_{\text{traits}}$	Pearson's *r*	**.63****	-.09	-.02		.17	.08	.01
	p-value	**<.001**	.67	.91		.38	.69	.96
	BF$_{10}$	**59.07**	0.26	0.24		0.34	0.25	0.24
TAS$_{\text{traits}}$	Pearson's *r*	**.36**	-.19	-.10	**.54****		.32	.13
	p-value	**.08**	.34	.63	**<.01**		.10	.51
	BF$_{10}$	**1.07**	0.37	0.27	**13.91**		0.84	0.29
WCST$_{\text{perseverative errors}}$	Pearson's *r*	-.06	**-.38**	.01	-.21	-.08		-.28
	p-value	.77	**.05**	.95	.30	.70		.15
	BF$_{10}$	0.26	**1.41**	0.24	0.40	0.26		0.62
Ongoing task hits	Pearson's *r*	-.05	0.02	**0.36**	.10	-.10	-.30	
	p-value	.82	.91	**.06**	.64	.63	.13	
	BF$_{10}$	0.25	0.24	**1.26**	0.27	0.27	0.73	

Notes. Significant and marginally significant correlations are highlighted in bold.

In the *time-based condition*, the correlation between autism traits and PM target accuracy remained significant, even after controlling for alexithymia traits ($r = .56$, $p < .01$, $BF_{10\ \text{positive correlation}} = 28.59$, $BF_{10\ \text{correlation}} = 14.33$). The inverse partial correlation was not significant ($r = .06$, $p = .77$, $BF_{10\ \text{positive correlation}} = 0.26$, $BF_{10\ \text{correlation}} = 0.31$). Furthermore, controlling for autistic traits resulted in a marginally significant correlation between PM target accuracy and interoceptive accuracy ($r = -0.35$, $p = .09$, $BF_{10\ \text{negative correlation}} = 1.83$, $BF_{10\ \text{correlation}} = 0.96$) but not when controlling for alexithymia traits ($r = -0.27$, $p = .19$, $BF_{10\ \text{negative correlation}} = 1.00$, $BF_{10\ \text{correlation}} = 0.56$). Additionally, autism traits were strongly associated with time-based PM after controlling for interoceptive accuracy ($r = .65$, $p < .001$, $BF_{10\ \text{positive correlation}} = 182.43$, $BF_{10\ \text{correlation}} = BF_{10} = 91.24$).

In the *event-based PM condition,* controlling for WCST performance resulted in a marginally significant correlation between PM hits and interoceptive accuracy ($r = .36$, $p = .06$, $BF_{10\ \text{positive correlation}} = 2.43$, $BF_{10\ \text{correlation}} = 1.26$). This indicates that better event-based PM was associated with better interoceptive accuracy when excluding the influence of cognitive flexibility. When reversing the partial correlation controlling for PM hits, WCST performance remained positively correlated with interoceptive accuracy ($r = .43$, $p = .02$, $BF_{10\ \text{positive correlation}} = 5.39$, $BF_{10\ \text{correlation}} = 2.73$).

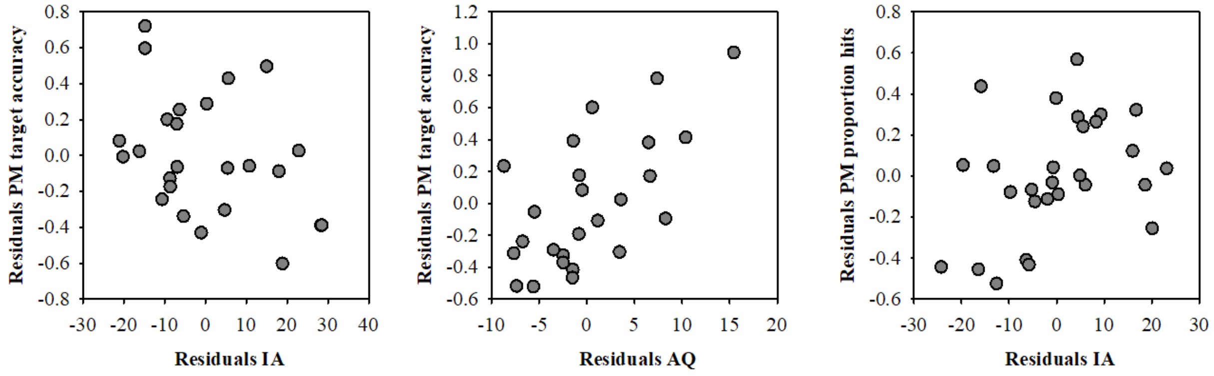

Figure 15. Illustration of partial correlations by plotting the correlations between the respective residuals for (1) interoceptive accuracy and time-based PM target accuracy controlling for autistic traits (left), (2) autism traits and time-based PM target accuracy controlling for alexithymia traits (middle), and (3) interoceptive accuracy and event-based PM proportion hits controlling for cognitive flexibility(right)

Discussion

This study aimed to disentangle the associations between event- and time-based PM, interoceptive accuracy, ASD traits and alexithymia traits in typically developing individuals using an individual differences approach. Previous research had found associations between event-based PM and interoception (Umeda et al., 2016), although this had not yet been explored for time-based PM. Due to the involvement of autonomous responses and interoception in time perception (Meissner & Wittmann, 2011; Wittmann, 2013), we hypothesised that time-based PM may equally be related to interoceptive processing. Furthermore, under the assumption that interoception may not be diminished in individuals with higher autism traits and thus unrelated to alexithymia traits, no influence of alexithymia or autism traits were expected on PM. Instead, it was predicted that autism traits would be uniquely associated with time- but not event-based PM performance. Finally, it was predicted that cognitive flexibility as an indicator of top-down cognitive control would be associated with both interoception and PM.

In the initial analysis, this study failed to directly replicate Umeda and colleagues finding of a moderate size association between interoceptive accuracy and event-based PM performance. Importantly, ongoing task performance was not associated with interoceptive processing (replicating Umeda and colleagues' results) supporting the idea that interoceptive accuracy was not associated with general dual-task demands. Interestingly, despite randomisation, participants in the event-based condition showed worse cognitive flexibility than participants in the time-based condition. As cognitive flexibility is thought to be involved at the interface of processing salient interoceptive stimuli to guide attention and response selection, poorer cognitive flexibility could have masked the relationship between interoception and event-based PM. When controlling the influence of cognitive flexibility, a marginally significant positive relationship between event-based PM and interoceptive accuracy was found, which was comparable in size to Umeda and colleagues finding. The

Bayes factor in favour of a positive correlation did just miss the threshold of providing evidence for the alternative hypothesis. However overall, it indicates that there was more evidence in support of a positive association between event-based PM and interoceptive accuracy. Limited statistical power due to a smaller sample than Umeda et al. (2016) will likely have contributed to this. Although, this result needs to be considered with care due to this restriction, it provides additional tentative support for the suggestion that the ability to detect and use these autonomous afferent signals likely facilitates the recognition of the PM cue as salient for behaviour leading to the successful retrieval and execution of the PM response. This strengthens the evidence that suggest that greater sensitivity to interoceptive processes benefits event-based PM performance.

Although this study found at least a trend for an association between PM and interoception, alexithymia did not play a role in PM performance. This supports the assumption that the ability to interpret physiological signals is what drives the association between interoception and PM. Thus, alexithymia can be excluded as a potential confound, which could have explained heterogeneous event-based PM results in ASD. Instead, since no association between event-based PM and autism traits was found, this strengthens the view of unimpaired event-based PM in ASD. The corresponding Bayes factors support this conclusion in favour of the null hypothesis.

With regards to time-based PM, it was hypothesized that increased interoceptive accuracy would be related to more accurate PM responses; i.e., responses more closely to the 2-minute target time, rather than the number of PM hits per se. Contrary to this prediction, no correlation between time-based PM performance and interoception was found. However, it was found that PM target accuracy was strongly positively related to the level of autism traits in this sample of typically-developing individuals, indicating that more autistic features were associated with less accurate correct PM responses. When controlling for autism traits, results revealed a trend indicating that PM target accuracy was associated with greater interoceptive accuracy. This might reflect the ability to make better use of bodily signals feeding temporal estimates in individuals who are more attuned to interoceptive processes. The Bayes factor for this correlation, similarly to the event-based PM result, provided more evidence for the alternative hypothesis but also missed the threshold to provide stronger support in favour of H_1, which again could be due to lower than desired power in this study. Thus, this result should be treated with caution.

Importantly, autism traits were not associated with interoceptive accuracy, nor was the relationship between PM and autism traits mediated by alexithymia traits in this condition. This finding is clearly in line with the consistent time-based PM impairments found in individuals with ASD (see Chapter 1). Moreover, the results from the pilot study in Appendix 4 (pp. 173-175) revealed a similar pattern of correlations and also no association between interoceptive accuracy and PM performance in a group of individuals with a confirmed diagnosis of ASD. This is important because although ASD is a continuous disorder, with ASD traits likely distributed continuously throughout the general population (e.g., Frazier et al., 2014), there can still be qualitative differences in the mechanisms/processes that underpin those traits in each population (e.g. Peterson et al., 2005; Mandy et al., 2012). Therefore, these findings suggest that time-based PM difficulties are unique to ASD and that they are not the result of interoceptive abilities in ASD. However, further research with a comparing a larger sample of ASD and NT individuals is needed to corroborate this conclusion.

Overall, this gives some initial tentative support that interoceptive processes play a role in time-based PM. Future research should aim to confirm this finding and establish how bodily signals such as heart rate variability reflect the association between interoceptive accuracy and time-based PM. Previous studies have shown that heart rate variability is associated with time perception in the range of 2 to 20 seconds (Meissner & Wittmann, 2011). Thus, it would be interesting to study cardiac reactivity in this time windows leading up to PM target times, and whether any increase in heart rate may be associated with PM performance.

Furthermore, the real-life implications of this finding would be an important area of research. Usually time-based intentions cover longer time intervals and are not characterised by frequent monitoring processes (Terry, 1988) or do involve restricted access to a clock. It would be interesting to explore whether interoceptive accuracy is positively related to time-based PM with no or restricted access to a time-monitoring device. A prediction to explore would be that individuals with greater interoceptive accuracy are more on time and reliable when it comes to fulfilling naturalistic time-based intentions.

Implications for alexithymia account of PM in ASD

In this study, interoception was not associated with autism traits, nor did it find a link between interoception and alexithymia. This is in contradiction with the emerging alexithymia hypothesis of ASD, which attributes social-affective and interoception difficulties in ASD to co-occurring alexithymia in ASD (Bird & Cook, 2013; Bird et al, 2010; Cook, Brewer, Shah, & Bird, 2013; Milosavljevic et al. 2016) and casts doubt into the associations between interoception, autism, and alexithymia. A recent study (Nicholson et al., 2017) that specifically aimed to test the predictions of Shah et al. (2016) has found similar results as this study did. In a much larger sample of neurotypical individuals (*n* = 137), Nicholson and colleagues did not find any associations between interoceptive accuracy and autism or alexithymia. Moreover, interoception was not impaired in a large sample (*n* = 46) of individuals with a full diagnosis of ASD (compared to 48 controls), even though more than half of the sample manifested clinically significant levels of alexithymia. Those and the present findings therefore provide support for unimpaired interoception along the autism spectrum in line with evidence of intact physical self-awareness in ASD.

Conclusion

In sum, the current results tentatively support and extend prior evidence linking interoception and PM. Furthermore, the associations found between autism traits and PM in this study precisely mirrored the pattern of unimpaired event-based and diminished time-based PM in individuals with ASD. Finally, the evidence suggests that neither the level of alexithymia traits nor interoceptive accuracy will have explanatory power to further advance our understanding of time-based PM problems in ASD (although this remains to be tested in an actual sample of ASD individuals).

CHAPTER 6

GENERAL DISCUSSION

Previous research has so far disputed whether event-based PM is impaired or not in whilst seeking to find an explanation for time-based PM impairments in ASD. This thesis explored both of these important aspects of PM in an attempt to advance our understanding of PM abilities as well as the underlying mechanisms for diminished PM in ASD. Two studies addressed the question of impairment of event-based PM in ASD, one study explored contributing factors for time-based PM impairments in ASD, and one study explored both event-based PM and time-based PM in relation to interoception and ASD traits among neurotypical individuals using an individual differences approach.

The results of this thesis enhance existing knowledge on PM, in general, and PM in ASD specifically. Results from Chapters 2 and 3 offer strong support for genuinely undiminished event-based PM in ASD. Chapter 4 provides novel insight into why time-based PM in ASD is impaired and that there may be ways to alleviate some of the severity of difficulties using simple strategies. Finally, Chapter 5 confirms this dichotomy in the association of PM abilities with autism traits in NT healthy individuals and gives insight into their relation with interoception and related constructs. The following discussion of the results presented in this thesis will integrate the findings within the broader literature, discuss their implications for everyday life in ASD, consider wider issues of PM research in ASD, as well as explore directions for future research.

Event-based PM in ASD

Chapters 2 and 3 assessed event-based PM in children with ASD and presented a consistent pattern of findings that indicated undiminished performance in ASD. Event-based PM was tested under two different assumptions to elucidate whether a specific pattern or the use of compensatory strategies underpinned the inconsistent previous evidence on event-based PM abilities in ASD. The results of both studies were in keeping with previous studies that report unimpaired event-based PM performance in ASD (Altgassen & Koch, 2014; Altgassen, Schmitz-Hübsch, et al., 2010; Henry et al., 2014; Williams et al., 2013; Williams et al., 2014). These findings have added to those previous results in two ways. (1) Results from Chapter 2 indicate that event-based PM is not significantly more negatively affected in ASD than in NT children, irrespective of the way the PM cue is embedded into the ongoing task (cue focality), as well as regardless of its sensory modality (auditory/visual). This finding aligns with findings of a recent study, which found that PM cue salience did also not negatively impact PM performance (Sheppard & Altgassen, 2016). This suggests that the multiprocess model (McDaniel & Einstein, 2000, 2007), as a descriptive framework of event-based PM, can be applied to PM in ASD. (2) Results from Chapter 3 strongly increase the confidence in the finding of unimpaired event-based PM in ASD since it ruled out the possibility that individuals with ASD might "hack out" solutions to event-based PM tasks using compensatory verbal strategies. Finally, findings from Chapter 5 confirm this pattern indicating that event-based PM is not associated with autistic traits in healthy adults. Complementary Bayesian analyses reliably supported this evidence in favour of the null hypothesis.

Time-based PM in ASD

In line with the general research and the findings of the meta-analysis conducted in Chapter 1, findings of Chapters 4 and 5 replicated the association of time-based PM difficulties with autism in both healthy typically developing individuals as well as individuals with a clinical diagnosis of ASD. Most importantly, however, using a manipulation that emphasised the importance of the time-based delayed intention (Chapter 4), it was found that time-based PM performance was significantly improved among individuals with ASD. The extent of the improvement in performance was significantly related to executive functioning in ASD (both on a behavioural measure of cognitive flexibility and a self-report measure of inhibition). Individuals who were characterised by lower executive functions benefitted *most* from the manipulation of relative task importance whereas mindreading ability was not involved in facilitating PM performance. The results of the Bayesian analyses supported the corresponding pattern of results.

PM in ASD in the context of broader theory

Taking the result of this thesis together and reflecting on them it in the light of the gateway hypothesis provides a promising approach to PM abilities in ASD. The gateway hypothesis suggests that a supervisory attentional gate constantly balances resources allocated to stimulus-oriented and stimulus-independent thought (Burgess et al., 2007). The key brain region involved in this process is the rostral prefrontal cortex (rPFC) with its medial part being involved in the former, and the lateral part being involved in the latter (Burgess et al., 2011). Applied to PM, it has been suggested that the medial rPFC is activated while performing the ongoing task in response to external stimuli, but also plays a role in the detection of PM cues in event-based PM tasks. Furthermore, regardless of the type of PM task (time or event-based), it has been found that in NT participants, medial rPFC is deactivated on PM trials indicating disengagement of attention away from the ongoing task accompanied by an increase in lateral rPFC activation (Gonneaud et al., 2014). This is thought to reflect the shift of attention towards the internal representation of one's intention in order to subsequently execute it

Dumontheil, Burgess, and Blakemore (2008) have proposed that rPFC functioning might play a pivotal role in atypical cognitive functioning in ASD. Based on the findings of PM in ASD - the dichotomy of impaired time-based and spared event-based PM - it may be that there is an imbalance between the two systems towards the medial rPFC stimulus-oriented system or problems in the switch from medial rPFC stimulus-oriented to lateral rPFC stimulus-independent processing in ASD. While this switch is facilitated by cues in the case of event-based PM, for time-based PM in absence of any specific cues and thus greater involvement of self-initiated processes, participants with ASD likely have problems to initiate a switch to disengage from the ongoing task and bring the intention to mind at the appropriate time despite having access to clocks. On a behavioural level this hypothesis is supported by the finding that cognitive flexibility was involved in successful PM in ASD (see Chapter 4). This would mean that stimulus-independent processing in ASD on its own should be intact however, without a cue these representations cannot be accessed. This idea fits well when considering the retrospective memory profile in ASD, the pattern of intact cued memory recall or recognition memory relying on stimulus-oriented processed, in the face of diminished free memory recall and autobiographical memory (Bowler et al., 2004; Lind, 2010), requiring stimulus-independent retrieval of mental representations. This also corresponds with findings on reduced metacognitive monitoring in ASD (the awareness of one's own current mental states and thoughts), which equally taps into stimulus-independent processing (Grainger, Williams, & Lind, 2014; Williams, Bergstrom, & Grainger, 2016; Wojcik, Moulin, & Souchay, 2013). Altogether, this adds to the behavioural evidence supporting the above notion of problems to access stimulus-independent mental representations in ASD, which would explain the pattern of impaired time- but unimpaired event-based PM.

