ADHD Attention Deficit and Hyperactivity Disorders (2019) 11:59–71
https://doi.org/10.1007/s12402-018-0273-x

ORIGINAL ARTICLE

Prospective memory (partially) mediates the link between ADHD symptoms and procrastination

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Received: 20 April 2018 / Accepted: 8 October 2018

Abstract
Individuals with attention deficit hyperactivity disorder (ADHD) often show poor planning and poor organization of tasks and activities which has been related to reduced memory for delayed intentions (prospective memory) and procrastination—in addition to other cognitive or motivational factors. This study set out to bring the fields of prospective memory and procrastination research together and to explore possible relations between the two constructs in ADHD. Twenty-nine adults with ADHD and 24 healthy controls performed several laboratory-based and real-life prospective memory tasks and filled in questionnaires measuring their symptom severity and procrastination behaviour. Overall, individuals' with ADHD showed clear deficits in everyday prospective memory performance. Individuals with ADHD recalled and executed less of their own real-life intentions. Moreover, there were clear links between everyday prospective memory performance and reported procrastination behaviour, and everyday prospective memory performance mediated the link between ADHD symptoms and procrastination behaviour.

Keywords ADHD · Procrastination · Prospective memory · Episodic future thinking

Introduction

Attention deficit hyperactivity disorder (ADHD) is characterized by three core symptoms: inattention, impulsivity and motor restlessness (APA 2000, 2013; WHO 2006). Symptoms evidence early in life (before age 12) are pervasive across different situations and persist throughout the lifespan (Asherson et al. 2016; Faraone et al. 2015), though severity may vary. Moreover, neuropsychological deficits are evident across multiple domains such as memory and attention (cf. meta-analysis on neuropsychological functioning, Hervey et al. 2004). Particularly, deficits in executive functions have been associated with ADHD, for example reduced response inhibition, switching, planning, vigilance and working memory (Corbett et al. 2009; Geurts et al. 2004; cf. meta-analytic review, Willcutt et al. 2005). Inhibition has been suggested to present a core deficit in ADHD (Barkley 1997; Boonstra et al. 2010). In line with these behavioural symptoms/deficits, neuroimaging studies indicate structural and functional alterations in ADHD in brain areas that subserve attention and executive functioning. For example, there is evidence for significantly smaller volumes or reduced cortical thickness in the dorsolateral prefrontal cortex, and regions that project to the prefrontal cortex, including caudate, pallidum, anterior cingulate and cerebellum (Makris et al. 2007; Seidman et al. 2005, 2006; cf. meta-analytic review, Valera et al. 2007; cf. mega-analysis, Hoogman et al. 2017). Similarly, functional imaging studies indicate dysfunctions of the anterior cingulate (Bush et al. 1999), prefrontal cortex (Schweitzer et al. 2000) and cerebellum (Valera et al. 2005) when completing response inhibition and working memory tasks (e.g. Cortese et al. 2012; Dickstein et al. 2006; Rubia et al. 2014).

In adults with a clinical diagnosis of ADHD, these executive function deficits may express in everyday life as

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s12402-018-0273-x) contains supplementary material, which is available to authorized users.

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impulsive decision making, low frustration tolerance, difficulties with time management (e.g. being late, having a reduced sense of time), self-management and self-motivation, and as relatively poor planning and poor organization of tasks and activities (e.g. tasks being forgotten or not completed, APA 2000; Barkley 2010; Barkley and Fischer 2011; Barkley and Murphy 2011; see Solanto 2011, for a cognitive-behavioural intervention targeting executive dysfunctions in ADHD). These latter difficulties may be related to deficits in prospective memory (PM, Mackinlay et al. 2006). PM refers to the execution of delayed intentions at a certain time (time-based tasks), event (event-based tasks) or after having completed an activity (activity-based tasks, Brandimonte et al. 1996). Examples of typical everyday PM tasks are remembering to pack up your daughter's swimming bag for her lessons today at 3 pm, or to discuss your students' grades with the second reader when you see her next, or to take one's medication after dinner. Successful PM performance is crucial to meet social, occupational and health-related demands of everyday life (Kliegel et al. 2008). Prospective remembering comprises multiple processes and phases. First, the individual has to form the intention and *plan* when he/she wants to do what. Then he/she has to *store* this intention in retrospective memory while being engaged in other ongoing tasks. When the appropriate moment for intention initiation arises, the individual has to *inhibit* other ongoing activities and *switch* to the intended action and execute it as planned (Kliegel et al. 2002). Thus, in terms of underlying cognitive processes, mainly executive functions and (retrospective) memory processes are involved in prospective remembering (Kliegel et al. 2011).

The extent to which these cognitive functions are needed for successful PM performance varies between tasks. Overall, time-based PM tasks are assumed to put higher demands on executive control resources than event-based PM tasks given that there is no external cue that may prompt retrieval of the intended action, but the individual has to actively keep track of the elapsing time (Einstein and McDaniel 1996). However, importantly, also event-based tasks can put high demands on executive control resources depending on the specific task characteristics (McDaniel and Einstein 2000). For example, a PM cue that is highly salient and stands out among the ongoing task items may attract attention and prompt retrieval of the intention more automatically than a PM cue that blends in with the ongoing task and needs to be carefully monitored for to be detected. Similarly, an ongoing task may be more or less demanding, thus leaving more or less cognitive resources available to work on the PM task.

In line with the known deficits in executive functions, memory and the reported everyday difficulties in ADHD, several PM studies have reported PM deficits in individuals with ADHD (cf. a review, Talbot et al. 2018). It is of note that using various types of tasks (e.g. with varying degrees of ecological validity) and across different age groups (children and adults), all studies on time-based PM in ADHD found poor performance (Altgassen et al. 2014b; Kerns and Price 2001; Mioni et al. 2017; Talbot and Kerns 2014; Zinke et al. 2010). This very consistent time-based deficit may indicate that when individuals with ADHD cannot rely on external cues but need to depend on internal signals and self-initiated strategies (e.g. regularly inhibiting task performance and switching attention without prompts) PM tasks are very difficult. At a first glance, results seem more inconsistent for event-based PM, with some studies finding ADHD-related impairments (Altgassen et al. 2014; Talbot and Kerns 2014), and others not (Altgassen et al. 2014b; Brandimonte et al. 2011; Kerns and Price 2001). However, when taking a closer look at the employed paradigms, ADHD individuals' difficulty with strategically allocating attentional resources becomes evident: Both studies that reported deficits in event-based PM either included an additional task to the ongoing activity (thus further tying up cognitive resources, Altgassen et al. 2014a) or involved a PM cue that was low in salience and thus required more monitoring to be detected (Talbot and Kerns 2014). On the other hand, all event-based tasks that resulted in spared performance in ADHD seem to be rather low demanding in terms of executive control resources (e.g. highly salient cues like the beeping of an egg cooker, Altgassen et al. 2014b; or finger snapping, Kerns and Price 2001) or employed a rather easy, low-absorbing ongoing task (Brandimonte et al. 2011).

All studies conducted so far were laboratory-based. However, PM tasks in everyday life differ strongly from laboratory-based tasks (Altgassen et al. 2012). Everyday PM tasks are typically more complex, open-ended and less structured, thus putting even higher demands on executive function skills, which may make successful PM performance even harder for populations with reduced executive functioning such as individuals with ADHD (Altgassen et al. 2012). In fact, there is evidence that executive function deficits of individuals with ADHD in everyday life are stronger than in laboratory-based settings (Barkley and Murphy 2011). Importantly, even though deficits in PM have been suggested to underlie ADHD individuals' organizational difficulties in everyday life, so far, no study has tested whether these deficits extend to everyday life and may indeed underlie ADHD individuals' difficulties with the organization of everyday tasks and activities.

Therefore, the first goal of this study was to investigate PM performance in everyday life in adults with a clinical diagnosis of ADHD and to compare it with PM performance in laboratory-based tasks. This is the first study to assess PM performance of ADHD individuals in- and outside the laboratory across various task settings using both experimenter- and self-assigned PM tasks (see Schnitzspahn et al. under revision, for a similar approach in older adults).

To this end, we used standard laboratory-based PM tasks (Zeintl et al. 2007), experimenter-generated naturalistic tasks (Maylor 1990) and a diary approach to assess actual real-life self-assigned PM performance (Freeman and Ellis 2003; Ihle et al. 2012; Schnitzspahn et al. 2016). Given previous evidence of reduced PM, we expected individuals with ADHD to show poorer PM performance in all settings and we expected a relation between laboratory-based, naturalistic experimenter-generated and everyday self-assigned PM performance.

Independent of the PM literature, the disorganized behaviour of people with ADHD has most recently been investigated as indicating procrastination. Procrastination refers to the irrational tendency to voluntarily delay the beginning or completion of tasks—even though one knows that one will be worse off in the long run (e.g. meeting friends for coffee instead of studying for an examination, Steel 2007). This phenomenon of giving in to an immediate temptation instead of pursuing one's long-term goal is associated with several negative consequences on individuals' performance, well-being, health and economic status (cf. meta-analysis, Steel 2007). So far, only four studies have targeted procrastination in ADHD, and all of them reported an increased tendency of patients with ADHD to put off tasks and intended actions. Niermann and Scheres (2014) investigated the association of ADHD-related symptoms with procrastination in a non-clinical sample of students and found only inattention, but not hyperactivity and impulsivity, to be significantly related to procrastination. Ramsay (2016) described a case study of a college student with ADHD who procrastinates strongly. Lefler et al. (2016) interviewed college students with ADHD and reported procrastination and difficulties with executive function tasks. Similarly, Gray et al. (2016) conducted semistructured telephone interviews with 135 students with ADHD and found severe levels of executive function impairments in everyday life as well as procrastination.