On a neural level, lateral rPFC is thought to play a content-free role in PM; its activation representing a state of readiness that an intention needs to be fulfilled in the future (Landsiedel & Gilbert, 2015). In line with this Gilbert, Bird, Brindley, Frith, and Burgess (2008) found similar lateral rPFC activation in ASD compared to NT participants in a task that specifically contrasted stimulus-oriented and stimulus-independent thought. This is in line with the finding that individuals with ASD do remember that there was an intention when being asked at the end of an experiment (thus they are able to form an intention in the first place). It may be that atypical functional organisation within medial rPFC (Gilbert et al., 2008; Gilbert, Meuwese, Towgood, Frith, & Burgess, 2009) might be involved in an increased stimulus-oriented attending in ASD. Based on the findings in Chapter 4, the switch from stimulus-oriented to stimulus-independent processing may have been facilitated when participants were instructed that the PM intention was more important than the ongoing task. This might have shifted the overall focus more towards one's internal representations. Alternatively, the observed increase in time-monitoring might have provided the necessary cue to bring the intention to mind at the appropriate time if it occurred closely enough to target time

Furthermore, lateral and medial rPFC have been described as part of two separate anti-correlated brain networks 1) the "task-positive", "multiple-demand" network, as well as the 2) task negative or default mode network (Duncan, 2010; Fox et al., 2005; Raichle et al., 2001). Several studies have suggested that the switch between these two networks is orchestrated by the anterior insula, which lies at the core of the saliency or cingulo-opercular network (Menon & Uddin, 2010). The insula is thought to mediate attention to external, thus stimulus-oriented, and internal, thus stimulus-independent, processing. This aligns with evidence that the insula is particularly activated during PM retrieval (Cona, Scarpazza, Sartori, Moscovitch, & Bisiacchi, 2015). This indicates insula function might be involved in the switch from stimulus-oriented ongoing task processing to accessing and retrieving a delayed intention, in the bottom-up detection of PM cues as salient stimuli (internal time- or external event-cues), and in the subsequent change in attentional allocation to promote task switching. However, in ASD, the anterior insula seems to be characterised by hypoactivity (Di Martino et al., 2009), possibly resulting in dysfunctional connectivity patterns with other brain regions (Uddin & Menon, 2009), which may be relevant here.

To test these hypotheses, further research needs to explicitly compare neural activity associated with stimulus-oriented and stimulus-independent processing for both time- and event-based PM in ASD. The analysis of psychophysiological interactions (e.g., between insula activity and rPFC) might further elucidate this question.

Mitigation of PM problems in ASD

On a day-to-day basis, PM impairments in ASD may result in reduced autonomy and greater dependency on carers, parents, or partners to support daily activities and time-management. For instance, PM problems might lead to forgetting to pay their mobile phone bill, pick up a parcel from the post-office, or to attend a medical appointment (Blomqvist, Bejerot, & Dahllöf, 2015). Equally, PM impairments could negatively impact employment opportunities for individuals with ASD (employers might understandably perceive a person with diminished PM as unreliable, because they forget to complete assignments, meet deadlines, or pass on important messages), which may contribute to low rates of full-time employment among individuals with ASD (Howlin & Moss, 2012). Based on the results of this thesis and previous research, PM abilities and mechanisms in ASD are more clearly understood. This offers the possibility to consider what type of strategies might be most useful to support PM under everyday life demands in ASD.

When PM is cued, no performance impairment is observed in ASD in line with the task support hypothesis of memory (Bowler et al., 2004). This indicates that delayed intentions should not be a problem in ASD given the appropriate implementation of cues in everyday life. In contrast in unstructured time-based situations PM impairment occurs. In Chapter 4, it was found that increasing structure through explicit task instructions reduced time-based PM impairment. This finding equally aligns with the task support hypothesis.

Importantly, no other study could previously demonstrate that time-based PM can be improved in ASD. One previous study (Kretschmer et al., 2014), used the method of implementation intentions unsuccessfully in an attempt to improve time-based PM in ASD. Although both manipulations targeted intention encoding to improve PM, their respective underlying mechanism differs substantially. The manipulation of importance influences the allocation of strategic resources, which has been shown to be beneficial for both types of PM (Walter & Meier, 2014). In contrast, implementation intentions are especially beneficial for event-based PM (Chen et al., 2015), because they result in an increased association between the future retrieval context and the intended action, and thus facilitate PM retrieval upon encountering the retrieval context (Gollwitzer, 1999). For time-based PM in real-life situations, it may actually be more beneficial to formulate an implementation intention on keeping track of the passage of time additionally to one about executing the delayed intention itself. For example, a person might have to remember to call a friend after one hour. To keep track of the time, they might form the intention to check the clock every time they go into the kitchen. The efficiency of this strategy remains to be tested in both typically developing individuals and ASD.

Crucially, implementation intentions and manipulation of an intention's importance differ in another important aspect. The former requires the *self-initiated* use in everyday life whereas the latter does not require the individual with ASD to apply a strategy themselves. Instead the structure of the task is externally enhanced by explicit task instructions. Thus, it is of interest whether individuals with ASD would be able to implement strategy use flexibly (such as implementation intentions or use of reminders, such setting an alarm or placing an object in an obvious location as a reminder) into their everyday lives or not. This would require a) self-awareness that one is prone to forgetting to accurately carry out delayed intentions; b) understanding of the potential (negative) consequences that forgetting of intentions carry; and c) insight that this necessitates the use of memory aids/strategies. Reduced psychological self-awareness (Lind, 2010; Williams, 2010) as well as problems with planning (Olde Dubbelink & Geurts, 2017) and cognitive flexibility (Landry & Al-Taie, 2016; Leung & Zakzanis, 2014) in ASD might therefore reduce the usefulness of memory strategies that need to be self-initiated. Furthermore, problems with episodic future thinking in ASD (Lind et al., 2014; Terrett et al., 2013) might lead to reduced awareness of the negative consequences of PM forgetting. A recent study which explored the use of external reminders in ASD provides some support for this claim (Cherkaoui & Gilbert, 2017). Participants completed a PM task twice, once with the possibility to offload their delayed intentions and once without (see pp. 160-161 for a detailed task description). Prior to each condition, participants had to rate their confidence that they would remember to fulfil the upcoming delayed intentions. Participants also completed an implicit measure of general self-confidence. Their results revealed that participants with ASD performed significantly poorer than NT controls in both conditions (with and without the chance to use reminders). Importantly, individuals with ASD did not completely fail to use the reminders and used more reminders when they had to keep three in comparison to one PM target in mind. However, despite being aware of their own PM difficulties, individuals with ASD did not set a greater number of reminders in order to compensate for PM problems. One possible explanation for this pattern of results was that the use of reminders may have been influenced by implicit overconfidence into their PM abilities, despite their accurate explicit performance perception. The further exploration of the role of metacognitive abilities in ASD is therefore required to further inform the usefulness of self-initiated memory strategies in ASD.

Thus, the existing evidence suggests that when individuals with ASD are merely “users” of memory cues or a structured environment/instruction, they do not encounter PM problems, or that they encounter them to a much smaller degree at least. In keeping with this view, successful approaches to support independent functioning (which usually requires successful PM) in children and adults with ASD entail supported learning and skill development by providing a structured classroom environment and explicit task instructions (Iovannone, Dunlap, Huber, & Kincaid, 2003). For instance, visual cues are used to help children with ASD to transition between activities. Similarly, supported employment programs in ASD incorporate clear structuring of work environment and duties, which benefits job performance (Hendricks, 2010), and have been shown to improve executive functions such as planning and flexibility (García-Villamisar & Hughes, 2007). This indicates a promising way to support PM in ASD. Future research should further explore how enhanced everyday structure might support PM in ASD, and also explicitly study if and why self-initiated use of PM strategies might be impaired in ASD.

Ecological validity of PM research in ASD

Most conclusions about PM abilities in ASD have been derived based on laboratory experiments. Laboratory research of PM, however, significantly differs in the level of control exerted on various variables in comparison to real-life PM tasks. In Chapter 1, it was concluded that the existing research clearly demonstrates time-based PM impairments in ASD, but that heterogeneity across event-based PM studies did not allow clear conclusions about the true level of event-based PM ability in ASD. Therefore, in all empirical chapters in this thesis, the aim was to consistently and rigorously apply the methodological guidelines outlined in Chapter 1: a) matching the ASD and control group for baseline characteristics (age and intellectual abilities) and ongoing performance; b) not mixing demands of different PM types within one condition; and c) ensuring that PM failure was not due to a failure to retain task instructions. The advantage of adhering to these guidelines is that it offers the opportunity to establish whether, under "ideal"/stable/experimentally-rigorous conditions, an impairment of event-based PM is present or not. However, due to this level of control, one might argue that laboratory studies of PM do not reflect the demands of real-life situations in which PM is required. It has been found that, among neurotypical individuals, performance on laboratory measures of PM does not correlate with naturalistic PM task performance (Uttl & Kibreab, 2011). Likewise, self-report measures of PM only show small associations with behavioural

PM performance in the lab (Cherkaoui & Gilbert, 2017; Uttl & Kibreab, 2011; Williams et al., 2014). This was also observed in this thesis: individuals with ASD reported higher levels of PM problems (see Chapter 4), however this was uncorrelated with actual PM performance. A recent study (Cherkaoui & Gilbert, 2017) suggested that these findings arise because traditional laboratory PM measures may not capture the demands imposed on PM in real-world scenarios. They proposed that traditional PM tasks are limited in their ecological validity as they usually involve a single intention, which might lead to a more habitual or automated execution of the delayed intention. In everyday life, however, individuals have to manage multiple demands and remember various intentions which need executing within different time frames. Thus, it is a viable possibility that the finding of unimpaired event-based PM in the laboratory may not be true in everyday life situations for individuals with ASD in comparison to NT peers. Of the three studies that previously tried to test PM under more naturalistic conditions but still within the lab (Altgassen et al., 2012; Henry et al., 2014; Kretschmer et al., 2014), two reported PM impairments. As all these studies used a mixed design of time- and event-based PM, which could conflate impairments in one PM domain with the other, this question needs to be addressed in a future study using an event-based only condition. Nonetheless, rigorous laboratory studies on event-based PM in ASD are essential. Their findings provided a clear understanding of what underpins an ability under stable conditions, free from the influence of potential confounding variables. In particular, these findings can serve as a foundation for the design of naturalistic studies, and more importantly, they could inform strategies how event-based PM problems in everyday life might be addressed if they were to be found. For instance, the notion that individuals with ASD struggle in everyday life with PM because they have to maintain multiple intentions at the same time could be addressed by giving specific instructions; e.g.; completing delayed intentions consecutively or back-to-back instead of coordinating the parallel completion of several intentions. With regard to time-based PM, it will be also important to explore whether difficulties manifest in the same way in everyday life situations in ASD. To be able to make predictions regarding these questions, it is of interest to consider three factors (changing context, motivation, and the use of reminders) that clearly distinguish laboratory tasks from real-world situations involving PM.

Influence of context on PM. Everyday life situations are far less structured, require the processing of more complex information, and involve constant changes in the environment in comparison to the laboratory. These situational demands are clearly implicated in PM. Usually in laboratory experiments the context within which tasks are carried out are held constant whereas in everyday life the context in which an intention is encoded might be very different from the one at retrieval. Imagine you are cooking a meal and you need to go into the pantry to retrieve some ingredients. However, once you enter the pantry you do not remember anymore what you needed to get there. Back upstairs in the kitchen you suddenly remember and subsequently go to get your required items. Probably everybody has experienced a similar situation as described in this anecdote, which illustrates the effect of environmental context on PM. Other context effects emerge due to emotional context or context expectations (Marsh, Hicks, & Cook, 2008).

In general, context can have both enhancing or detrimental effects on PM. Beneficial effects of context on PM were reported by Waldum and Sahakyan (2013). They found that context information in the form of background music positively informed time-based PM responses when participants did not have the opportunity to use a clock to monitor the elapsing time. In contrast, a study by McDaniel, Robinson-Riegler, and Einstein (1998) found that PM performance was worse when the encoding of the PM intention took place in a room that was different to the one where an intention had to be retrieved. Other studies demonstrated that a change in context can lead to forgetting whether an intention was previously completed (Marsh, Hicks, Cook, & Mayhorn, 2007), or that PM performance is worse if the retrieval context is different to the one a person expected a PM cue to appear in (Nowinski & Dismukes, 2005). Other studies (Clark-Foos, Brewer, Marsh, Meeks, & Cook, 2009; Graf & Yu, 2015) have found that positive or negative valence of a PM cue results in worse PM in comparison to neutral cues, whereas neutral cues appearing in valenced context have a greater impact than in a neutral context. Finally on a neural level, Gilbert, Armbruster, and Panagiotidi (2012) found that PM hits were characterised by a greater similarity in the pattern of brain activity than PM failure indicating a positive "cortical context" reinstatement effect.

Context effects on PM in ASD have not been explicitly studied however research on retrospective memory might give some indication how context affects cognition in ASD. Bowler, Gaigg, and Gardiner (2008) have found that individuals with ASD require support in situations where memory recall is usually enhanced by contextual effects. This may be due to source memory problems in ASD in free recall tasks, which indicate that without support individuals with ASD struggle to retrieve the context in which a memory was encoded in (Bowler et al., 2004). In line with these findings, Maras and Bowler (2012) found that mental reinstatement of context at encoding only benefitted memory retrieval in ASD if it was supported by physical cues. With regards to emotional context, Deruelle, Hubert, Santos, and Wicker (2008) reported a significantly reduced influence of negative valence on memory in ASD in a memory recognition task involving pictures. NT individuals showed better recognition memory for negative pictures in comparison to the ASD group, whereas no group differences were observed for positive or neutral stimuli. Furthermore, Gaigg and Bowler (2008) found some benefit of emotionally arousing word stimuli on memory in ASD, however in contrast to typically developing participant this effect did not prevail over a longer delay. These findings suggest that emotional valence has reduced impact on memory in ASD.

In sum, this suggests that changing context might at least to some extent present an additional challenge when performing PM in everyday life for individuals with ASD. Based on the above evidence, one might predict that positive context effect on PM in ASD will likely only occur in event-based, but not time-based, PM tasks. Conversely though, context induced forgetting effects might affect them less than NT participants. These predictions remain to be explored in future studies. If positive effects of context on PM were to be found in ASD, this would present a unique opportunity to develop further strategies to improve their PM abilities. For instance, similarly to Waldum and Sahakyan's (2013) study, the use of context information could be used to improve time-based PM in ASD if context itself served as PM cue.

Influence of intention source and motivation on PM. The source of one's delayed intentions is another important factor when considering PM tasks in the lab and the real life. In experimental studies, intentions are usually provided by the experimenter (other-generated) whereas in everyday life individuals generate their intentions themselves based on their individual goals and needs (self-generated), which will naturally influence the level of personal importance of these intentions. As discussed in Chapter 4, the importance of an intention influences the motivation to fulfil it (Walter & Meier, 2014) and is therefore a crucial moderator for PM success. A study has shown that self-generated naturalistic intentions are completed more frequently than naturalistic intentions instructed by an experimenter (Oates & Peynircioglu, 2014). However, the advantage for self-generated intentions was dependent on the intention specificity; self-generated specific intentions were completed more often than experimenter-generated ones but for broader intentions no difference of intention source could be observed. Two other studies found that the personally rated importance of intentions influenced completion of naturalistic intentions (Ihle, Schnitzspahn, Rendell, Luong, & Kliegel, 2012; Niedźwieńska, Janik, & Jarczyńska, 2013), and revealed that importance and better planning seem to moderate an age-effect of older adults performing better at naturalistic PM tasks. Thus, personal importance of own goals and intentions might increase individuals' motivation leading to increased efforts (e.g., better planning) to complete them. However, the personal importance of self-generated intentions is not necessarily greater than other-generated ones (Kvavilashvili & Ellis, 1996). Certainly, everyone can think of a time when they forgot to carry out something important intention that they intended to do (e.g., booking a medical appointment) but remembered to do something important they got told by someone else (e.g. booking a table at a restaurant for family celebrations). In the case of other-/experimenter-generated intentions, positive effects of social importance (Altgassen, Kliegel, Brandimonte, & Filippello, 2010; Cicogna & Nigro, 1998; Penningroth, Scott, & Freuen, 2011) might balance out potential negative effects of other-generated intentions. For the study of PM in ASD, personal importance of intentions has so far not been considered. It would be therefore crucial to investigate how their motivation to fulfil intentions is influence by a) the source of an intention and b) personal relevance/importance of an intention, and whether these effects vary under different conditions (lab vs real life) and PM tasks (event- vs time-based). Given that time-based PM improved in ASD using a relative importance instruction (see Chapter 4), it may well be that self-generated personally highly important intentions could have similar beneficial effects. However, personal importance was found to benefit PM performance in older adults due to better planning (Niedźwieńska et al., 2013). Given difficulties with planning in ASD (Olde Dubbelink & Geurts, 2017; Williams & Jarrold, 2013), it could also be that personal importance does not positively affect PM in ASD.