Taken together, there is accumulating behavioural evidence for procrastination in ADHD. To date, procrastination has typically been considered as a self-regulation failure and has been related to stable personality traits such as low conscientiousness (Schouwenburg and Lay 1995), low self-discipline (Rabin et al. 2011) and high impulsiveness (Steel 2007), or to certain task characteristics (e.g. more aversive tasks are associated with more procrastination, Blunt and Pychyl 2000). More recently, the role of cognitive variables like time orientation or episodic future thinking (i.e. mentally projecting oneself into a future situation, Buckner and Carroll 2007; Schacter et al. 2008) in procrastination has been investigated. For example, there is some evidence indicating that people who procrastinate more frequently show a stronger focus on the presence as compared to the future (Diaz-Morales et al. 2008; Ferrari and Diaz-Morales 2007; Jackson et al. 2003) and have more difficulties with imagining future scenarios (and possibly anticipating negative consequences of postponing tasks, Rebetez et al. 2016). Importantly, most recently, this ability of imagining future scenarios and thus, mentally projecting oneself into a future situation has been suggested to be involved in the intention formation phase of prospective remembering; with more detailed envisioning of the future situation and intention execution leading to better PM performance (Altgassen et al. 2014c; Nigro et al. 2014; Schacter et al. 2008). This possible overlap in underlying mechanisms of PM and procrastination may suggest a link between the two constructs that have, so far, only been studied in isolation. Possibly, people who procrastinate more show reduced PM due to less good intention formation (i.e. less detailed intentions, less focus on the future situation) which may make it harder for them to shield their intentions against temptations and follow their plans. However, so far, no study has investigated if PM performance is linked to procrastination.

Therefore, the second goal of the present study was to fill this gap and to assess participants' procrastination behaviour and future time orientation in addition to their PM performance across various settings using a combination of naturalistic experimenter- and real-life self-assigned tasks. Given empirical evidence of increased procrastination behaviour (Lefler et al. 2016; Niermann and Scheres 2014) and reduced future orientation in ADHD (Carelli and Wiberg 2012), we expected more reports of procrastination and reduced future orientation in ADHD as compared to controls and expected a relation between these measures and measures of PM performance. Importantly, even though, future orientation and episodic future thinking both relate to the future and may impact the decisions we make, they do not reflect the same construct. Future orientation describes a more general orientation or focus on the future comprising cognitive, attitudinal and motivational aspects (Steinberg et al. 2009), whereas episodic future thinking refers to the cognitive ability of disengaging from the immediate present and imagining a future situation (Buckner and Carroll 2007).

Given the possible overlap in underlying mechanisms (i.e. episodic future thinking) between procrastination and PM, the third goal of the present study was to test whether the relation between clinical adult ADHD and procrastination behaviour may be (partly) mediated by (self-assigned) PM performance in everyday life. Bearing in mind that only a longitudinal study could make any causal inferences, we conducted a mediation analysis and expected ADHD symptoms not only to predict procrastination behaviour, but also PM performance which, in turn, should influence procrastination behaviour. We predicted that the link between ADHD symptoms and procrastination behaviour should be reduced by adding everyday (self-assigned) PM performance as a mediator.

Method

Participants

In total, 55 adults participated in the present study. After the first testing session, one individual with ADHD and one control participant discontinued. Thus, the final sample comprised 29 individuals with ADHD (16 men, 13 women) and 24 healthy controls (7 men, 17 women). Groups were comparable for age, education in years and cognitive ability as indicated by a German vocabulary test (MWT-B, Lehrl et al. 1991). To assess ADHD severity, participants were requested to fill in a German questionnaire (FEA-ASB, Döpfner et al. 2006). As expected, participants with ADHD reported significantly more symptoms of inattention, impulsivity and hyperactivity than controls (see Table 1). All participants spoke German as their first language. Diagnoses were established through expert clinical evaluation in accordance with DSM-5 criteria (APA 2013): Eight adults were diagnosed with predominantly inattentive presentation, two with predominantly hyperactive-impulsive presentation and 19 with the combined presentation. In terms of comorbidities, ten individuals with ADHD and one control participant were additionally diagnosed with major recurrent depression (in remission) or dysthymia. Five of those seven ADHD patients also had a diagnosis of personality disorder, and one a diagnosis of social phobia. One participant with ADHD was diagnosed with posttraumatic stress disorder, and one with bipolar disorder. Individuals with ADHD were recruited through a specialized clinic. Controls were recruited through advertisements and flyers. Twelve participants with ADHD were medically treated. Six participants were on stimulants (i.e. methylphenidate) and seven took antidepressants and one antipsychotic medication. Participants treated with stimulants were requested to refrain from taking medication 24 h prior to testing. Exclusion criteria were neurological disorders as well as drug and alcohol abuse. Any human data included in this manuscript was obtained in compliance with the Helsinki Declaration. Each participant was tested individually, and before testing, all participants gave written informed consent.

Table 1 Individual characteristics

	ADHD	Controls	
	M (SD)	*M* (SD)	*F* (df)
Age	36.52 (11.1)	37.58 (14.1)	< 1
Education	15.02 (4.2)	15.54 (4.5)	< 1
Cognitive ability	31.31 (2.7)	29.96 (3.8)	2.26 (1,51)
ADHD symptoms	33.86 (10.7)	9.46 (5.5)	102.66 (1,51)***
Future orientation			
Total	22.56 (18.3)	32.40 (16.8)	3.98 (1,50)+
Planning ahead	8.32 (5.5)	12.16 (5.6)	6.14 (1,50)*
Time perspective	7.88 (5.2)	9.52 (4.6)	< 1.4
Anticipated consequences	8.35 (5.8)	12.05 (5.4)	5.53 (1,50)*
Procrastination	67.86 (8.7)	40.04 (9.1)	129.32 (1,51)***
Immediate recall (max. 24)	19.76 (3.9)	20.00 (3.7)	< 1
Delayed recall (max. 8)	7.10 (1.1)	7.46 (.6)	1.89 (1,51)

*$p < .05$; ***$p < .001$; +$p = .052$

Materials

Individual difference variables As a measurement of immediate and delayed episodic memory, participants performed the Verbal Paired Associates subtask from the Wechsler Memory Scale revised (Härting et al. 2000). Participants' tendency to procrastinate and postpone the execution of activities or tasks in everyday life was assessed with a self-report questionnaire (Tuckman Procrastination Scale, Tuckman 1991). Here, participants have to indicate for 16 statements (e.g. I needlessly delay finishing jobs, even when they're important) on a 4-point Likert scale to which extent these statements describe themselves. The reliability (Cronbach's alpha = .86) and validity of this widely used scale is high (e.g. correlations with a General Self-Efficacy Scale of .77). Participants' future orientation was measured via self-report using the future orientation scale (Steinberg et al. 2009) which, in addition to a total score, assesses anticipation of consequences (considering potential future outcomes of decisions before deciding), planning ahead (making plans before starting to act) and time perspective (thinking about the future). Here, participants are presented with 10 pairs of statements separated by the word BUT and have to choose for each pair which statement describes them best; they then have to indicate whether the chosen statement is really true or sort of true. An example for the subscale time perspective is: "Some people would rather be happy today than take their chances on what might happen in the future BUT Other people will give up their happiness now so that they can get what they want in the future". Reliability (Cronbach's alpha = .80) and validity are high (e.g. correlations with the Zuckerman Sensation-Seeking Scale $r = .40$ or the Barratt Impulsivity Scale $r = .44$).

Laboratory-based PM tasks Event-based PM was assessed with the Token task (Zeintl et al. 2007). Here, participants had to remember to take a token out of a box and to give it to the experimenter whenever he or she said, "The next task concerns memory". The number of tokens in the box was higher than the number of cues (3 cues). Time-based PM was measured with a modified version of the stop-clock task (Rendell and Thomson 1999) during which participants were asked to say the time whenever 10, 20 and 30 min had passed. Participants could monitor the time by turning around and looking at a small table clock. Responses were scored as correct PM answers ± 10 s around the target times (see Kliegel et al. 2001; Rendell and Thomson 1999, for a similar procedure).

Naturalistic experimenter-assigned PM tasks Participants were told to call the experimenter 3 days after the laboratory session at a specific time that suited both, the participant and the experimenter, and again 3 days later after the first telephone date. Calls were considered as correct PM answers ± 5 min around the agreed time.

Real-life self-assigned PM tasks Following Schnitzspahn et al. (under revision), individuals were required to report five to seven activities that they intended to complete across the next 3 days. Participants were informed that they should not list routine tasks (e.g. making one's bed in the morning), but focus on currently intended actions (e.g. calling the hairdresser to make an appointment). Participants were asked to rate each intention regarding its valence (positive, neutral, negative). Furthermore, participants were told to behave in their usual way and not to try harder to remember their intended actions, as we were interested in exploring their natural everyday memory behaviour. Three days after the laboratory testing session during the first telephone call, individuals were first asked to recall their intended actions. In case not all initially intended actions were spontaneously reported, the experimenter gave a general prompt by saying that these were not all planned activities. If the participant could still not recall all intentions, he/she was informed which ones were missing. Participants were then asked to indicate which of the planned actions they had completed as intended and whether they used a reminder. Thereafter, participants were prompted again to report five to seven intended actions for the next 3 days and to indicate their valence. During a second phone call 3 days later, participants were again asked to recall their intended actions and report their (un)successful realization. Real-life PM performance was aggregated across the 6 days of assessment. Dependent measures were number of formed intentions, and percentage of remembered and correctly executed intentions.

Procedure

During the laboratory session, participants were first instructed to the two laboratory-based PM tasks which they then performed while working on the immediate and delayed recall task as well as other neuropsychological tests and the questionnaires assessing future orientation, ADHD symptom severity and procrastination. Thereafter participants were asked to report five to seven intentions for the next 3 days and the first telephone meeting in 3 days was arranged. If the participant did not remember to call within 10 min of the agreed time, the experimenter called him/her to assess recall and implementation of the intended actions. Thereafter, participants reported their planned activities for the next 3 days and the second telephone date was arranged, and the just described procedure was repeated.

Data analyses. First, analyses of variance (ANOVAs) were conducted to explore possible group effects between ADHD individuals and controls in measures of procrastination, future orientation and immediate and delayed recall. Second, ANOVAs were used to test for possible group effects in laboratory-based event- and time-based PM performance. Naturalistic experimenter-assigned PM performance was compared between groups using Chi squared test. Group differences in real-life self-assigned PM performance (number of formed intentions, percentages of recalled and executed intentions) were investigated using ANOVAs. Third, correlational analyses between the variables were conducted. Fourth, a mediation analysis with bootstrapping (following Preacher and Hayes 2008) was applied to explore whether PM performance (percentage of executed everyday self-assigned intentions) mediated the relation between ADHD symptoms (independent variable) and procrastination (dependent variable). Additional analyses on the valence of intentions and ADHD subgroups with and without depression can be taken from the supplement.