Intention offloading. In everyday life, the use of memory aids or setting reminders is a common strategy to support PM. For instance, Kim and Mayhorn (2008) found that university students reported the frequent use of memory aids in everyday life, which was enhancing PM performance, especially time-based PM, outside the laboratory setting. The process of setting an external reminder as an environmental PM cue has been termed "intention offloading" (Risko & Gilbert, 2016). Gilbert (2015a) developed a novel laboratory intention offloading PM task, which might be more reflective of everyday life PM demands. In this task, using the computer mouse, participants have to drag 10 circles containing the numbers one to 10 in order to the bottom of the screen where they disappear. A delayed intention is implemented on a trial-by-trial basis by giving the instruction to drag a specific number out of the box at a different location (left, right, or top). The task allows to manipulate PM memory load by using different number of targets (one to three). Although Gilbert (2015a) recognised that this task only involved very brief delays and, thus, may be more akin to a working memory/vigilance task, it might actually mirror real-life PM demands more accurately due to the constant change of number of intentions to be kept in mind. In keeping with this, they found that PM performance on the intention offloading task in NT participants predicted fulfilment of a naturalistic intention after several days. Gilbert (2015a) also found beneficial effects of intention offloading on PM, especially when several intentions had to be fulfilled or when distractions during the ongoing task occurred. Furthermore, metacognitive confidence ratings of PM abilities were found to predict the use of strategically setting reminders significantly (Gilbert, 2015b); i.e., participants with lower confidence ratings would use more reminders.

As discussed above (p. 154) Cherkaoui and Gilbert (2017) explored intention offloading in ASD. There results indicated that individuals with ASD were able to employ reminders to some extent, however they did not adjust the level of reminder usage commensurate with their PM abilities, which was potentially linked to metacognition. These initial results on the effectiveness of intention offloading to facilitate PM in ASD in the laboratory are slightly discouraging. Given the large amount of evidence from retrospective memory literature that shows that cued memory retrieval is not impaired in ASD (Boucher, Mayes, & Bigham, 2012; Bowler, Gardiner, & Berthollier, 2004; Bowler, Gardiner, & Grice, 2000), it seems highly unlikely that memory cues have actually negative effects, acting as additional ‘noise’ in the stream of stimuli that have to be processed. Equally, if memory cues were ineffective in ASD, we would expect to see impaired event-based PM, which has not been shown in a number of well-controlled studies (see Chapter 1). It could be that the additional task to set reminders themselves increases overall processing demands in ASD. Thus, it may be the self-initiated generation of reminders that is not beneficial to performance in ASD rather than the use of the reminders in everyday life itself. Nonetheless, the relative usefulness of intention offloading should be explored under real-life demands for both event- and time-based PM with a critical focus on the role of metacognitive skills in ASD.

Challenges of PM research in ASD

In terms of prevalence rates, around 1% of the population receive a diagnosis of ASD (Baird et al., 2006; Brugha, McManus, Bankart, & et al., 2011). Due to the vast heterogeneity of the autism spectrum, the requirement of a minimum level of intellectual abilities, as well as the need for stringent matching procedures to achieve meaningful and informative results (Mervis & Klein-Tasman, 2004; Shaked & Yirmiya, 2004), the participant pool of ASD participants who can realistically take part in research studies is small. This naturally affects the sample size with which autism researchers have to work with and leads inevitably to a discussion of the question of statistical power. Potential lack of power was an issue in the studies reported in Chapters 2 and 3, especially, in which no significant group differences were found. The following section will discuss the issue of power in ASD research and how it could be addressed by the use of Bayesian analyses.

The aim of any power analysis is to calculate the number of participants that are required to achieve statistically and clinically meaningful results (Cicchetti et al., 2011). However, given a large enough sample size, statistical power will be large enough for even trivial effects to become significant. With regard to recruitment issues ASD research, it is therefore important to find a balance between the fear of being underpowered to detect clinically negligible small effects and the effort it requires to achieve greater power. In economics, this is reflected in the marginal utility/diminishing returns concept, which essentially reflects that more of something (in this case adding participants to a sample) is only beneficial up to a certain point at which it reverts to “too much of a good thing” (Von Wieser, 1893). Thus, together with the practical reality of recruitment in autism research, this ultimately leads to a trade-off between the aim to achieve good statistical power and precision in the results. Of course, statistical power in ASD research could always be increased by recruiting more participants, however the effort is required to do so is usually not commensurate with the return (Cicchetti et al., 2011). Additionally, it is not an option to sacrifice stringent procedural guidelines such as matching for the sake of power if it results in uninterpretable results. For instance, recruiting more participants to eventually find a negligible effect would be inefficient given the cost and time to administer and score measures that are (perceived as) gold-standard in ASD research (such as measures of intelligence, WASI-II, WISC-IV, or autism features, ADOS-2). Especially, the use of reliable instruments to measure intellectual ability is crucial as individuals with ASD display an uneven performance profile of strengths and weaknesses on different subtests or scales that are related to general intelligence level. For instance, studies have shown that certain measures of verbal and non-verbal abilities, such as the British Picture Vocabulary Scale (Dunn et al., 2009) or the Raven Progressive Matrices (Raven, 1939) over-estimate cognitive ability in individuals with ASD in comparison to the Wechsler verbal IQ and full scale IQ (Bölte, Dziobek, & Poustka, 2009; Mottron, 2004). Therefore, to ensure that participant groups were appropriately matched on baseline cognitive abilities in all studies, the WASI-II was employed throughout all experiments in this thesis as a more rigorous and more reliable measure of intelligence in ASD (Mottron, 2004). Equally, the sole use of self-report measures of ASD, such as the AQ questionnaire, has been found to lead to a high number of “false-negatives”; i.e., participants who had received a clinical diagnosis of ASD scored below the AQ screening cut-off for ASD

(Ashwood et al., 2016). Therefore, the ADOS-2 (Lord et al., 2012) was employed to enhance the characterisation of the ASD sample in Chapter 4 of this thesis instead of solely relying on a self-report measure of autism traits using the AQ questionnaire.

Along with the challenge of power, comes the question how to deal with null results. Classic null hypothesis significance testing does not provide any means to quantify the degree of evidence in favour of a null hypothesis. Arguably due to “file-drawer” problem in psychological research (Pashler & Wagenmakers, 2012), null results in ASD studies might be misrepresented in the literature. However, null results can still be clinically relevant in demonstrating that individuals with ASD show undiminished performance on certain tasks or exclude hypotheses that aimed to explain behaviour in ASD. Therefore, in this thesis additional Bayes factor analyses were employed to enrich the presented data as they offer a more graded approach to interpreting results (Wagenmakers, Marsman, et al., 2017). The major benefit of Bayesian analyses is that a Bayes factor quantifies the evidence that the data provides in favour of either the alternative or the null hypothesis, but equally it expresses if the data does not fit well with either of the two hypotheses (Dienes, 2014). Thus, in contrast to classical statistical interference which always test against the null hypothesis, a Bayes factor can provide a perspective how well the data is accounted for by the null. Therefore, Bayes factors are a helpful tool to complement the interpretation of the results obtained by classical null hypothesis testing in ASD research. For both Chapter 2 and 3, these analyses provide broad support in favour of the reported null results. Thus, despite some power issues, the combined evidence suggests that one can trust these results and the subsequent interpretation of unimpaired event-based PM in ASD.

Final remarks and conclusion

Given the well-established, large diminution of time-based PM in ASD, it will be important to develop training strategies to support this ability in order to promote greater functional independence. This requires to fill in the gaps in our understanding of how individuals with ASD engage in time-based prospective remembering. To this end, a systematic exploration of cognitive mechanisms that underpin PM performance in ASD is necessary. Conversely, finding strategies that may improve time-based PM could also reveal underlying causes of its impairment in ASD. If, for example, efforts to improve executive functioning (or episodic future thinking or theory of mind) were found to improve time-based PM in individuals with ASD, this would suggest that executive dysfunction is a key contributory factor to diminished time-based PM in ASD. Another approach could be to test whether manipulations that lead to PM improvement in older NT adults might have a similar beneficial effect in ASD (see Hering et al., 2014 for a review). The results of Chapter 4 have provided initial positive evidence for this approach. Therefore, the main aim for future research should clearly focus further on the implementation of useful PM strategies in everyday life for individuals with ASD, their families, and advising clinicians alike.

APPENDICES

Appendix 1: Supplementary data and analyses in Chapter 4

Appendix 2: Results of subsample analyses for participant groups matched on ongoing performance in Chapter 4

Appendix 3: Results from Fisher *z*-tests conducted in Chapter 5

Appendix 4: Pilot study on the role of interoception in time-base PM in ASD

Appendix 1: Supplementary sample data for Chapter 4

Table A1. Sample characteristics for all scales of the BRIEF-A

	Group means (SD)					
	ASD (*n* = 25)	**Neurotypical (*n* = 22)**	***T***	***df***	***p***	**Cohen's *d***
Clinical scales						
BRIEF Inhibit	63.40 (12.47)	51.82 (9.81)	-3.50	45	.001	1.17
BRIEF Shift	72.04 (13.82)	50.59 (8.16)	-6.37	45	<.001	2.07
BRIEF Emotional Control	61.80 (16.70)	47.64 (6.47)	-3.74	45	.001	1.01
BRIEF Self-monitoring	62.72 (14.36)	46.18 (10.01)	-4.52	45	<.001	1.51
BRIEF Initiate	65.72 (13.93)	51.27 (10.42)	-3.98	45	<.001	1.48
BRIEF Working memory	72.96 (12.97)	52.82 (10.97)	-5.71	45	<.001	1.83
BRIEF Plan	65.24 (13.46)	52.41 (12.48)	-3.37	45	.002	1.23
BRIEF Task monitoring	65.88 (14.39)	53.00 (11.46)	-3.36	45	.002	1.20
BRIEF Organisation of materials	56.44 (14.45)	46.73 (8.99)	-2.72	45	.009	0.85
Composite scores						
BRIEF Behavioural Regulation Index	68.24 (13.88)	48.64 (6.73)	-6.03	45	<.001	2.04
BRIEF Metacognition Index	68.00 (12.94)	51.68 (11.56)	-4.53	45	<.001	1.60
BRIEF Global Executive Composite	69.52 (13.51)	51.82 (9.81)	-5.63	45	<.001	2.01

Appendix 2: Results of subsample analyses for participant groups matched on ongoing performance in Chapter 4

Using the full sample in this study, the experimental groups significantly differed in their ongoing task performance. As this might affect the outcome of between-group analyses of PM performance an additional subsample analysis was conducted. For this analysis using the collapsed ongoing proportion hit scores, the highest performing participants in the NT group (*n* = 4) and the lowest performing participants in the ASD (*n* = 6) group were excluded stepwise until no group differences emerged and the corresponding effect size was small, *t*(36) = 1.40, *p* = .17, *d* = - 0.45. Thus, the subsample analysis was conducted with groups consisting of 19 participants (3 females in each respectively). Subsequently, matching on baseline characteristics was checked (all *p*s ≤ .05, all *d*s ≤ 0.53, see Table A2).

Table A2. Group characteristics of sub-sample matched with groups matched for ongoing task performance (collapsed across conditions)

	Group means (SD)					
	ASD (*n* = 19, 1 female)	**NT (*n* =19, 3 female)**	***T***	***df***	***p***	**Cohen's *d***
Age	34.26 (12.60)	39.15 (12.52)	0.953	36	.347	-0.31
VIQ	107.68 (13.00)	102.00 (7.98)	-1.624	36	.113	0.53
PIQ	107.63 (18.71)	104.21 (11.19)	-0.684	36	.498	0.22
FSIQ	108.21 (15.59)	103.37 (8.91)	-1.176	36	.247	0.38
AQ	31.53 (9.23)	17.74 (6.90)	-5.214	36	<.001	1.69
ADOS	7.95 (3.55)	-	-	-	-	-

Ongoing task

Ongoing proportion hit scores were entered into a 2 × 2 mixed ANOVA with group (ASD/NT) as between-subject factor and condition (PM low/high importance) as within-subject factor. The main effect of condition was significant, *F*(1,36) = 6.62, *p* = .01, η_p^2 = .16, BF_{10} = 3.42 with better ongoing performance in the *PM low importance condition*. No significant main effect of group or interaction effect emerged (all *F*s ≤ 1.96, all *p*s ≥ .17, all η_p^2

$\leq .05$, all $BF_{10} \leq 0.77$; see Table A3). Neither, the full ($BF_{10} = 0.87$) nor the additive ($BF_{10} = 2.69$) model of the Bayesian analysis fitted the data better than the main effect of condition only.

PM task

The Group (ASD/NT) × Condition (PM low/high importance) mixed ANOVA on PM proportion hit scores revealed a main effect of group, $F(1,36) = 7.35$, $p = .01$, $\eta_p^2 = .17$, $BF_{10} = 4.64$, with the ASD group performing worse overall than the NT group, and a main effect of condition, $F(1,36) = 12.83$, $p = .001$, $\eta_p^2 = .26$, $BF_{10} = 20.25$, indicating better PM performance in the PM high importance condition. Importantly, these effects were qualified by a significant group by condition interaction, $F(1,36) = 5.39$, $p = .03$, $\eta_p^2 = .13$, $BF_{10} = 2.31$. The BF_{10} for the additive model was 101.04 and for the full model 232.34. This means that the full model provided the greatest evidence for the present data. Post-hoc tests revealed that only the ASD group showed a significant increase in PM hit proportion scores from the PM low to the PM high importance condition (ASD: $F(1,36) = 17.43$, $p < .001$, $\eta_p^2 = .33$, $BF_{10} = 8.92$; NT: $F(1,36) = .79$, $p = .38$, $\eta_p^2 = .02$, $BF_{10} = 0.83$). Tests of simple effects of indicated that the NT group outperformed the ASD group in the PM low importance condition, $F(1,36) = 9.49$, $p = .004$, $\eta_p^2 = .21$, $BF_{10} = 10.30$. In the PM high importance condition, however, PM performance did not differ significantly between groups, $F(1,36) = 1.92$, $p = .17$, $\eta_p^2 = .05$, $BF_{10} = 0.67$ (see Ongoing and PM performance scores by condition of sub-sample matched with groups matched for ongoing task performance (collapsed across conditions)Table A3 for means and SD). However, both groups performed at ceiling in the PM high importance condition, ASD: $t(18) = =1.61$, $p = .13$, NT: $t(18) = -1.00$, $p = .33$; thus cautious interpretation of the interaction effect is required.

With regard to PM target accuracy a Group (ASD/NT) × Condition (PM low/high importance) mixed ANOVA was performed on the data of those participants who at a minimum of one PM hit (low importance both groups $n = 23$, high importance ASD: $n = 18$, TD: $n = 19$). A main effect of group, $F(1,35) = 5.28, p = .03, \eta_p^2 = .13$, $\mathrm{BF}_{10} = 2.34$, emerged indicating that NT group overall responded closer to target time than the ASD group (see Table A3). Neither the main of condition nor the interaction were significant (all Fs ≤ 2.76, all ps $\geq .11$, all $\eta_p^2 \leq .07$, all $\mathrm{BF}_{10} \leq 0.74$). The BF_{10} for the additive model was 1.73 and for the full model 0.81.

Table A3. Ongoing and PM performance scores by condition of sub-sample matched with groups matched for ongoing task performance (collapsed across conditions)

		Group means (SD)		
Condition		**ASD**	**NT**	**Cohen's *d***
PM low importance	Ongoing proportion hits	.71 (0.11)	.75 (0.09)	-0.40
	PM proportion hits	.72 (0.32)	.95 (0.09)	-0.98
	PM target accuracy	2.20 (1.67)	1.26 (0.89)	0.70
PM high importance	Ongoing proportion hits	.67 (0.11)	.71 (0.12)	-0.35
	PM proportion hits	.91 (0.24)	.99 (0.05)	-0.46
	PM target accuracy	1.66 (0.98)	1.13 (0.89)	0.57

Time-monitoring

A 2 ×2 × 4 mixed ANOVA was conducted on the mean number of time checks carried out during the task with group (ASD/NT) as between-subject factor, and condition (PM low/high importance) and time interval (0-30, 31-60, 61-90, 91-120 seconds) as within-subject factors. Mauchly's test indicated that the assumption of sphericity had been violated for the main effect of interval and the interval × importance interaction effect. Therefore, Greenhouse-Geisser correction was used for those effects. No main effect of group was found, $F(1,36) = 0.75, p = .39, \eta_p^2 = .02$, $\mathrm{BF}_{10} = 0.28$. There were significant main effects of condition, $F(1,36) = 15.89, p < .001, \eta_p^2 = .31$, $\mathrm{BF}_{10} = 20.22$, and interval $F(1.35,48.58) = 94.55, p < .001, \eta_p^2 = .72$, $\mathrm{BF}_{10} = 1.25*10^{40}$. The overarching three-way interaction Group × Importance × Interval was not significant, $F(2.04,73,32) = 1.42, p = .25, \eta_p^2 = .04$, $\mathrm{BF}_{10} = 0.15$, however some two-way interactions were. The significant interaction between group and interval *F*(1.35,48.58) = 5.58, p = .01, η_p^2 = .13, BF$_{10}$ = 124.07, indicated that the NT group checked the time more often than the ASD group. However, tests of simple effects only revealed a marginally significant group difference for the interval prior to target time (91-120 seconds) with more time checks in the NT group (*M*=2.75, *SE* =.27) in comparison to the ASD group (*M* = 2.02, *SE* = .27), *F*(1,36) = 3.53, *p* = .06, η_p^2 = .09, BF$_{10}$ = 1.29. Furthermore the Condition × Interval interaction, *F*(2.04,73.32) = 6.51, *p* = .002, η_p^2 = .15, BF$_{10}$ = 1.77, revealed that for three intervals (31-60, 61-90, 91-120 seconds) across both groups, participants checked the time significantly more often in the high importance condition than in the low importance condition (all *p*s ≤ .001, all η_p^2 ≥ .50, all BF$_{10}$ ≥ 3.65).. The Group × Importance interaction was not significant, *F*(1,36) = 0.10, *p* = .76, η_p^2 = .003, BF$_{10}$ = 0.18.

Appendix 3: Results from Fisher-z tests conducted in Chapter 5

Table A4. Results of Fisher z tests comparing findings by Umeda et al. (2016) with correlations found in this study separately by condition

Correlation comparison PM and interoceptive accuracy	r_1	r_2	**Fisher-*z***	***p***
Umeda et al. vs EBPM condition	0.35	0.26	0.38	0.70
Umeda et al. vs TBPM condition, a)	0.35	0.29’	0.25	0.80
Umeda et al. vs TBPM condition, b)	0.35	0.26	-0.826	0.409

Note. EBPM: event-based PM; TBPM: time-based PM. For the time-based PM conditions two comparisons were conducted a) the comparison that involved the correlation between PM target accuracy and interoception and b) the comparison that involved the correlation between PM target accuracy and interoception

Table A5. Results of Fisher z tests comparing correlations between the event- and time-based PM condition

Correlation comparison	**TBPM condition *r***	**EBPM condition *r***	**Fisher-*z***	***p***
PM - interoceptive accuracy (IA)				
Comparison A	0.29’	0.26	0.11	0.91
Comparison B	0.03	0.26	-0.83	0.41
PM - autism traits($\mathrm{AQ}_{\mathrm{traits}}$)				
Comparison A	-0.63	-0.09	-2.28	0.02*
Comparison B	-0.09	-0.09	0.00	1.00
PM - alexithymia traits ($\mathrm{TAS}_{\mathrm{traits}}$)				
Comparison A	-0.36	-0.1	-0.97	0.33
Comparison B	-0.19	-0.1	0.04	0.97
PM - WCST perseverative errors ($WCST_{PE}$*)*				
Comparison A	-0.06	-0.2	0.50	0.62
Comparison B	-0.38	-0.2	-0.32	0.75
AQ_{traits} *- IA*	-0.02	0.14	-0.56	0.57
$AQ_{ttraits}$ *-* TAS_{traits}	0.54	0.17	1.51	0.13
$AQ_{ttraits}$ *-* $WCST_{PE}$	-0.21	0.08	-1.03	0.30
TAS_{traits} *- IA*	-0.10	0.33	-1.55	0.12
TAS - $WCST_{PE}$	-0.08	0.32	-0.74	0.46
$WCST_{PE}$ *- IA*	0.01	0.35	-1.24	0.21
Ongoing task hits - PM hits	0.022	0.335	-1.14	0.25
Ongoing task hits - IA	0.36	0.09	1.00	0.32
Ongoing task hits - AQ_{traits}	0.103	0.01	0.33	0.74
Ongoing task hits - TAS_{traits}	-0.10	0.13	-0.80	0.42
Ongoing task hits - $WCST_{PE}$	-0.30	-0.28	-0.10	0.92

Note. Comparison A: The correlation in the time-based PM condition involves PM target accuracy. Comparison B: The correlation in the time-based PM condition involves PM proportion hits. EBPM: event-based PM; IA: interoceptive accuracy; TBPM: time-based PM.

Appendix 4: Pilot study on the role of interoception in time-base PM in ASD

A pilot study was conducted to investigate the potential roles of interoception and alexithymia in time-based PM in individuals diagnosed with ASD.

Methods

A subsample of the participants from Chapter 4 (*N* = 27) took part in this pilot. Thirteen participants (11 male) with ASD, as well 14 NT individuals (12 male) completed all measures as described in Chapter 4 (WASI-II, ADOS-2, AQ questionnaire, WCST, etc.), as well additional measures of interoceptive accuracy (heart beat detection task) and alexithymia (TAS-20 questionnaire) as described in Chapter 5. Groups were closely matched for gender, chronological age, verbal, and non-verbal abilities (see Table A 6). As a measure of time-based PM in ASD, performance data of the PM low importance condition used in Chapter 4 was analysed (see Chapter 4 for a detailed description of the task procedure and scoring).

Table A 6. Group characteristics and matching of sub-sample

	Group means (SD)					
	ASD (*n* = 13, 2 female)	**NT (*n* =14, 2 female)**	***t***	***df***	***p***	**Cohen's *d***
Age	35.27 (9.82)	35.64 (12.67)	-0.08	25	.93	-0.03
VIQ	106.85 (14.47)	104.64 (8.11)	0.49	25	.63	0.19
PIQ	109.00 (18.89)	104.00 (10.81)	0.85	25	.40	0.33
FSIQ	108.38 (15.85)	104.79 (8.68)	0.74	25	.48	0.29
AQ	31.08 (9.74)	14.64 (5.24)	5.52	25	< .001	2.12
ADOS	11.77			25		
TAS	58.92 (14.31)	42.29 (8.37)	3.72	25	.001	1.43
WCST perseverative errors	15.70 (12.44)	6.36 (4.78)	2.58	25	.02	1.07
Interoceptive accuracy	55.68 (31.74)	70.44 (17.44)	-1.51	25	.14	-0.58

Results

Ongoing and PM performance. Using independent samples t-tests, between-group differences in ongoing task accuracy and RT ongoing hits performance was analysed. No significant group differences emerged for either comparison. For between-group differences in PM proportion hits and PM target accuracy, independent samples t-tests revealed a significant group difference in time-based PM proportion hits, indicating fewer correct responses in the ASD group (similar to what was found in Chapter 4). Furthermore, there was also a trend evident for less timely PM responses in the ASD group when scoring a PM hit (see Table A 7). A Group × Interval mixed ANOVA was used to explore differences in the frequency of time checks. The main effect of group was non-significant indicating a similar pattern of time checks between groups, $F(1,25) = 0.14$, $p = .72$, $\eta_p^2 < .01$, $BF_{10} = 0.31$. the main effect of interval was significant, $F(1.89, 47.29) = 44.61$ $p \leq .001$, $\eta_p^2 = .64$, $BF_{10} = 2.20*10^{10}$. The Group × Interval interaction was not significant, $F(1.89, 47.29) = 0.76$, $p = .47$, $\eta_p^2 = .03$, $BF_{10} = 0.20$. The BF_{10} for the additive model was $8.89*10^{13}$ and for the full model $1.84*10^{13}$. Post-hoc contrasts (Bonferroni corrected for multiple comparisons) revealed that across groups participants checked the time significantly more frequently in the fourth critical interval compared to all other intervals (all ps $\leq .001$, all $BF_{10} > 100$) and also significantly more in the third interval compared to the first interval (p = .005, $BF_{10} = 40.48$).

Table A 7. Results of independent sample t-tests of time-based PM performance for the subsample groups

	Group means (SD)						
	ASD	**NT**	***t***	***df***	***p***	**Cohen's *d***	**BF_{10}**
Ongoing proportion accuracy	0.71 (0.16)	0.77 (0.11)	-1.00	25	.33	0.38	0.52
PM proportion hits	0.68 (0.32)	0.93 (0.10)	-2.70	14.12	.02	1.06	5.14
PM target accuracy	2.62 (1.79)	1.58 (1.17)	1.79	25	.09	-0.68	1.13

Correlates of PM performance. In both groups, interoceptive accuracy did not significantly correlated with any of the other measures (PM proportion hits, PM target accuracy, OT accuracy, AQ, TAS, or WCST; ASD group all *p*s > .22, all $BF_{10} < 0.67$, NT group all *p*s > .14, all $BF_{10} < 0.52$). In both groups, AQ and TAS scores correlated significantly (ASD: $r = .62$, $p = .03$, $BF_{10} = 3.28$) or marginally (NT: $r = .49$, $p = .08$, $BF_{10} = 1.35$). In the ASD group, both measures of PM performance were significantly correlated with autism traits as measured by the AQ (r = -.59, p = .04, $BF_{10} = 2.55$ for PM proportion hits, and r = .74, p = .004, $BF_{10} = 14.55$ for PM target accuracy) as well as marginally significantly correlated with alexithymic traits ($r = -.54$, $p = .06$, $BF_{10} = 1.79$ for PM proportion hits, and $r = .55$, $p = .05$, $BF_{10} = 1.85$ for PM target accuracy). In the NT group, the correlation between autism traits and PM proportion hits just missed significance ($r = .54$, $p = .05$, $BF_{10} = 1.97$) and similarly a trend was observed for the correlation with PM target accuracy ($r = -.43$, $p =.13$, $BF_{10} = 0.94$). In line with the finding in Chapter 4, a correlation between perseverative errors on the WCST and PM proportion hits was found in the ASD ($r = -.77$, $p = .01$, $BF_{10} = 7.04$) but not in the NT group ($r = .16$, $p = .60$, $BF_{10} = 0.44$).

Controlling for either AQ scores, TAS scores, or WCST perseverative errors, did not result in significant associations between interoceptive accuracy and PM target accuracy in either group (all *p*s > 0.19, all $BF_{10} < 0.93$). In the ASD group, partial correlation analyses revealed PM target accuracy was specifically associated with autism traits when controlling for alexithymic traits (r = .61, p = .04, BF10 = 3.16) but not vice versa associated with alexithymia when controlling for autism traits (r = .17, p = .59, BF10 = 0.39), however this was not the case in the NT group where both correlations were insignificant when controlling for the respective variables.

REFERENCES

Abell, F., Happé, F., & Frith, U. (2000). Do triangles play tricks? Attribution of mental states to animated shapes in normal and abnormal development. *Cognitive Development, 15*(1), 1-16. doi:10.1016/s0885-2014(00)00014-9

Adolfsdottir, S., Wollschlaeger, D., Wehling, E., & Lundervold, A. J. (2016). Inhibition and Switching in Healthy Aging: A Longitudinal Study. *Journal of the International Neuropsychological Society, 23*(01), 90-97. doi:10.1017/S1355617716000898

Allman, M. J., DeLeon, I. G., & Wearden, J. H. (2011). Psychophysical assessment of timing in individuals with autism. *American Journal on Intellectual and Developmental Disabilities, 116*(2), 165-178. doi:10.1352/1944-7558-116.2.165

Altgassen, M., Kliegel, M., Brandimonte, M., & Filippello, P. (2010). Are older adults more social than younger adults? Social importance increases older adults' prospective memory performance. *Aging Neuropsychology and Cognition, 17*(3), 312-328. doi:10.1080/13825580903281308

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. doi: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*(3), 198-204. doi: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. doi:10.1177/1087054712445484

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. *The Quarterly Journal of Experimental Psychology, 68*(1), 192-204. doi:10.1080/17470218.2014.956127

Altgassen, M., Schmitz-Hübsch, M., & Kliegel, M. (2010). Event-based prospective memory performance in autism spectrum disorder. *Journal of Neurodevelopmental Disorders, 2*(1), 2-8. doi:10.1007/s11689-009-9030-y

Altgassen, M., Vetter, N. C., Phillips, L. H., Akgün, C., & Kliegel, M. (2014). Theory of mind and switching predict prospective memory performance in adolescents. *Journal of Experimental Child Psychology, 127*, 163-175. doi:10.1016/j.jecp.2014.03.009

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. doi:10.1375/brim.10.1.52

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders: DSM-IV* (4th ed.). Washington, DC: American Psychiatric Publishing.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders: DSM-5* (5th ed.). Washington, DC: American Psychiatric Publishing.

Ashwood, K. L., Gillan, N., Horder, J., Hayward, H., Woodhouse, E., McEwen, F. S., . . . Murphy, D. G. (2016). Predicting the diagnosis of autism in adults using the Autism-Spectrum Quotient (AQ) questionnaire. *Psychological Medicine, 46*(12), 2595-2604. doi:10.1017/S0033291716001082

Atance, C. M., & Jackson, L. K. (2009). The development and coherence of future-oriented behaviors during the preschool years. *Journal of Experimental Child Psychology, 102*(4), 379-391. doi:10.1016/j.jecp.2009.01.001

Atance, C. M., & O'Neill, D. K. (2001). Episodic future thinking. *Trends in Cognitive Science, 5*(12), 533-539. doi:10.1016/S1364-6613(00)01804-0

Awh, E., Jonides, J., Smith, E. E., Schumacher, E. H., Koeppe, R. A., & Katz, S. (1996). Dissociation of storage and rehearsal in verbal working memory: Evidence from positron emission tomography. *Psychological Science, 7*(1), 25-31. doi:10.1111/j.1467-9280.1996.tb00662.x

Bagby, R. M., Parker, J. D. A., & Taylor, G. J. (1994). The twenty-item Toronto Alexithymia scale-I. Item selection and cross-validation of the factor structure. *Journal of Psychosomatic Research, 38*(1), 23-32. doi:10.1016/0022-3999(94)90005-1

Baird, G., Simonoff, E., Pickles, A., Chandler, S., Loucas, T., Meldrum, D., & Charman, T. (2006). Prevalence of disorders of the autism spectrum in a population cohort of children in South Thames: the Special Needs and Autism Project (SNAP). *The Lancet, 368*, 210-215.

Bakroon, A., & Lakshminarayanan, V. (2016). Visual function in autism spectrum disorders: a critical review. *Clinical and Experimental Optometry, 99*(4), 297-308. doi:10.1111/cxo.12383

Ballhausen, N., Schnitzspahn, K. M., Horn, S. S., & Kliegel, M. (2017). The interplay of intention maintenance and cue monitoring in younger and older adults' prospective memory. *Memory & Cognition*. doi:10.3758/s13421-017-0720-5

Barban, F., Carlesimo, G. A., Macaluso, E., Caltagirone, C., & Costa, A. (2013). Functional brain activity within the medial and lateral portion of BA10 during a prospective memory task. *Behavioural Neurology, 26*(3), 207-209. doi:10.3233/BEN-2012-129012

Barban, F., Carlesimo, G. A., Macaluso, E., Caltagirone, C., & Costa, A. (2014). Functional interplay between stimulus-oriented and stimulus-independent attending during a prospective memory task. *Neuropsychologia, 53*, 203-212. doi:10.1016/j.neuropsychologia.2013.12.001

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The Autism Spectrum Quotient: Evidence from Asperger syndrome/high functioning autism, males and females, scientists and mathematicians. *Journal of Autism and Developmental Disorders, 31*(1), 5-17. doi:10.1023/A:1005653411471

Baum, S. H., Stevenson, R. A., & Wallace, M. T. (2015). Behavioral, perceptual, and neural alterations in sensory and multisensory function in autism spectrum disorder. *Progress in Neurobiology, 134*, 140-160. doi:10.1016/j.pneurobio.2015.09.007

Ben Shalom, D. (2003). Memory in autism: Review and synthesis. *Cortex, 39*(4-5), 1129-1138. doi:10.1016/S0010-9452(08)70881-5

Berg, E. A. (1948). A Simple Objective Technique for Measuring Flexibility in Thinking. *The Journal of General Psychology, 39*(1), 15-22. doi:10.1080/00221309.1948.9918159

Berthoz, S., & Hill, E. L. (2005). The validity of using self-reports to assess emotion regulation abilities in adults with autism spectrum disorder. *European Psychiatry, 20*(3), 291-298. doi:10.1016/j.eurpsy.2004.06.013

Bird, G., & Cook, R. (2013). Mixed emotions: the contribution of alexithymia to the emotional symptoms of autism. *Translational Psychiatry, 3*(7), e285-e285. doi:10.1038/tp.2013.61

Bird, G., Silani, G., Brindley, R., White, S., Frith, U., & Singer, T. (2010). Empathic brain responses in insula are modulated by levels of alexithymia but not autism. *Brain, 133*(5), 1515-1525. doi:10.1093/brain/awq060

Block, R. A., & Zakay, D. (2006). Prospective remembering involves time estimation and memory processes. In J. Glicksohn & M. S. Myslobodsky (Eds.), *Timing the Future: The Case for a Time-Based Prospective Memory* (pp. 25-49). River Edge, NJ, US: World Scientif Publishing.

Blomqvist, M., Bejerot, S., & Dahllöf, G. (2015). A cross-sectional study on oral health and dental care in intellectually able adults with autism spectrum disorder. *BMC Oral Health, 15*(1), 81. doi:10.1186/s12903-015-0065-z

Bölte, S., Dziobek, I., & Poustka, F. (2009). Brief report: The level and nature of autistic intelligence revisited. *Journal of Autism and Developmental Disorders, 39*(4), 678-682. doi:10.1007/s10803-008-0667-2

Boucher, J., & Bowler, D. M. (2008). *Memory in autism: Theories and evidence*. Cambridge: Cambridge University Press.