Results

Individual difference variables ANOVAs indicated large group differences in procrastination and more modest group differences in future orientation (see Table 1). Overall, individuals with ADHD reported to procrastinate more than controls ($\eta_p^2 = .71$). In terms of future orientation, the ADHD group reported to plan ahead less ($\eta_p^2 = .11$) and to anticipate consequences less than the control group ($\eta_p^2 = .10$); groups did not differ in their time perspective ($\eta_p^2 = .03$) and the total score only tended towards significance ($\eta_p^2 = .07$). There were no group effects for immediate ($\eta_p^2 = .001$) or delayed recall ($\eta_p^2 = .04$).

PM performance With regard to *lab*oratory-*based PM* performance, one-way ANOVAs did not indicate any group differences for any of the tests (all η_p^2 *s* < .02). Groups performed comparably in event-based and time-based PM (see Table 2).

In contrast, groups differed in their *naturalistic* experimenter-assigned *PM* performance ($\chi^2(2) = 12.36$, $p = .002$). ADHD participants remembered to call less often than controls: 21% of the individuals in the control group forgot to call, and 52% in the ADHD group (see Fig. 1).

Regarding *real-life* self-assigned PM performance, across all three variables (number of intended actions, percentage

Table 2 Prospective memory performance

	ADHD	Controls	
	M (SD)	*M* (SD)	*F* (df)
Laboratory-based PM			
Event-based PM (max. 3)	1.79 (1.1)	2.13 (1.2)	< 1.1
Time-based PM (max. 3)	2.03 (1.0)	1.92 (1.3)	< 1
Real-life PM			
Intended actions (number)	9.55 (1.6)	10.38 (.6)	5.35 (1,51)*
Recalled intentions (%)	67.23 (22.0)	81.03 (18.8)	5.87 (1,51)*
Executed intentions (%)	52.11 (28.6)	80.8 (14.6)	19.85 (1,51)***

*$p < .05$; ***$p < .001$

of recalled intentions, percentage of executed intentions) significant group differences emerged. As compared to controls, ADHD individuals generated ($\eta_p^2 = .08$), recalled ($\eta_p^2 = .10$) and executed fewer intended actions ($\eta_p^2 = .20$). From Fig. 2, an overview of the reasons that participants gave for not performing intended actions can be taken. As the most frequent reason for not having executed their intentions as planned ADHD individuals stated that they did not feel like it, whereas controls most often mentioned external factors that were beyond their own control to have prevented them from completing their intended actions.

Only one control participant and four ADHD participants reported having used reminders. Given the small number of people using reminders, no further analyses were conducted.

Correlations between PM measures across the different settings and individual difference measures were conducted across groups (Table 3). Percentage of recalled intentions correlated positively with percentage of executed (self-assigned) intentions, delayed recall, laboratory-based time-based PM, naturalistic time-based PM and the laboratory-based event-based PM task. Thus, a higher recall of real-life self-assigned intentions was related to better recall of word pairs after a delay, better laboratory-based time-based PM and better naturalistic PM performance. Better naturalistic experimenter-assigned PM performance was related to better real-life self-assigned PM performance. Higher reports of procrastination and more ADHD symptoms were correlated with less recalled real-life self-assigned intentions and with less executed real-life self-assigned intentions. Similarly, higher reports of procrastination were related to less future orientation (i.e. negative correlations with all subscales and the total score. More ADHD symptoms were associated with less future orientation (i.e. less planning and worse anticipation of consequences). Delayed recall of word pairs correlated positively with laboratory-based event- and time-based PM as well as with future orientation (i.e. total score, planning, time perspective).

PM as a possible mediator of procrastination We used a mediation analysis with bootstrapping (following Preacher and Hayes 2008) to explore whether PM performance (percentage of executed self-assigned everyday intentions) mediated the relation between ADHD symptoms and procrastination across groups. ADHD symptoms significantly predicted both procrastination (path [c] in Fig. 3; path [c]; c: $b = .76$, $t(51) = 6.9$, $p < .001$) and real-life self-assigned PM performance (path [a]; $b = -.75$, $t(51) = -3.25$, $p < .002$), supporting the outcome of the group comparison analysis. When the link between PM and procrastination (path [b]; $b = -.21$, $t(50) = -3.45$, $p < .001$) was added, ADHD predicted procrastination to a lesser degree (path [c′]; $b = .61$, $t(50) = 5.48$, $p < .001$). Importantly, the difference between path c and path c′ [c–c′] was significant, as indicated by the Sobel test ($z = 2.31$, $p = .02$).

Discussion

The goals of this study were (1) to investigate PM performance, for the first time, in everyday life in adult patients with ADHD, and to compare it with PM performance in laboratory-based tasks; (2) to explore possible relations between PM and procrastination in ADHD; and (3) to replicate the association between ADHD and procrastination and to test whether this relation may be (partly) mediated by real-life PM performance.