Boucher, J., Mayes, A., & Bigham, S. (2012). Memory in autistic spectrum disorder. *Psychological Bulletin, 138*(3), 458-496. doi:10.1037/a0026869

Bowler, D. M., Gaigg, S. B., & Gardiner, J. M. (2008). Effects of related and unrelated context on recall and recognition by adults with high-functioning autism spectrum disorder. *Neuropsychologia, 46*(4), 993-999. doi:10.1016/j.neuropsychologia.2007.12.004

Bowler, D. M., Gaigg, S. B., & Lind, S. E. (2011). Memory in autism: Binding, self and brain. In I. Roth & P. Rezaie (Eds.), *Researching the autism spectrum: contemporary perspectives* (pp. 316-346). Cambridge: Cambridge University Press.

Bowler, D. M., Gardiner, J. M., & Berthollier, N. (2004). Source memory in adolescents and adults with Asperger's syndrome. *Journal of Autism and Developmental Disorders, 34*(5), 533-542. doi:10.1007/s10803-004-2548-7

Bowler, D. M., Gardiner, J. M., & Grice, S. J. (2000). Episodic memory and remembering in adults with Asperger syndrome. *Journal of Autism and Developmental Disorders, 30*(4), 295-304.

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision, 10*(4), 433-436. doi:10.1163/156856897x00357

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*(1), 56-66. doi:10.1080/09658211.2010.535657.

Brewer, G. A., Knight, J., Meeks, J. T., & Marsh, R. L. (2011). On the role of imagery in event-based prospective memory. *Consciousness and Cognition, 20*(3), 901-907. doi:10.1016/j.concog.2011.02.015

Brewer, G. A., & Marsh, R. L. (2010). On the role of episodic future simulation in encoding of prospective memories. *Cognitive Neuroscience, 1*(2), 81-88. doi:10.1080/17588920903373960

Brewer, R., Cook, R., & Bird, G. (2016). Alexithymia: a general deficit of interoception. *Royal Society Open Science, 3*(10), 150664-150664. doi:10.1098/rsos.150664

Brockmole, J. R., Wang, R. F., & Irwin, D. E. (2002). Temporal integration between visual images and visual percepts. *Journal of Experimental Psychology-Human Perception and Performance, 28*(2), 315-334. doi:10.1037/0096-1523.28.2.315

Brown, S. W. (1997). Attentional resources in timing: Interference effects in concurrent temporal and nontemporal working memory tasks. *Perception & Psychophysics, 59*(7), 1118-1140. doi:10.3758/BF03205526

Brugha, T. S., McManus, S., Bankart, J., & et al. (2011). Epidemiology of autism spectrum disorders in adults in the community in england. *Archives of General Psychiatry, 68*(5), 459-465. doi:10.1001/archgenpsychiatry.2011.38

Buckner, R. L., & Carroll, D. C. (2007). Self-projection and the brain. *Trends in Cognitive Sciences, 11*(2), 49-57. doi:10.1016/j.tics.2006.11.004

Burgess, P. W., Dumontheil, I., & Gilbert, S. J. (2007). The gateway hypothesis of rostral prefrontal cortex (area 10) function. *Trends in Cognitive Sciences, 11*(7), 290-298. doi:10.1016/j.tics.2007.05.004

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. doi:10.1016/j.neuropsychologia.2011.02.014

Burgess, P. W., Quayle, A., & Frith, C. D. (2001). Brain regions involved in prospective memory as determined by positron emission tomography. *Neuropsychologia, 39*(6), 545-555. doi:10.1016/S0028-3932(00)00149-4

Burgess, P. W., Scott, S. K., & Frith, C. D. (2003). The role of the rostral frontal cortex (area 10) in prospective memory: A lateral versus medial dissociation. *Neuropsychologia, 41*(8), 906-918. doi:10.1016/S0028-3932(02)00327-5

Cellini, N., Mioni, G., Levorato, I., Grondin, S., Stablum, F., & Sarlo, M. (2015). Heart rate variability helps tracking time more accurately. *Brain and Cognition, 101*, 57-63. doi:10.1016/j.bandc.2015.10.003

Chatterjee, S., & Hadi, A. S. (2012). *Regression Analysis by Example* (5th ed.). New York: Wiley.

Chen, X.-j., Wang, Y., Liu, L.-l., Cui, J.-f., Gan, M.-y., Shum, D. H. K., & Chan, R. C. K. (2015). The effect of implementation intention on prospective memory: A systematic and meta-analytic review. *Psychiatry Research, 226*(1), 14-22. doi:10.1016/j.psychres.2015.01.011

Cherkaoui, M., & Gilbert, S. J. (2017). Strategic use of reminders in an ‘intention offloading’ task: Do individuals with autism spectrum conditions compensate for memory difficulties? *Neuropsychologia, 97*, 140-151. doi:10.1016/j.neuropsychologia.2017.02.008

Cianchetti, C., Corona, S., Foscoliano, M., Contu, D., & Sannio-Fancello, G. (2007). Modified Wisconsin Card Sorting Test (MCST, MWCST): normative data in children 4-13 years old, according to classical and new types of scoring. *The Clinical Neuropsychologist, 21*(3), 456-478. doi:10.1080/13854040600629766

Cicchetti, D. V., Koenig, K., Klin, A., Volkmar, F. R., Paul, R., & Sparrow, S. (2011). From Bayes through marginal utility to effectsizes: A guide to understanding the clinical and statistical significance of the results of autism research findings. *Journal of Autism and Developmental Disorders, 41*(2), 168-174. doi:10.1007/s10803-010-1035-6

Cicogna, P. C., & Nigro, G. (1998). Influence of importance of intention on prospective memory performance. *Perceptual and Motor Skills, 87*(3), 1387-1392. doi:10.2466/pms.1998.87.3f.1387

Clark-Foos, A., Brewer, G. A., Marsh, R. L., Meeks, J. T., & Cook, G. I. (2009). The valence of event-based prospective memory cues or the context in which they occur affects their detection. *American Journal of Psychology, 122*(1), 89-97. doi:10.2307/27784377

Cockburn, J., & Smith, P. T. (1991). The relative influence of intelligence and age on everyday memory. *Journal of Gerontology, 46*(1), P31-36. doi:10.1093/geronj/46.1.P31

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Cohen, J. (1990). Things I Have Learned (So Far). *American Psychologist, 45*(12), 1304-1312. doi:Doi 10.1037//0003-066x.45.12.1304

Cohen, J. (1992). A power primer. *Psychological Bulletin, 112*(1), 155-159.

Coltheart, M. (1981). The MRC psycholinguistic database. *The Quarterly Journal of Experimental Psychology Section A, 33*(4), 497-505. doi:10.1080/14640748108400805

Cona, G., Bisiacchi, P. S., & Moscovitch, M. (2014). The effects of focal and nonfocal cues on the neural correlates of prospective memory: Insights from ERPs. *Cerebral Cortex, 24*(10), 2630-2646. doi:10.1093/cercor/bht116

Cona, G., Scarpazza, C., Sartori, G., Moscovitch, M., & Bisiacchi, P. S. (2015). Neural bases of prospective memory: A meta-analysis and the “Attention to Delayed Intention” (AtoDI) model. *Neuroscience & Biobehavioral Reviews, 52*, 21-37. doi:10.1016/j.neubiorev.2015.02.007

Constantino, J. N., & Gruber, P. C. (2005). *Social Responsiveness Scale (SRS)*. Los Angeles, CA: Western Psychological Services.

Cook, R., Brewer, R., Shah, P., & Bird, G. (2013). Alexithymia, Not Autism, Predicts Poor Recognition of Emotional Facial Expressions. *Psychological Science, 24*(5), 723-732. doi:10.1177/0956797612463582

Craig, A. D. (2003). Interoception: The sense of the physiological condition of the body. *Current Opinion in Neurobiology, 13*(4), 500-505. doi:10.1016/S0959-4388(03)00090-4

Craig, A. D. (2009). How do you feel — now? The anterior insula and human awareness. *Nature Reviews Neuroscience, 10*(1), 59-70. doi:10.1038/nrn2555

Craik, F. I. M., & Anderson, N. D. (1999). Applying cognitive research to problems of aging. In D. Gopher & A. Koriat (Eds.), *Attention and Performance XVII: Cognitive regulation of performance: Interaction of theory and application* (Vol. 17, pp. 583-615). Cambridge, MA, US: The MIT Press.

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, 11*(3), 261-275. doi:10.1080/09658210244000027

Critchley, H. D., & Garfinkel, S. N. (2017). Interoception and emotion. *Curr Opin Psychol, 17*, 7-14. doi:10.1016/j.copsyc.2017.04.020

Critchley, H. D., & Garfinkel, S. N. (2018). The influence of physiological signals on cognition. *Current Opinion in Behavioral Sciences, 19*, 13-18. doi:10.1016/j.cobeha.2017.08.014

Critchley, H. D., & Harrison, N. A. (2013). Visceral influences on brain and behavior. *Neuron, 77*(4), 624-638. doi:10.1016/j.neuron.2013.02.008

Critchley, H. D., Wiens, S., Rotshtein, P., Öhman, A., & Dolan, R. J. (2004). Neural systems supporting interoceptive awareness. *Nature Neuroscience, 7*(2), 189-195. doi:10.1038/nn1176

Dajani, D. R., & Uddin, L. Q. (2015). Demystifying cognitive flexibility: Implications for clinical and developmental neuroscience. *Trends in Neurosciences, 38*(9), 571-578. doi:10.1016/j.tins.2015.07.003

de Vito, S., Buonocore, A., Bonnefon, J.-F., & Della Sala, S. (2015). Eye movements disrupt episodic future thinking. *Memory, 23*(6), 796-805. doi:10.1080/09658211.2014.927888

de Vries, M., & Geurts, H. (2015). Influence of autism traits and executive functioning on quality of life in children with an autism spectrum disorder. *Journal of Autism and Developmental Disorders, 45*(9), 2734-2743. doi:10.1007/s10803-015-2438-1

Delmonte, S., Balsters, J. H., McGrath, J., Fitzgerald, J., Brennan, S., Fagan, A. J., & Gallagher, L. (2012). Social and monetary reward processing in autism spectrum disorders. *Molecular Autism, 3*(1), 7-7. doi:10.1186/2040-2392-3-7

Demetriou, E. A., Lampit, A., Quintana, D. S., Naismith, S. L., Song, Y. J. C., Pye, J. E., . . . Guastella, A. J. (2017). Autism spectrum disorders: a meta-analysis of executive function. *Molecular Psychiatry*(November 2016), 1-7. doi:10.1038/mp.2017.75

Dempster, F. N., & Vegas, L. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review, 12*(1), 45-75. doi:10.1016/0273-2297(92)90003-K

DePape, A.-M. R., Hall, G. B. C., Tillmann, B., & Trainor, L. J. (2012). Auditory processing in high-functioning adolescents with autism spectrum disorder. *PLoS ONE, 7*(9). doi:10.1371/journal.pone.0044084

Deruelle, C., Hubert, B., Santos, A., & Wicker, B. (2008). Negative emotion does not enhance recall skills in adults with autistic spectrum disorders. *Autism Research, 1*(2), 91-96. doi:10.1002/aur.13

Di Martino, A., Ross, K., Uddin, L. Q., Sklar, A. B., Castellanos, F. X., & Milham, M. P. (2009). Functional Brain Correlates of Social and Nonsocial Processes in Autism Spectrum Disorders: An Activation Likelihood Estimation Meta-Analysis. *Biological Psychiatry, 65*(1), 63-74. doi:10.1016/j.biopsych.2008.09.022

Diamond, A. (2013). Executive Functions. *Annual Review of Psychology, 64*, 135-168.

Dienes, Z. (2014). Using Bayes to get the most out of non-significant results. *Frontiers in Psychology, 5*. doi:10.3389/Fpsyg.2014.00781

DuBois, D., Ameis, S. H., Lai, M.-C., Casanova, M. F., & Desarkar, P. (2016). Interoception in autism spectrum disorder: A review. *International Journal of Developmental Neuroscience, 52*, 104-111. doi:10.1016/j.ijdevneu.2016.05.001

Dumontheil, I., Burgess, P. W., & Blakemore, S.-J. (2008). Development of rostral prefrontal cortex and cognitive and behavioural disorders. *Developmental Medicine and Child Neurology, 50*(3), 168-181. doi:10.1111/j.1469-8749.2008.02026.x

Duncan, J. (2010). The multiple-demand (MD) system of the primate brain: mental programs for intelligent behaviour. *Trends in Cognitive Sciences, 14*(4), 172-179. doi:10.1016/j.tics.2010.01.004

Dunn, L. M., Dunn, D. M., Styles, B., & Sewell, J. (2009). *The British Picture Vocabulary Scale III* (3rd ed.). London: GL Assessement.

Durrleman, S., & Franck, J. (2015). Exploring links between language and cognition in autism spectrum disorders: Complement sentences, false belief, and executive functioning. *Journal of Communication Disorders, 54*, 15-31. doi:10.1016/j.jcomdis.2014.12.001

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

Einstein, G. O., & McDaniel, M. A. (2005). Prospective memory: Multiple retrieval processes. *Current Directions in Psychological Science, 14*(6), 286-290. doi:10.1111/j.0963-7214.2005.00382.x

Einstein, G. O., McDaniel, M. A., Richardson, S. L., Guynn, M. J., & Cunfer, A. R. (1995). Aging and prospective memory: examining the influences of self-initiated retrieval processes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*(4), 996-1007.

Einstein, G. O., McDaniel, M. A., Thomas, R., Mayfield, S., Shank, H., Morrisette, N., & Breneiser, J. (2005). Multiple processes in prospective memory retrieval: Factors determining monitoring versus spontaneous retrieval. *Journal of Experimental Psychology: General, 134*(3), 327-342. doi:10.1037/0096-3445.134.3.327

Einstein, G. O., Smith, R. E., McDaniel, M. A., & Shaw, P. (1997). Aging and Prospective Memory: The Influence of Increased Task Demands at Encoding and Retrieval. *Psychology and Aging, 12*(3), 479-488. doi:10.1037/0882-7974.12.3.479

Ellis, J. (1996). Prospective memory or the realization of delayed intentions: A conceptual framework for research. In M. A. Brandimonte, G. O. Einstein, & M. A. McDaniel

(Eds.), *Prospective memory: Theory and applications* (pp. 1-22). Mahwah NJ: Lawrence Erlbaum Associates, Inc.

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*(2), 175-191. doi:10.3758/BF03193146

Fleiss, J. L., Levin, B., & Paik, M. C. (2003). *Statistical Methods for Rates and Proportions* (3rd ed.). Hoboken, New Jersey: Wiley.

Ford, R. M., Driscoll, T., Shum, D., & Macaulay, C. E. (2012). Executive and theory-of-mind contributions to event-based prospective memory in children: Exploring the self-projection hypothesis. *Journal of Experimental Child Psychology, 111*(3), 468-489. doi:10.1016/j.jecp.2011.10.006

Fox, M. D., Snyder, A. Z., Vincent, J. L., Corbetta, M., Van Essen, D. C., & Raichle, M. E. (2005). The human brain is intrinsically organized into dynamic, anticorrelated functional networks. *Proceedings of the National Academy of Sciences of the United States of America, 102*(27), 9673-9678. doi:10.1073/pnas.0504136102

Frazier, T. W., Ratliff, K. R., Gruber, C., Zhang, Y., Law, P. A., & Constantino, J. N. (2014). Confirmatory factor analytic structure and measurement invariance of quantitative autistic traits measured by the Social Responsiveness Scale-2. *Autism, 18*(1), 31-44. doi:10.1177/1362361313500382

Frith, C., & Frith, U. (2005). Theory of mind. *Current Biology, 15*(17), R644-R645. doi:10.1016/j.cub.2005.08.041

Fung, B. J., Crone, D. L., Bode, S., & Murawski, C. (2017). Cardiac Signals Are Independently Associated with Temporal Discounting and Time Perception. *Frontiers in Behavioral Neuroscience, 11*(January), 1-11. doi:10.3389/fnbeh.2017.00001

Gaigg, S. B., & Bowler, D. M. (2008). Free recall and forgetting of emotionally arousing words in autism spectrum disorder. *Neuropsychologia, 46*(9), 2336-2343. doi:10.1016/j.neuropsychologia.2008.03.008

García-Villamisar, D., & Hughes, C. (2007). Supported employment improves cognitive performance in adults with Autism. *Journal of Intellectual Disability Research, 51*(2), 142-150. doi:10.1111/j.1365-2788.2006.00854.x

Garfinkel, S. N., Barrett, A. B., Minati, L., Dolan, R. J., Seth, A. K., & Critchley, H. D. (2013). What the heart forgets: Cardiac timing influences memory for words and is modulated by metacognition and interoceptive sensitivity. *Psychophysiology, 50*(6), 505-512. doi:10.1111/psyp.12039

Garfinkel, S. N., Seth, A. K., Barrett, A. B., Suzuki, K., & Critchley, H. D. (2015). Knowing your own heart: Distinguishing interoceptive accuracy from interoceptive awareness. *Biological Psychology, 104*, 65-74. doi:10.1016/j.biopsycho.2014.11.004

Gelman, A., & Stern, H. (2006). The difference between "significant" and "not significant" is not itself statistically significant. *American Statistician, 60*(4), 328-331. doi:10.1198/000313006X152649

Geurts, H. M., Sinzig, J., Booth, R., & Happe, F. (2014). Neuropsychological heterogeneity in executive functioning in autism spectrum disorders. *International Journal of Developmental Disabilities, 60*(3), 155-162. doi:10.1179/2047387714Y.0000000047

Gil, S., Chambres, P., Hyvert, C., Fanget, M., & Droit-Volet, S. (2012). Children with autism spectrum disorders have "the working raw material" for time perception. *PLoS ONE, 7*(11), e49116-e49116. doi:10.1371/journal.pone.0049116

Gilbert, S. J. (2015a). Strategic offloading of delayed intentions into the external environment. *Quarterly Journal of Experimental Psychology, 68*(5), 971-992. doi:10.1080/17470218.2014.972963

Gilbert, S. J. (2015b). Strategic use of reminders: Influence of both domain-general and task-specific metacognitive confidence, independent of objective memory ability. *Consciousness and Cognition, 33*, 245-260. doi:10.1016/j.concog.2015.01.006

Gilbert, S. J., Armbruster, D. J. N., & Panagiotidi, M. (2012). Similarity between brain activity at encoding and retrieval predicts successful realization of delayed intentions. *Journal of Cognitive Neuroscience, 24*(1), 93-105. doi:10.1162/jocn_a_00094

Gilbert, S. J., Bird, G., Brindley, R., Frith, C. D., & Burgess, P. W. (2008). Atypical recruitment of medial prefrontal cortex in autism spectrum disorders: An fMRI study of two executive function tasks. *Neuropsychologia, 46*(9), 2281-2291. doi:10.1016/j.neuropsychologia.2008.03.025

Gilbert, S. J., Frith, C. D., & Burgess, P. W. (2005). Involvement of rostral prefrontal cortex in selection between stimulus-oriented and stimulus-independent thought. *European Journal of Neuroscience, 21*(5), 1423-1431. doi:10.1111/j.1460-9568.2005.03981.x

Gilbert, S. J., Meuwese, J. D. I., Towgood, K. J., Frith, C. D., & Burgess, P. W. (2009). Abnormal functional specialization within medial prefrontal cortex in high-functioning autism: A multi-voxel similarity analysis. *Brain, 132*(4), 869-878. doi:10.1093/brain/awn365

Gilbert, S. J., Simons, J. S., Frith, C. D., & Burgess, P. W. (2006). Performance-related activity in medial rostral prefrontal cortex (area 10) during low-demand tasks. *Journal of Experimental Psychology: Human Perception and Performance, 32*(1), 45-58. doi:10.1037/0096-1523.32.1.45

Gollwitzer, P. M. (1999). Implementation intentions. *American Psychologist, 54*(7), 493-503. doi:10.1037//0003-066x.54.7.493

Gonneaud, J., Rauchs, G., Groussard, M., Landeau, B., Mézenge, F., de La Sayette, V., . . . Desgranges, B. (2014). How do we process event-based and time-based intentions in the brain? an fMRI study of prospective memory in healthy individuals. *Human Brain Mapping, 35*(7), 3066-3082. doi:10.1002/hbm.22385

Graf, P., & Grondin, S. (2006). Time perception and time-based prospective memory. In J. Glicksohn & M. S. Myslobodsky (Eds.), *Timing the future: The case for a time-based prospective memory* (pp. 1-24). River Edge, NJ, US: World Scientific Publishing.

Graf, P., & Uttl, B. (2001). Prospective memory: A new focus for research. *Consciousness and Cognition, 10*(4), 437-450. doi:10.1006/ccog.2001.0504

Graf, P., & Yu, M. (2015). Valenced cues and contexts have different effects on event-based prospective memory. *PLoS ONE, 10*(2), 1-17. doi:10.1371/journal.pone.0116953

Grainger, C., Williams, D. M., & Lind, S. E. (2014). Metacognition, metamemory, and mindreading in high-functioning adults with autism spectrum disorder. *Journal of Abnormal Psychology, 123*(3), 650-659. doi:10.1037/a0036531

Hair, J., Anderson, R., Tatham, R., & Black, W. (1998). *Multivariate Data Analysis* (5th ed.). Englewood Cliffs, NJ: Prentice Hall.

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. doi:10.1007/s10803-013-1896-6

Happé, F., & Frith, U. (1995). Theory of mind in autism. In E. Schopler & G. Mesibov (Eds.), *Learning and Cognition in Autism* (pp. 177-197): Springer US.

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. doi:10.1007/s10803-005-0039-0

Healy, A. F., & Nairne, J. S. (1985). Short-term memory processes in counting. *Cognitive Psychology, 17*(4), 417-444. doi:10.1016/0010-0285(85)90015-5

Hedges, L. V. (1981). Distribution theory for Glass's estimator of effect size and related estimators. *Journal of Educational and Behavioral Statistics, 6*(2), 107-128. doi:10.3102/10769986006002107

Hedges, L. V., & Olkin, I. (1985). *Statistical methods for meta-analysis*. Orlando, FL: Academic Press.

Hendricks, D. (2010). Employment and adults with autism spectrum disorders: Challenges and strategies for success. *Journal of Vocational Rehabilitation, 32*(2), 125-134.

Henry, J. D., MacLeod, M. S., Phillips, L. H., & Crawford, J. R. (2004). A meta-analytic review of prospective memory and aging. *Psychology and Aging, 19*(1), 27-39. doi:10.1037/0882-7974.19.1.27

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. doi:10.1016/j.jecp.2014.01.011

Herbert, B. M., Herbert, C., & Pollatos, O. (2011). On the relationship between interoceptive awareness and alexithymia: Is interoceptive awareness related to emotional awareness? *Journal of Personality, 79*(5), 1149-1175. doi:10.1111/j.1467-6494.2011.00717.x

Hering, A., Rendell, P. G., Rose, N. S., Schnitzspahn, K. M., & Kliegel, M. (2014). Prospective memory training in older adults and its relevance for successful aging. *Psychological Research, 78*(6), 892-904. doi:10.1007/s00426-014-0566-4

Hiebel, N., & Zimmer, H. D. (2015). Individual differences in working memory capacity and attentional control. *Canadian Journal of Experimental Psychology=Revue canadienne de psychologie expérimentale, 69*(1), 17-27. doi:10.1037/cep0000029

Hill, E. L. (2004). Executive dysfunction in autism. *Trends in Cognitive Science, 8*(1), 26-32. doi:10.1016/j.tics.2003.11.003

Hill, E. L., Berthoz, S., & Frith, U. (2004). Brief Report: Cognitive processing of own emotions in individuals with autistic spectrum disorder and in their relatives. *Journal of Autism and Developmental Disorders, 34*(2), 229-235. doi:10.1023/B:JADD.0000022613.41399.14

Howlin, P., & Moss, P. (2012). Adults with Autism Spectrum Disorders. *The Canadian Journal of Psychiatry, 57*(5), 275-283. doi:10.1177/070674371205700502

Hus, V., Gotham, K., & Lord, C. (2014). Standardizing ADOS Domain Scores: Separating Severity of Social Affect and Restricted and Repetitive Behaviors. *Journal of Autism and Developmental Disorders, 44*(10), 2400-2412. doi:10.1007/s10803-012-1719-1

Ihle, A., Hering, A., Mahy, C. E. V., Bisiacchi, P. S., & Kliegel, M. (2013). Adult age differences, response management, and cue focality in event-based prospective memory: A meta-analysis on the role of task order specificity. *Psychology and Aging, 28*(3), 714-720. doi:10.1037/a0033653

Ihle, A., Schnitzspahn, K., Rendell, P. G., Luong, C., & Kliegel, M. (2012). Age benefits in everyday prospective memory: The influence of personal task importance, use of reminders and everyday stress. *Neuropsychology, development, and cognition. Section B, Aging, neuropsychology and cognition, 19*(1-2), 84-101. doi:10.1080/13825585.2011.629288

Iovannone, R., Dunlap, G., Huber, H., & Kincaid, D. (2003). Effective educational practices for students with autism spectrum disorders. *Focus on autism and other developmental disabilities, 18*(3), 150-165. doi:10.1177/10883576030180030301

Ishihara, S. (1951). *Tests for Colour-Blindness* (10th ed.). Tokyo, Japan: Kanehara.

JASP Team. (2017). JASP (Version 0.8.1.2). [Computer software].

Jeffreys, H. (1961). *Theory of probability* (3rd ed.). Oxford: Oxford University Press, Clarendon Press.

Jennings, J. R. (1992). Is it important that the mind is in a body? Inhibition and the heart. *Psychophysiology, 29*(4), 369-383. doi:10.1111/j.1469-8986.1992.tb01710.x

Jennings, J. R., van der Molen, M. W., Brock, K., & Somsen, R. J. (1991). Response inhibition initiates cardiac deceleration: evidence from a sensory-motor compatibility paradigm. *Psychophysiology, 28*(1), 72-85. doi:10.1111/j.1469-8986.1991.tb03390.x

Jones, C. R. G., Happé, F., Pickles, A., Marsden, A. J. S., Tregay, J., Baird, G., . . . Charman, T. (2011). 'Everyday memory' impairments in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 41*(4), 455-464. doi:10.1007/s10803-010-1067-y

Katai, S., Maruyama, T., Hashimoto, T., & Ikeda, S. (2003). Event based and time based prospective memory in Parkinson's disease. *Journal of Neurology, Neurosurgery and Psychiatry, 74*(6), 704-709. doi:10.1136/jnnp.74.6.704

Kenworthy, L., Yerys, B. E., Anthony, L. G., & Wallace, G. L. (2008). Understanding executive control in autism spectrum disorders in the lab and in the real world. *Neuropsychology Review, 18*(4), 320-338. doi:10.1007/s11065-008-9077-7

Keogh, R., & Pearson, J. (2011). Mental Imagery and Visual Working Memory. *PLoS ONE, 6*(12), e29221. doi:10.1371/journal.pone.0029221

Kercood, S., Grskovic, J. A., Banda, D., & Begeske, J. (2014). Working memory and autism: A review of literature. *Research in Autism Spectrum Disorders, 8*(10), 1316-1332. doi:10.1016/j.rasd.2014.06.011

Kerns, K. A. (2000). The CyberCruiser: an investigation of development of prospective memory in children. *Journal of the International Neuropsychological Society, 6*(1), 62-70. doi:10.1017/S1355617700611074

Kim, P. Y., & Mayhorn, C. B. (2008). Exploring students' prospective memory functions inside and outside the lab. *The American Journal of Psychology, 121*(2), 241-254. doi:10.2307/20445459

Kimhi, Y. (2014). Theory of Mind Abilities and Deficits in Autism Spectrum Disorders. *Topics in Language Disorders, 34*(4), 329-343. doi:10.1097/tld.0000000000000033

Kirchner, W. K. (1958). Age differences in short-term retention of rapidly changing information. *Journal of experimental psychology, 55*(4), 352-358. doi:10.1037/h0043688

Kleiner, M., Brainard, D., & Pelli, D. (2007). What's new in Psychtoolbox-3? *Perception 6 ECVP Abstract Supplement*, 14-14.

Kliegel, M., Guynn, M. J., & Zimmer, H. (2007). The role of noticing in prospective memory forgetting. *International Journal of Psychophysiology, 64*(3), 226-232. doi:10.1016/j.ijpsycho.2006.09.007

Kliegel, M., Jäger, T., Altgassen, M., & Shum, D. (2008). Clinical neuropsychology of prospective memory. In M. Kliegel & M. A. McDaniel (Eds.), *Prospective memory: Cognitive, neuroscience, developmental, and applied perspectives* (pp. 283-308). New York: Taylor and Francis.

Kliegel, M., Jäger, T., & Phillips, L. H. (2008). Adult age differences in event-based prospective memory: A meta-analysis on the role of focal versus nonfocal cues. *Psychology and Aging, 23*(1), 203-208. doi:10.1037/0882-7974.23.1.203

Kliegel, M., Mackinlay, R., & Jäger, T. (2008). Complex prospective memory: Development across the lifespan and the role of task interruption. *Developmental Psychology, 44*(2), 612-617. doi:10.1037/0012-1649.44.2.612

Kliegel, M., Mahy, C. E. V., Voigt, B., Henry, J. D., Rendell, P. G., & Aberle, I. (2013). The development of prospective memory in young schoolchildren: The impact of ongoing task absorption, cue salience, and cue centrality. *Journal of Experimental Child Psychology, 116*(4), 792-810. doi:10.1016/j.jecp.2013.07.012

Kliegel, M., Martin, M., McDaniel, M. A., & Einstein, G. O. (2001). Varying the importance of a prospective memory task: Differential effects across time- and event-based prospective memory. *Memory, 9*(1), 1-11. doi:10.1080/09658210042000003

Kliegel, M., Martin, M., McDaniel, M. A., & Einstein, G. O. (2002). Complex prospective memory and executive control of working memory: A process model. *Psychologische Beitraege, 44*, 303-318.

Kliegel, M., Martin, M., McDaniel, M. A., & Einstein, G. O. (2004). Importance effects on performance in event-based prospective memory tasks. *Memory, 12*(5), 553-561. doi:10.1080/09658210344000099

Kliegel, M., McDaniel, M. A., & Einstein, G. O. (2008). *Prospective memory: Cognitive, neuroscience, developmental, and applied perspectives*. New York: Taylor & Francis.

Kliegel, M., Ramuschkat, G., & Martin, M. (2003). Exekutive Funktionen und prospektive Gedächtnisleistung im Alter - Eine differentielle Analyse von ereignis- und zeitbasierter prospektiver Gedächtnisleistung. *Zeitschrift fur Gerontologie und Geriatrie, 36*(1), 35-41. doi:10.1007/s00391-003-0081-5

Kooiman, C. G., Spinhoven, P., & Trijsburg, R. W. (2002). The assessment of alexithymia. A critical review of the literature and a psychmetric study of the Toronto Alexuthymia Scale-20. *Journal of Psychsomatic Research, 53*(6), 1083-1090. doi:10.1016/S0022-3999(02)00348-3

Kosslyn, S. M., Ganis, G., & Thompson, W. L. (2001). Neural foundations of imagery. *Nature Reviews: Neuroscience, 2*(9), 635-642. doi:10.1038/35090055

Kretschmer, A., Altgassen, M., Rendell, P. G., Bolte, S., & 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. doi:10.1016/j.ridd.2014.07.052

Kucera, H., & Francis, W. N. (1967). *Computational analysis of present-day American English*. Providence, RI: Brown University Press.

Kvavilashvili, L., & Ellis, J. (1996). Varieties of intention: Some distinctions and classifications. In M. A. Brandimonte, G. O. Einstein, & M. A. McDaniel (Eds.), (pp. 23-51). Mahwah, New Jersey: Lawrence Erlbaum Associates, Publishers.

Kvavilashvili, L., & Fisher, L. (2007). Is time-based prospective remembering mediated by self-initiated rehearsals? Role of incidental cues, ongoing activity, age, and motivation. *Journal of Experimental Psychology: General, 136*(1), 112-132. doi:10.1037/0096-3445.136.1.112

Lai, C. L., Lau, Z., Lui, S. S., Lok, E., Tam, V., Chan, Q., . . . Cheung, E. F. (2016). Meta-analysis of neuropsychological measures of executive functioning in children and adolescents with high-functioning autism spectrum disorder. *Autism Research*, 1-29. doi:10.1002/aur.1723

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics, 33*(1), 159-174. doi:10.2307/2529310

Landry, O., & Al-Taie, S. (2016). A Meta-analysis of the Wisconsin Card Sort Task in Autism. *Journal of Autism and Developmental Disorders, 46*(4), 1220-1235. doi:10.1007/s10803-015-2659-3

Landsiedel, J., & Gilbert, S. J. (2015). Creating external reminders for delayed intentions: Dissociable influence on "task-positive" and "task-negative" brain networks. *NeuroImage, 104*, 231-240. doi:10.1016/j.neuroimage.2014.10.021

Larsen, J. K., Brand, N., Bermond, B., & Hijman, R. (2003). Cognitive and emotional characteristics of alexithymia: A review of neurobiological studies. *Journal of Psychosomatic Research, 54*(6), 533-541. doi:10.1016/S0022-3999(02)00466-X

Lee, M. D., & Wagenmakers, E.-J. (2013). *Bayesian cognitive modeling: A practical course*. New York: Cambridge University Press.

Lenroot, R. K., & Yeung, P. K. (2013). Heterogeneity within Autism Spectrum Disorders: What have We Learned from Neuroimaging Studies? *Frontiers in Human Neuroscience, 7*(October), 1-16. doi:10.3389/fnhum.2013.00733

Leung, R. C., & Zakzanis, K. K. (2014). Brief report: Cognitive flexibility in autism spectrum disorders: A quantitative review. *Journal of Autism and Developmental Disorders, 44*(10), 2628-2645. doi:10.1007/s10803-014-2136-4

Lind, S. E. (2010). Memory and the self in autism: A review and theoretical framework. *Autism, 14*(5), 430-456. doi:10.1177/1362361309358700

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), 55-55. doi:10.1037/neu0000005

Lind, S. E., Williams, D. M., Raber, J., Peel, A., & Bowler, D. M. (2013). Spatial navigation impairments among intellectually high-functioning adults with autism spectrum disorder: Exploring relations with theory of mind, episodic memory, and episodic future thinking. *Journal of Abnormal Psychology, 122*(4), 1189-1189.