In contrast to our expectations of an overall PM deficit in ADHD across testing settings given previous evidence of reduced prospective remembering (e.g. Altgassen et al. 2014b; Talbot and Kerns 2014), we observed a clear dissociation between testing settings. There were no group differences in the laboratory-based PM tasks, neither in the event-based nor in the time-based task. In contrast, very clear ADHD-related PM impairments emerged in everyday life, both in the naturalistic experimenter-assigned task (i.e. calling the experimenter at a certain time) and in participants' own, self-assigned real-life intentions. With regard to the applied laboratory-based tasks, even though they have previously been shown to reliably reflect PM deficits in other populations with reduced executive control resources, such as older adults (Zeintl et al. 2007) or individuals with autism (Altgassen et al. 2012), it is possible that they were too easy and too structured for individuals with ADHD as compared to more recently in this population used computerized PM tasks (Altgassen et al. 2014a; Talbot and Kerns 2014). For example, given that participants knew that the cue indicating the appropriate moment to initiate the event-based task was always embedded within task instructions, they may have only monitored for the PM cue when the experimenter was

Table 3 Correlations

	Executed Intentions	Procrastination	ADHD symptoms	immediate recall	delayed recall	Laboratory time-based PM	Laboratory event-based PM	Naturalistic time-based PM	FO total	FO planning	FO time perspective	FO consequences
Recalled intentions	.35*	− .30*	− .35**	.07	.41**	.31*	.40**	.47***	.21	.17	.22	.23
Executed Intentions		− .57***	− .41**	.13	− .01	− .11	.23	.30*	.17	.15	.13	.23
Procrastination			.69**	− .10	− .03	.06	− .06	− .43***	− .36**	− .38**	− .29*	− .41**
ADHD symptoms				− .02	− .16	.06	− .22	− .34*	− .24	− .27+	− .19	− .31*
immediate recall					− .01	.04	.17	− .09	.04	.05	− .03	.12
delayed recall						.31*	.35*	.13	.32*	.38**	.30*	.20
Laboratory time-based PM							.42**	.11	.06	.03	.13	.03
Laboratory event-based PM								.13	.06	.04	.10	.05
Naturalistic time-based PM									− .14	− .08	− .16	− .13
FO total										.95***	.94***	.97***
FO planning											.84***	.89***
FO time perspective												.89***

FO future orientation

$^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$; $+p = .052$

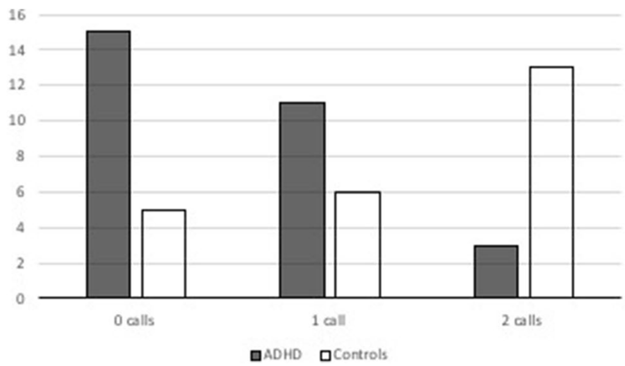

Fig. 1 Naturalistic experimenter-assigned prospective memory performance. It shows the number of on time phone calls for both groups

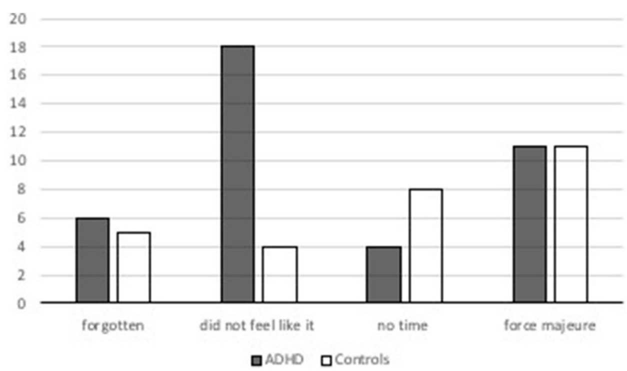

Fig. 2 Overview of the reasons for non-completion of intended actions. Please note that the numbers stated here reflect the number of people that indicated a certain reason for non-completion; the same person may have given the same reason multiple times, but this is not reported here

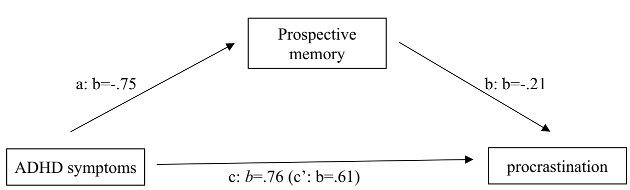

Fig. 3 Prospective memory as a mediator of the association between ADHD symptoms and procrastination behaviour. The effect of ADHD on prospective memory is path [a]. The effect of prospective memory on procrastination is path [b]. Path [c] represents the effect of ADHD symptoms on procrastination. Path [c′] represents the effect of ADHD symptoms on procrastination after including prospective memory in the model