Lipsey, M. W., & Wilson, D. B. (2001). *Practical meta-analysis*. Thousand Oaks, California: Sage Publications.

Loft, S., Kearney, R., & Remington, R. (2008). Is task interference in event-based prospective memory dependent on cue presentation? *Memory & Cognition, 36*(1), 139-148. doi:10.3758/Mc.36.1.139

Logie, R. H., Gilhooly, K. J., & Wynn, V. (1994). Counting on working memory in arithmetic problem solving. *Memory & Cognition, 22*(4), 395-410. doi:10.3758/bf03200866

Lord, C., Rutter, M., DiLavore, P. C., Risi, S., Gotham, K., & Bishop, S. L. (2012). *Autism diagnostic observeration schedule, 2nd edition (ADOS-2)*. Torrance, CA: Western Psychological Services.

Losh, M., Adolphs, R., Poe, M. D., Couture, S., Penn, D., Baranek, G. T., & Piven, J. (2009). The neuropsychological profile of autism and the broad autism phenotype. *Archives of General Psychiatry, 66*(5), 518-526. doi:10.1001/archgenpsychiatry.2009.34.

Macar, F., Grondin, S., & Casini, L. (1994). Controlled Attention Sharing Influences Time-Estimation. *Memory & Cognition, 22*(6), 673-686. doi:Doi 10.3758/Bf03209252

Mackinlay, R. J., Kliegel, M., & Mäntylä, T. (2009). Predictors of time-based prospective memory in children. *Journal of Experimental Child Psychology, 102*(3), 251-264. doi:10.1016/j.jecp.2008.08.006

Mahy, C. E. V., Mohun, H., Müller, U., & Moses, L. J. (2016). The role of subvocal rehearsal in preschool children's prospective memory. *Cognitive Development, 39*, 189-196. doi:10.1016/j.cogdev.2016.07.001

Mahy, C. E. V., & Moses, L. J. (2011). Executive functioning and prospective memory in young children. *Cognitive Development, 26*(3), 269-281. doi:10.1016/j.cogdev.2011.06.002

Mahy, C. E. V., & Moses, L. J. (2015). The effect of retention interval task difficulty on young children's prospective memory: Testing the intention monitoring hypothesis. *Journal of Cognition and Development, 16*(5), 742-758. doi:10.1080/15248372.2014.930742

Mahy, C. E. V., Moses, L. J., & Kliegel, M. (2014). The development of prospective memory in children: An executive framework. *Developmental Review, 34*(4), 305-326. doi:10.1016/j.dr.2014.08.001

Mandy, W., Charman, T., Puura, K., & Skuse, D. (2014). Investigating the cross-cultural validity of DSM-5 autism spectrum disorder: evidence from Finnish and UK samples. *Autism, 18*(1), 45-54. doi:10.1177/1362361313508026

Mäntylä, T., & Carelli, M.-G. (2006). Time monitoring and executive functioning: Individual and developmental differences. In J. Glicksohn & M. S. Myslobodsky (Eds.), *Timing the future: The case for a time-based prospective memory.* (pp. 191-211). River Edge, NJ, US: World Scientific Publishing.

Mäntylä, T., Carelli, M. G., & Forman, H. (2007). Time monitoring and executive functioning in children and adults. *Journal of Experimental Child Psychology, 96*(1), 1-19. doi:10.1016/j.jecp.2006.08.003

Maras, K. L., & Bowler, D. M. (2012). Context reinstatement effects on eyewitness memory in autism spectrum disorder. *British Journal of Psychology, 103*(3), 330-342. doi:10.1111/j.2044-8295.2011.02077.x

Marsh, R. L., & Hicks, J. L. (1998). Event-based prospective memory and executive control of working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*(2), 336-349. doi:10.1037/0278-7393.24.2.336

Marsh, R. L., Hicks, J. L., & Cook, G. I. (2008). On beginning to understand the role of context in prospective memory. In M. Kliegel, M. A. McDaniel, & G. O. Einstein (Eds.), *Prospective memory: Cognitive, neuroscience, develoopmental, and applied perspectives* (pp. 77-100). New York: Taylor & Francis.

Marsh, R. L., Hicks, J. L., Cook, G. I., & Mayhorn, C. B. (2007). Comparing older and younger adults in an event-based prospective memory paradigm containing an output monitoring component. *Aging, Neuropsychology, and Cognition, 14*(2), 168-188. doi:10.1080/138255891007074

Martin, J. S., Poirier, M., & Bowler, D. M. (2010). Brief report: Impaired temporal reproduction performance in adults with autism spectrum disorder. *Journal of Autism and Developmental Disorders, 40*(5), 640-646. doi:10.1007/s10803-009-0904-3

Martin, M., Kliegel, M., & McDaniel, M. A. (2003). The involvement of executive functions in prospective memory performance of adults. *International Journal of Psychology, 38*(5), 323-334. doi:10.1080/00207590244000205

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. doi:10.1007/s12264-017-0100-y

Mateer, C. A., Kerns, K. A., & Eso, K. L. (1996). Management of attention and memory disorders following traumatic brain injury. *J Learn Disabil, 29*(6), 618-632. doi:10.1177/002221949602900606

Maylor, E. A. (1996). Age-related impairment in an event-based prospective-memory task. *Psychology and Aging, 11*(1), 74-78. doi:10.1037/0882-7974.11.1.74

Maylor, E. A., Smith, G., Della Sala, S., & Logie, R. H. (2002). Prospective and retrospective memory in normal aging and dementia: An experimental study. *Memory & Cognition, 30*(6), 871-884. doi:10.3758/Bf03195773

McCartney, K., Burchinal, M. R., & Bub, K. L. (2006). Best practices in quantitative methods for developmentalists. *Monographs of the Society for Research in Child Development, 71*(3), i-145. Retrieved from http://www.jstor.org/stable/4121953.

McDaniel, M. A., & Einstein, G. O. (2000). Strategic and automatic processes in prospective memory retrieval: A multiprocess framework. *Applied Cognitive Psychology, 14*(7), S127-S144. doi:10.1002/acp.775

McDaniel, M. A., & Einstein, G. O. (2007). *Prospective memory: An overview and synthesis of an emerging field*. Thousand Oaks, CA, US: Sage Publications.

McDaniel, M. A., Robinson-Riegler, B., & Einstein, G. O. (1998). Prospective remembering: perceptually driven or conceptually driven processes? *Memory & Cognition, 26*(1), 121-134. doi:10.3758/BF03211375

McGovern, C. W., & Sigman, M. (2005). Continuity and change from early childhood to adolescence in autism. *Journal of Child Psychology and Psychiatry, 46*(4), 401-408.

Meier, B., & Zimmermann, T. D. (2015). Loads and loads and loads: The influence of prospective load, retrospective load, and ongoing task load in prospective memory. *Frontiers in Human Neuroscience, 9*, 322-322. doi:10.3389/fnhum.2015.00322

Meissner, K., & Wittmann, M. (2011). Body signals, cardiac awareness, and the perception of time. *Biological Psychology, 86*(3), 289-297. doi:10.1016/j.biopsycho.2011.01.001

Mella, N., Conty, L., & Pouthas, V. (2011). The role of physiological arousal in time perception: Psychophysiological evidence from an emotion regulation paradigm. *Brain and Cognition, 75*(2), 182-187. doi:10.1016/j.bandc.2010.11.012

Menon, V., & Uddin, L. Q. (2010). Saliency, switching, attention and control: A network model of insula function. *Brain Structure and Function, 214*(5-6), 655-667. doi:10.1007/s00429-010-0262-0

Mervis, C. B., & Klein-Tasman, B. P. (2004). Methodological issues in group-matching designs: Alpha levels for control variable comparisons and measurement characteristics of control and target variables. *Journal of Autism and Developmental Disorders, 34*(1), 7-17. doi:10.1023/B:Jadd.0000018069.69562.B8

Milosavljevic, B., Carter Leno, V., Simonoff, E., Baird, G., Pickles, A., Jones, C. R. G., . . . Happ, F. (2016). Alexithymia in Adolescents with Autism Spectrum Disorder: Its Relationship to Internalising Difficulties, Sensory Modulation and Social Cognition. *Journal of Autism and Developmental Disorders, 46*(4), 1354-1367. doi:10.1007/s10803-015-2670-8

Mioni, G., & Stablum, F. (2014). Monitoring behaviour in a time-based prospective memory task: The involvement of executive functions and time perception. *Memory, 22*(5), 536-552. doi:10.1080/09658211.2013.801987

Mioni, G., Stablum, F., McClintock, S. M., & Cantagallo, A. (2012). Time-based prospective memory in severe traumatic brain injury patients: the involvement of executive functions and time perception. *Journal of the International Neuropsychological Society, 18*(4), 697-705. doi:10.1017/S1355617712000306

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. *Cognitive Psychology, 41*(1), 49-100. doi:10.1006/cogp.1999.0734

Mottron, L. (2004). Matching strategies in cognitive research with individuals with high-functioning autism: Current practices, instrument biases, and recommendations. *Journal of Autism and Developmental Disorders, 34*(1), 19-27. doi:10.1023/B:Jadd.0000018070.88380.83

Nelson, H. E. (1976). A modificed card sorting test sensitive to frontal lobe defects. *Cortex, 12*(4), 313-324. doi:10.1016/S0010-9452(76)80035-4

Neroni, M. A., Gamboz, N., & Brandimonte, M. a. (2014). Does episodic future thinking improve prospective remembering? *Consciousness and Cognition, 23*, 53-62. doi:10.1016/j.concog.2013.12.001

Nicholson, T., Williams, D. M., Grainger, C., Christensen, J. F., Calvo-Merino, B., & Gaigg, S. B. (2017). *Interoceptive impairments do not lie at the heart of autism or alexithymia*. Manuscript submitted for publicaton.

Niedźwieńska, A., Janik, B., & Jarczyńska, A. (2013). Age-related differences in everyday prospective memory tasks: The role of planning and personal importance. *International Journal of Psychology, 48*(6), 1291-1302. doi:10.1080/00207594.2012.752097

Nigro, G., Brandimonte, M. a., Cicogna, P., & Cosenza, M. (2014). Episodic future thinking as a predictor of children's prospective memory. *Journal of Experimental Child Psychology, 127*, 82-94. doi:10.1016/j.jecp.2013.10.013

Nishiyama, T., Suzuki, M., Adachi, K., Sumi, S., Okada, K., Kishino, H., . . . Kanne, S. M. (2014). Comprehensive comparison of self-administered questionnaires for measuring quantitative autistic traits in adults. *Journal of Autism and Developmental Disorders, 44*(5), 993-1007. doi:10.1007/s10803-013-2020-7

Nowinski, J. L., & Dismukes, K. R. (2005). Effects of ongoing task context and target typicality on prospective memory performance: The importance of associative cueing. *Memory, 13*(6), 649-657. doi:10.1080/09658210444000313

Okuda, J., Fujii, T., Ohtake, H., Tsukiura, T., Yamadori, A., Frith, C. D., & Burgess, P. W. (2007). Differential involvement of regions of rostral prefrontal cortex (Brodmann area 10) in time- and event-based prospective memory. *International Journal of Psychophysiology, 64*(3), 233-246. doi:10.1016/j.ijpsycho.2006.09.009

Olde Dubbelink, L. M. E., & 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. doi:10.1007/s10803-016-3013-0

Olu-Lafe, O., Liederman, J., & Tager-Flusberg, H. (2014). Is the ability to integrate parts into wholes affected in autism spectrum disorder? *Journal of Autism and Developmental Disorders, 44*(10), 2652-2660. doi:10.1007/s10803-014-2120-z

Palermo, L., Cinelli, M. C., Piccardi, L., Ciurli, P., Incoccia, C., Zompanti, L., & Guariglia, C. (2015). Women outperform men in remembering to remember. *Quarterly Journal of Experimental Psychology*, 1-10. doi:10.1080/17470218.2015.1023734

Parker, J. D. A., Taylor, G. J., & Bagby, R. M. (2003). The 20-Item Toronto Alexithymia Scale: III. Reliability and factorial validity in a community population. *Journal of Psychosomatic Research, 55*(3), 269-275. doi:10.1016/S0022-3999(02)00578-0

Pashler, H., & Wagenmakers, E. J. (2012). Editors' introduction to the special section on replicability in psychological science. *Perspectives on Psychological Science, 7*(6), 528-530. doi:10.1177/1745691612465253

Pearson, D. G., Deeprose, C., Wallace-Hadrill, S. M. a., Burnett Heyes, S., & Holmes, E. a. (2013). Assessing mental imagery in clinical psychology: A review of imagery measures and a guiding framework. *Clinical Psychology Review, 33*(1), 1-23. doi:10.1016/j.cpr.2012.09.001

Peirce, J. W. (2007). PsychoPy—Psychophysics software in Python. *Journal of Neuroscience Methods, 162*(1), 8-13. doi:10.1016/j.jneumeth.2006.11.017

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10*(4), 437-442. doi:10.1163/156856897x00366

Penningroth, S. L., Scott, W. D., & Freuen, M. (2011). Social motivation in prospective memory: Higher importance ratings and reported performance rates for social tasks. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale, 65*(1), 3-11. doi:10.1037/a0022841

Peterson, C. C., Wellman, H. M., & Liu, D. (2005). Steps in theory-of-mind development for children with deafness or autism. *Child Development, 76*(2), 502-517. doi:10.1111/j.1467-8624.2005.00859.x

Pollatos, O., Laubrock, J., & Wittmann, M. (2014). Interoceptive focus shapes the experience of time. *PLoS ONE, 9*(1), 1-6. doi:10.1371/journal.pone.0086934

Pollatos, O., Traut-Mattausch, E., Schroeder, H., & Schandry, R. (2007). Interoceptive awareness mediates the relationship between anxiety and the intensity of unpleasant feelings. *Journal of Anxiety Disorders, 21*(7), 931-943. doi:10.1016/j.janxdis.2006.12.004

Pollatos, O., Yeldesbay, A., Pikovsky, A., & Rosenblum, M. (2014). How much time has passed? Ask your heart. *Frontiers in Neurorobotics, 8*, 1-9. doi:10.3389/fnbot.2014.00015

Pugliese, C. E., Anthony, L. G., Strang, J. F., Dudley, K., Wallace, G. L., Naiman, D. Q., & Kenworthy, L. (2016). Longitudinal examination of adaptive behavior in autism spectrum disorders: Influence of executive function. *Journal of Autism and Developmental Disorders, 46*(2), 467-477. doi:10.1007/s10803-015-2584-5

Raichle, M. E., MacLeod, A. M., Snyder, A. Z., Powers, W. J., Gusnard, D. A., & Shulman, G. L. (2001). A default mode of brain function. *Proceedings of the National Academy of Sciences of the United States of America, 98*(2), 676-682. doi:10.1073/pnas.98.2.676

Ramírez, E., Ortega, A. R., & Reyes Del Paso, G. A. (2015). Anxiety, attention, and decision making: The moderating role of heart rate variability. *International Journal of Psychophysiology, 98*(3), 490-496. doi:10.1016/j.ijpsycho.2015.10.007

Raven, J. (1939). *Progressive matrices: A perceptual test of intelligence*. Oxford: Oxford Psychologists Press Ltd.

Raz, N., Lindenberger, U., Rodrigue, K. M., Kennedy, K. M., Head, D., Williamson, A., . . . Acker, J. D. (2005). Regional brain changes in aging healthy adults: General trends, individual differences and modifiers. *Cerebral Cortex, 15*(11), 1676-1689. doi:10.1093/cercor/bhi044

Redshaw, J., Henry, J. D., & Suddendorf, T. (2016). Disentangling the effect of event-based cues on children's time-based prospective memory performance. *Journal of Experimental Child Psychology, 150*, 130-140. doi:10.1016/j.jecp.2016.05.008

Reed, P., & McCarthy, J. (2012). Cross-modal attention-switching is impaired in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 42*(6), 947-953. doi:10.1007/s10803-011-1324-8

Rendell, P. G., & Craik, F. I. M. (2000). Virtual week and actual week: Age-related differences in prospective memory. *Applied Cognitive Psychology, 14*(7), S43-S62. doi:10.1002/acp.770

Rendell, P. G., & Henry, J. D. (2009). A review of Virtual Week for prospective memory assessment: Clinical implications. *Brain Impairment, 14*(1), 14-22. doi:10.1375/brim.10.1.14

Repovs, G., & Baddeley, A. (2006). The multi-component model of working memory: Explorations in experimental cognitive psychology. *Neuroscience, 139*(1), 5-21. doi:10.1016/j.neuroscience.2005.12.061

Risko, E. F., & Gilbert, S. J. (2016). Cognitive offloading. *Trends in Cognitive Sciences, 20*(9), 676-688. doi:10.1016/j.tics.2016.07.002

Roth, R. M., Isquith, P. K., & Gioia, G. A. (2005). *Behaviour Rating Inventory of Executive Function - Adult Version (BRIEF-A)*. Lutz, FL: Psychological Assessment Resources.