introducing new tasks and not while being engaged in other tasks that also taxed their cognitive resources. Moreover, no interruption of other tasks was needed to perform the PM task (Kvavilashvili et al. 2001; McDaniel et al. 2004). This may have made the laboratory-based event-based PM task rather low-demanding in terms of executive control resources (e.g. low monitoring, inhibiting and switching demands, Kliegel et al. 2011; McDaniel and Einstein 2000). In contrast, in standard computerized tasks the PM cue can typically appear at any moment while the individual is working on a more or less demanding ongoing activity that needs to be interrupted to perform the PM task. The spared performance in the laboratory-based event-based task is in line with other studies applying event-based tasks in ADHD that also found unimpaired performance (Brandimonte et al. 2011; Kerns and Price 2001). Given that PM deficits in previous studies most consistently emerged in tasks that put rather high demands on executive control resources (e.g. time-based tasks, event-based tasks with an additional task to the ongoing task), it is possible that even though ADHD is related to reduced executive functioning, that ADHD individuals executive control resources were sufficient for the here applied low-demanding event-based task (Kliegel et al. 2011). Similarly, having to remember to indicate whenever 10 min have passed, might require less consistent monitoring than indicating whenever 1 or 2 min have passed (i.e. more commonly used times in computerized time-based tasks). Importantly, though, neither controls nor ADHD individuals performed at ceiling in either of the tasks which supports our assumption that the tasks were just not executive function-taxing enough to cause PM deficits in ADHD.

In contrast to the spared PM performance in the laboratory, very clear deficits emerged in everyday life PM, both with regard to naturalistic experimenter- and self-assigned tasks. Overall, the ADHD group proved to be quite "unreliable" and did not call on time, but then still participated in the study when being called, thus did not drop out. Fifty-two per cent of individuals with ADHD, and only 21% of controls never called on time. Similarly, individuals with ADHD performed fewer of their self-assigned intended actions than controls. Consequently, this is the first study to show that PM deficits in ADHD, which were observed in previous studies in laboratory settings, may also emerge in everyday life and might indeed underlie the reported deficits in the organization of everyday tasks. Importantly, this strong deficit in everyday PM is in line with results on executive functioning in ADHD which have shown larger impairments in everyday life than in laboratory-based tasks (Barkley and Murphy 2011).

Interestingly, even though participants were instructed to form a rough number of intentions (i.e. 5 to 7 for the following 3 days), the difference in the actual number of formed intentions between groups was approaching significance and might have turned significant if no guideline of to be formed intentions was given and groups may have responded more spontaneously. The observed trend may indicate that people with ADHD plan less ahead which is in line with the questionnaire findings of reduced future orientation (specifically reduced planning ahead and reduced anticipation of future consequences). Furthermore, individuals with ADHD recalled fewer of their own intentions during the telephone meeting 3 days after intention formation which may indicate that they are generally less aware of their plans or that they truly forgot their intended actions.

In terms of underlying mechanisms, across groups, retrospective memory seemed to play an important role for successful prospective remembering. Participants who remembered more self-assigned intended actions, also executed more of their own intentions. Furthermore, there was a clear link between better recall of intended actions and better PM performance in any setting, underlining the importance of memory processes for the successful execution of delayed intentions (Einstein et al. 1992). Recall of intended actions was also significantly related to laboratory-based measures of delayed (but not immediate) recall which is in line with general demands of PM tasks that require the retention of an intention over a delay (Kliegel et al. 2002). More ADHD symptoms were associated with poorer PM performance in everyday life (both for experimenter- and self-assigned intentions), but not in the laboratory, thereby reflecting the group effects and supporting previous evidence of spared event-based PM performance. Also, more ADHD symptoms were related to fewer recalled intentions and showed a trend towards reduced future orientation. Taken together, the present findings indicate a clear PM deficit in everyday life which may underlie the reported deficits in the organization of everyday tasks.

The second goal of the present study was to explore whether there is a possible relation between PM and procrastination. Overall, as predicted, ADHD individuals reported more procrastination behaviour, and this effect was large. Additionally, patients with ADHD demonstrated reduced future orientation than controls with more modest effect sizes. Correlational analyses indicated that, as expected, procrastination was strongly related to percentage of executed (self-assigned) intentions, and also to ADHD severity and future orientation. More procrastination behaviour was related to fewer executed (self-assigned) intentions and lower future orientation. While better naturalistic experimenter-assigned PM performance and more fulfilled real-life self-assigned intentions were associated with fewer reports of procrastination behaviour, there was no relation between laboratory-based PM performance and procrastination behaviour. Laboratory-based PM tasks leave no room for procrastination, as there is no option to perform the task later, and therefore, no links were expected. Interestingly, the pattern of reasons participants gave for not executing their own real-life intentions differed between the two groups. Overall, the ADHD group reported more often that they “did not feel like it” than controls which clearly points to a conscious decision of not doing the task, and thus procrastinating. This finding may also be interpreted along the same lines as a previous study in which adolescents with ADHD acted more in accordance with their subjective feelings than controls did (Scheres et al. 2013). Possibly, individuals’ with ADHD actions are more strongly driven by their feelings than is the case for controls, and/or this finding may reflect a strategy that emphasizes reducing discrepancies between feelings and actions in those with ADHD. In contrast to the reason “did not feel like it”, both groups mentioned comparably often having forgotten their intentions or force majeure as a reason, and slightly more controls blamed not performing the task on having had no time.