Rouder, J. N., Speckman, P. L., Sun, D. C., Morey, R. D., & Iverson, G. (2009). Bayesian t tests for accepting and rejecting the null hypothesis. *Psychonomic Bulletin & Review, 16*(2), 225-237. doi:10.3758/Pbr.16.2.225

Salthouse, T. A. (2010). Selective review of cognitive aging. *Journal of the International Neuropsychological Society, 16*(05), 754-760. doi:10.1017/S1355617710000706

Salthouse, T. A., Berish, D. E., & Siedlecki, K. L. (2004). Construct validity and age sensitivity of prospective memory. *Memory & Cognition, 32*(7), 1133-1148. doi:10.3758/BF03196887

Samson, F., Mottron, L., Soulières, I., & Zeffiro, T. A. (2012). Enhanced visual functioning in autism: An ALE meta-analysis. *Human Brain Mapping, 33*(7), 1553-1581. doi:10.1002/hbm.21307

Schandry, R. (1981). Heart beat perception and emotional experience. *Psychophysiology, 18*(4), 483-488. doi:10.1111/j.1469-8986.1981.tb02486.x

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime User's Guide*. Pittsburgh: Psychology Software Tools Inc.

Schnitzspahn, K. M., Ihle, A., Henry, J. D., Rendell, P. G., & Kliegel, M. (2011). The age-prospective memory-paradox: An exploration of possible mechanisms. *International Psychogeriatrics, 23*(4), 583-592. doi:10.1017/S1041610210001651

Schnitzspahn, K. M., Stahl, C., Zeintl, M., Kaller, C. P., & Kliegel, M. (2013). The role of shifting, updating, and inhibition in prospective memory performance in young and older adults. *Developmental Psychology, 49*(8), 1544-1553. doi:10.1037/a0030579

Schopler, E., Reichler, R. J., DeVellis, R. F., & Daly, K. (1980). Toward objective classification of childhood autism: Childhood Autism Rating Scale (CARS). *Journal of Autism and Developmental Disorders, 10*(1), 91-103. doi:10.1007/bf02408436

Scullin, M. K., McDaniel, M. A., Shelton, J. T., & Lee, J. H. (2010). Focal/nonfocal cue effects in prospective memory: Monitoring difficulty or different retrieval processes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36*(3), 736-749. doi:10.1037/a0018971

Sellen, A. J., Louie, G., Harris, J. E., & Wilkins, A. J. (1997). What brings intentions to mind? An in situ study of prospective memory. *Memory, 5*(4), 483-507. doi:10.1080/741941433

Shah, P., Catmur, C., & Bird, G. (2016). Emotional decision-making in autism spectrum disorder: The roles of interoception and alexithymia. *Molecular Autism, 7*(1), 43-43. doi:10.1186/s13229-016-0104-x

Shah, P., Hall, R., Catmur, C., & Bird, G. (2016). Alexithymia, not autism, is associated with impaired interoception. *Cortex, 81*(July), 215-220. doi:10.1016/j.cortex.2016.03.021

Shaked, M., & Yirmiya, N. (2004). Matching procedures in autism research: Evidence from meta-analytic studies. *Journal of Autism and Developmental Disorders, 34*(1), 35-40. doi:10.1023/B:JADD.0000018072.42845.83

Sheppard, D. P., & Altgassen, M. (2016). *Sensory salience and prospective memory in autistic children*. Paper presented at the International Conference on Memory, Budapest.

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. doi:10.1016/j.ridd.2015.09.018

Smith, G., Della Sala, S., Logie, R. H., & Maylor, E. A. (2000). Prospective and retrospective memory in normal ageing and dementia: A questionnaire study. *Memory, 8*(5), 311-321.

Smith, R. E. (2003). The cost of remembering to remember in event-based prospective memory: Investigating the capacity demands of delayed intention performance. *Journal* *of Experimental Psychology: Learning, Memory, and Cognition, 29*(3), 347-361. doi:10.1037/0278-7393.29.3.347

Smith, R. E. (2017). Chapter Six - Prospective Memory in Context. In B. H. Ross (Ed.), *Psychology of Learning and Motivation* (Vol. 66, pp. 211-249): Academic Press.

Smith, R. E., & Bayen, U. J. (2004). A multinomial model of event-based prospective memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*(4), 756-777. doi:10.1037/0278-7393.30.4.756

Smith, R. E., & Bayen, U. J. (2005). The effects of working memory resource availability on prospective memory - A formal modeling approach. *Experimental Psychology, 52*(4), 243-256. doi:10.1027/1618-3169.52.4.243

Spreng, R. N., & Grady, C. L. (2009). Patterns of brain activity supporting autobiographical memory, prospection, and theory of mind, and their relationship to the default mode network. *Journal of Cognitive Neuroscience, 22*(6), 1112-1123.

Stavropoulos, K. K. M., & Carver, L. J. (2014). Reward anticipation and processing of social versus nonsocial stimuli in children with and without autism spectrum disorders. *Journal of Child Psychology and Psychiatry, 55*(12), 1398-1408. doi:10.1111/jcpp.12270

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of experimental psychology, 18*(6), 643-662. doi:10.1037/h0054651

Suarez, M. A. (2012). Sensory processing in children with autism spectrum disorders and impact on functioning. *Pediatric Clinics of North America, 59*(1), 203-214. doi:10.1016/j.pcl.2011.10.012

Szelag, E., Kowalska, J., Galkowski, T., & Pöppel, E. (2004). Temporal processing deficits in high-functioning children with autism. *British Jouranl of Psychology, 95*(3), 269-282. doi:10.1348/0007126041528167

Taylor, G. J. (2000). Recent developments in alexithymia theory and research. *Canadian Journal of Psychiatry, 45*(2), 134-142. doi:10.1177/070674370004500203

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. doi:10.1007/s10803-013-1806-y

Terrett, G., Rose, N. S., Henry, J. D., Bailey, P. E., Altgassen, M., Phillips, L. H., . . . Rendell, P. G. (2016). The relationship between prospective memory and episodic future thinking in younger and older adulthood. *The Quarterly Journal of Experimental Psychology, 69*(2), 310-323. doi:10.1080/17470218.2015.1054294

Terry, W. S. (1988). Everyday Forgetting: Data from a diary study. *Psychological Reports, 62*(1), 299-303. doi:10.2466/pr0.1988.62.1.299

Tong, F. (2013). Imagery and visual working memory: one and the same? *Trends in Cognitive Sciences, 17*(10), 489-490. doi:10.1016/j.tics.2013.08.005

Towgood, K. J., Meuwese, J. D. I., Gilbert, S. J., Turner, M. S., & Burgess, P. W. (2009). Advantages of the multiple case series approach to the study of cognitive deficits in autism spectrum disorder. *Neuropsychologia, 47*(13), 2981-2988. doi:10.1016/j.neuropsychologia.2009.06.028

Tsakiris, M., & Critchley, H. (2016). Interoception beyond homeostasis: affect, cognition and mental health. *Philosophical Transactions of the Royal Society B: Biological Sciences, 371*(1708), 20160002-20160002. doi:10.1098/rstb.2016.0002

Uddin, L. Q. (2011). The self in autism: An emerging view from neuroimaging. *Neurocase, 17*(3), 201-208. doi:10.1080/13554794.2010.509320

Uddin, L. Q., & Menon, V. (2009). The anterior insula in autism: Under-connected and under-examined. *Neuroscience and Biobehavioral Reviews, 33*(8), 1198-1203. doi:10.1016/j.neubiorev.2009.06.002.

Umeda, S., Tochizawa, S., Shibata, M., & Terasawa, Y. (2016). Prospective memory mediated by interoceptive accuracy: A psychophysiological approach. *Philosophical Transactions of the Royal Society B, 371*(1708). doi:10.1098/rstb.2016.0005

Underwood, A. G., Guynn, M. J., & Cohen, A.-L. (2015). The future orientation of past memory: The role of BA 10 in prospective and retrospective retrieval modes. *Frontiers in Human Neuroscience, 9*, 1-12. doi:10.3389/fnhum.2015.00668

Uttl, B. (2006). Age-related changes in event-cued visual and auditory prospective memory proper. *Aging, Neuropsychology, and Cognition: A Journal on Normal and Dysfunctional Development, 13*(2), 141-172. doi:10.1080/138255890969618

Uttl, B. (2008). Transparent meta-analysis of prospective memory and aging. *PLoS ONE, 3*(2), e1568. doi:10.1371/journal.pone.0001568

Uttl, B. (2011). Transparent meta-analysis: Does aging spare prospective memory with focal vs. non-focal cues? *PLoS ONE, 6*(2), e16618. doi:10.1371/journal.pone.0016618

Uttl, B., & Kibreab, M. (2011). Self-report measures of prospective memory are reliable but not valid. *Canadian Journal of Experimental Psychology, 65*(1), 57-68. doi:10.1037/a0022843

Uttl, B., White, C. A., Gonzalez, D. W., McDouall, J., & Leonard, C. A. (2013). Prospective memory, personality, and individual differences. *Frontiers in Psychology, 4*, 1-15. doi:10.3389/fpsyg.2013.00130

van Heijst, B. F., & Geurts, H. M. (2015). Quality of life in autism across the lifespan: A meta-analysis. *Autism, 19*(2), 158-167. doi:10.1177/1362361313517053

Vanneste, S., Baudouin, A., Bouazzaoui, B., & Taconnat, L. (2016). Age-related differences in time-based prospective memory: The role of time estimation in the clock monitoring strategy. *Memory, 24*(6), 812-825. doi:10.1080/09658211.2015.1054837

Verbruggen, F., & Logan, G. D. (2008). Automatic and controlled response inhibition: Associative learning in the go/no-go and stop-signal paradigms. *Journal of Experimental Psychology: General, 137*(4), 649-672. doi:10.1037/a0013170

Voigt, B., Mahy, C. E. V., Ellis, J., Schnitzspahn, K. M., Ivonne, K., Altgassen, M., & Kliegel, M. (2014). The development of time-based prospective memory in childhood: The role of working memory updating. *Developmental Psychology, 50*(10), 2393-2404. doi:10.1037/a0037491

Volle, E., Gonen-Yaacovi, G., de Lacy Costello, A., Gilbert, S. J., & Burgess, P. W. (2011). The role of rostral prefrontal cortex in prospective memory: A voxel-based lesion study. *Neuropsychologia, 49*(8), 2185-2198. doi:10.1016/j.neuropsychologia.2011.02.045

Von Wieser, F. (1893). *Natural value*. New York: MacMillan.

Wagenmakers, E.-J., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., . . . Morey, R. D. (2017). Bayesian inference for psychology. Part II: Example applications with JASP. *Psychonomic Bulletin & Review*. doi:10.3758/s13423-017-1323-7

Wagenmakers, E.-J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Love, J., . . . Morey, R. D. (2017). Bayesian inference for psychology. Part I: Theoretical advantages and practical ramifications. *Psychonomic Bulletin & Review*. doi:10.3758/s13423-017-1343-3

Waldum, E. R., & Sahakyan, L. (2013). A role for memory in prospective timing informs timing in prospective memory. *Journal of experimental psychology. General, 142*(3), 809-826. doi:10.1037/a0030113

Wallace, G. L., & Happé, F. (2008). Time perception in autism spectrum disorders. *Research in Autism Spectrum Disorders, 2*(3), 447-455. doi:10.1016/j.rasd.2007.09.005

Walter, S., & Meier, B. (2014). How important is importance for prospective memory? A review. *Frontiers in Psychology, 5*, 657-657. doi:10.3389/fpsyg.2014.00657

Wang, L. J., Altgassen, M., Liu, W., Xiong, W. R., Akgun, C., & Kliegel, M. (2011). Prospective memory across adolescence: The effects of age and cue focality. *Developmental Psychology, 47*(1), 226-232. doi:10.1037/a0021306

Wang, Y., Cao, X.-y., Cui, J.-f., Shum, D. H. K., & Chan, R. C. K. (2013). The relation between prospective memory and working memory: Evidence from event-related potential data. *PsyCh Journal, 2*(2), 113-121. doi:10.1002/pchj.24

Wechsler, D. (1999). *Wechsler Abbreviated Scale of Intelligence (WASI)*. San Antonio, TX: Psychological Corporation.

Wechsler, D. (2011). *Wechsler Abbreviated Scale of Intelligence-Second Edition (WASI-II)*. San Antonio, TX: NCS Pearson.

Werner, N. S., Peres, I., Duschek, S., & Schandry, R. (2010). Implicit memory for emotional words is modulated by cardiac perception. *Biological Psychology, 85*(3), 370-376. doi:10.1016/j.biopsycho.2010.08.008

West, R. (2008). The cognitive neuroscience of prospective memory. In M. Kliegel & M. A. McDaniel (Eds.), *Prospective memory: Cognitive, neuroscience, developmental, and applied perspectives* (pp. 261-282). New York: Taylor and Francis.

White, S. J. (2013). The Triple I Hypothesis: Taking another('s) perspective on executive dysfunction in autism. *Journal of Autism and Developmental Disorders, 43*(1), 114-121. doi:10.1007/s10803-012-1550-8

White, S. J., Frith, U., Milne, E., Rosen, S., Swettenham, J., & Ramus, F. (2006). A double dissociation between sensorimotor impairments and reading disability: A comparison of autistic and dyslexic children. *Cognitive Neuropsychology, 23*(5), 748-761. doi:10.1080/02643290500438607

Williams, D. M. (2010). Theory of own mind in autism. *Autism, 14*(5), 474-494. doi:10.1177/1362361310366314

Williams, D. M., Bergstrom, Z., & Grainger, C. (2016). Metacognitive monitoring and the hypercorrection effect in autism and the general population : Relation to autism (-like) traits and mindreading. *Autism*(November), 1-12. doi:10.1177/1362361316680178

Williams, D. M., Boucher, J., Lind, S. E., & 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. doi:10.1007/s10803-012-1703-9.

Williams, D. M., & Happé, F. (2009). What did I say? Versus what did I think? Attributing false beliefs to self amongst children with and without autism. *Journal of Autism and Developmental Disorders, 39*(6), 865-873. doi:10.1007/s10803-009-0695-6

Williams, D. M., & Happé, F. (2010). Representing intentions in self and other: studies of autism and typical development. *Developmental Science, 13*(2), 307-319. doi:10.1111/j.1467-7687.2009.00885.x

Williams, D. M., & Jarrold, C. (2013). Assessing planning and set-shifting abilities in autism: Are experimenter-administered and computerised versions of tasks equivalent? *Autism Research, 6*(6), 461-467. doi:10.1002/aur.1311

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. doi:10.1037/neu0000008

Williams, D. M., Peng, C., & Wallace, G. L. (2016). Verbal thinking and inner speech use in autism spectrum disorder. *Neuropsychology Review, 26*(4), 394-419. doi:10.1007/s11065-016-9328-y

Wilson, B. A., & Baddeley, A. (1991). *The Rivermead Behavioural Memory Test* (2nd ed.). Bury St Edmunds, UK: Thames Valley Test Company.

Wittmann, M. (2009). The inner experience of time. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences, 364*(1525), 1955-1967. doi:10.1098/rstb.2009.0003

Wittmann, M. (2013). The inner sense of time: How the brain creates a representation of duration. *Nature Reviews Neuroscience, 14*(3), 217-223. doi:10.1038/nrn3452

Wojcik, D. Z., Moulin, C. J., & Souchay, C. (2013). Metamemory in children with autism: Exploring "feeling-of-knowing" in episodic and semantic memory. *Neuropsychology, 27*(1), 19-27. doi:10.1037/a0030526

Woodbury-Smith, M. R., Robinson, J., Wheelwright, S., & Baron-Cohen, S. (2005). Screening adults for Asperger Syndrome using the AQ: A preliminary study of its diagnostic validity in clinical practice. *Journal of Autism and Developmental Disorders, 35*(3), 331-335. doi:10.1007/s10803-005-3300-7

Woods, S. P., Weinborn, M., Li, Y. R., Hodgson, E., Ng, A. R. J., & Bucks, R. S. (2015). Does prospective memory influence quality of life in community-dwelling older adults? *Aging, Neuropsychology, and Cognition, 22*(6), 679-692. doi:10.1080/13825585.2015.1027651

Woods, S. P., Weinborn, M., Velnoweth, A., Rooney, A., & Bucks, R. S. (2012). Memory for intentions is uniquely associated with instrumental activities of daily living in healthy older adults. *Journal of the International Neuropsychological Society, 18*(01), 134-138. doi:10.1017/S1355617711001263

World Health Organization. (2006). *International statistical classification of diseases and related health problems: 10th revision*. Geneva: World Health Organization.

Yang, T.-x., Wang, Y., Lin, H., Zheng, L.-n., & Chan, R. C. K. (2013). Impact of the aging process on event-, time-, and activity-based prospective memory. *PsyCh Journal, 2*(1), 63-73. doi:10.1002/pchj.19

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. doi:10.1016/j.rasd.2014.03.005

Zuber, S., Kliegel, M., & Ihle, A. (2016). An individual difference perspective on focal versus nonfocal prospective memory. *Memory & Cognition*, 1-12. doi:10.3758/s13421-016-0628-5