The third goal of the present study was to explore whether the relation between ADHD and procrastination behaviour may be (partly) mediated by (self-assigned) PM performance in everyday life given the possible overlap in underlying mechanisms between procrastination and PM (Brewer and Marsh 2010; Rebetez et al. 2016; Terrett et al. 2015). To this end, a mediation analysis was conducted. As expected, including everyday PM performance (percentage of executed self-assigned intentions) reduced the link between ADHD symptoms and procrastination. This is the first study to show that procrastination behaviour in adults with ADHD may be related to specific *cognitive* mechanisms such as PM. Given that the ability to mentally project oneself into the future has been related to procrastination behaviour and to PM performance (Nigro et al. 2014; Rebetez et al. 2016), we suggest that the link between PM and procrastination may follow the (possibly) shared cognitive function of episodic future thinking. Specifically, people who are less able to imagine the future (and possibly positive and negative consequences of not performing their intentions as planned), tend to give in to immediate temptations and to procrastinate more (Peters and Buchel 2010). Similarly, people with better future thinking ability show better PM performance (Nigro et al. 2014) and explicit instructions during intention formation to vividly imagine performing the PM task later (i.e. to engage in episodic future thinking during intention encoding), increases PM performance as compared to standard instructions (Altgassen et al. 2014c, 2017; Kretschmer-Trendowicz et al. 2016). However, future studies are needed that directly test whether episodic future thinking indeed creates the link between PM and procrastination. Moreover, so far episodic future thinking instructions have only been administered in laboratory-based PM tasks where no procrastination is possible, and episodic future thinking ability has only been linked to self-reports of procrastination. It is yet to be tested whether episodic future thinking can reduce actual procrastination behaviour and increase the implementation of intentions. If so, episodic future thinking could form an additional component in interventions for adults with ADHD that target other cognitive functions such as executive function deficits (Solanto 2011). However, importantly, given the finding that individuals with ADHD reported frequently that they did not feel like doing the intended action, procrastination in ADHD may not only be related to cognitive mechanisms such as PM, episodic future thinking or executive functioning, but also motivational mechanisms such as reduced neural responsiveness to reward anticipation (cf. a meta-analysis, Plichta and Scheres 2015) and steep discounting of delayed rewards likely play a role in the link between ADHD and procrastination (cf. reviews, Jackson and MacKillop 2016; Patros et al. 2016). Further studies are required to explore the complex interactions between cognitive and motivational mechanisms and to shed further light on the relevant problem of procrastination as well as the observed disorganized behaviour in everyday life in general in ADHD. In a similar vein, it will be of interest to consider the potential role of comorbid depression and associated motivational deficits herein (Stringaris et al. 2015).

When interpreting the results of the mediation analysis, a caveat may be that all data were concurrently collected and are merely correlational. Therefore, although ADHD was entered as a predictor and procrastination as outcome, inferences can only be made about the association of ADHD and procrastination and not about any potential causal relations. Thus, even though the mediation analysis indicates that PM mediates the association between ADHD and procrastination, we cannot make any statement about the direction of this relation. It is possible that symptoms of ADHD, such as inattention and impulsivity, contribute to procrastination over time, but it may also be hypothesized that the tendency to procrastinate could result in increasing impulsivity/inattention over time. Alternatively, it could be that there is a bidirectional relation between ADHD symptoms and procrastination. Future studies are needed that use longitudinal designs to address these questions.

A potential limitation of the present study may be the fact that measures of procrastination and real-life PM (operationalized as percentage of executed intentions) relied on retrospective self-report as to why intentions are (not) performed. This may pose the question of sufficient distinguishability of the two measures. However, even though the correlation between executed self-assigned intentions and procrastination was significant ($r = -.57$), it was still far away from 1.0. This indicates that while there is overlap between these measures, they do not assess the same construct. Future studies using ecological momentary assessment, i.e. real-life and immediate (instead of retrospective) measurements, may contribute to a better understanding of the communalities and differences of real-life PM and procrastination. Another potential caveat may be that diagnostic groups were unbalanced with regard to gender distribution. Future studies should try to ensure that both groups comprise an equal proportion of both genders. Furthermore, it is possible that the laboratory-based PM tasks may have simply not been important for participants given that the (non)-fulfilment of the tasks has no real-life consequences. Even though this may potentially be true for many laboratory-based tasks, future studies should assess the subjective importance and commitment to perform these tasks.

Taken together, this study showed that adult ADHD patients' show deficits in everyday PM tasks. Overall, ADHD individuals recalled and executed less of their own real-life intentions. Moreover, there were clear links between everyday PM performance (experimenter- and self-assigned intentions) and reported procrastination behaviour and everyday (self-assigned) PM performance mediated the link between ADHD symptoms and procrastination behaviour. Future studies are needed to investigate whether different people with ADHD may procrastinate for different reasons. Such a finding could have important implications for the design of interventions. If PM is an important reason for a substantial portion of individuals with ADHD, then interventions focusing on tackling procrastination (e.g. Solanto 2011) could include a module on improving PM in individuals with ADHD as a tool to decrease procrastination.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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