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Erstveröffentlichung in / First published in:

Journal of Attention Disorders. 2014, 18(7), S. 617 - 624 [Zugriff am: 14.08.2019]. SAGE journals. ISSN 1557-1246.

DOI: <https://doi.org/10.1177/1087054712445484>

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Journal of Attention Disorders
2014, Vol. 18(7) 617–624
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sagepub.com/journalsPermissions.nav
DOI: 10.1177/1087054712445484
jad.sagepub.com

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Abstract

Objective: The present study investigated, for the first time, event- and time-based prospective memory (PM) in the same sample of adults with ADHD within one paradigm using parallel task constraints. **Method:** A total of 25 individuals with ADHD and 25 matched neurotypical controls completed a computerized version of the Dresden Breakfast Task, which required participants to prepare breakfast following a set of rules and time restrictions. **Results:** Although groups did not differ in event-based PM, results demonstrated a large-sized impairment in individuals with ADHD in time-based PM. **Conclusion:** Findings suggest a task-specific impairment in PM functioning and are discussed in an executive control framework of neurocognitive functioning in ADHD. (*J. of Att. Dis.* 2014; 18(7) 617-624)

Keywords

ADHD, adult, cognitive control, prospective memory

ADHD is characterized by inattention, impulsivity, and motor restlessness (American Psychiatric Association [APA], 2000; World Health Organization, 2006). Severity of these three major symptoms may vary. Symptoms evidence early in life (before age of 7 years), are chronic, and are pervasive across different situations. Moreover, neuropsychological deficits are evident across multiple domains such as memory (e.g., Marchetta, Hurks, Krabbendam, & Jolles, 2008; Roth et al., 2004) and attention (cf. meta-analysis; Hervey, Epstein, & Curry, 2004). Particularly, deficits in executive functions have been associated with ADHD (e.g., Barkley, 1997; Tannock, 1998). Several studies have reported reduced response inhibition, switching, planning, vigilance, and working memory (Hale, Hariri, & McCracken, 2000; Minshew, 1996; Shaywitz, Fletcher, Pugh, Klorman, & Shaywitz, 1999; cf. meta-analytic review, Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Neuroimaging studies indicate structural brain alterations in ADHD in areas that are assumed to 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., 2006; Seidman, Valera, & Makris, 2005, cf. meta-analytic review, Valera, Faraone, Murray, & Seidman, 2007). Similarly, functional imaging studies indicate dysfunctions of the anterior cingulate

(Bush et al., 1999), prefrontal cortex (Schweitzer et al., 2000), and cerebellum (Valera, Faraone, Biederman, Poldrack, & Seidman, 2005) when completing response inhibition and working memory tasks.

In terms of everyday functioning, individuals with ADHD have difficulties with the organization of tasks and activities in everyday life. For example, they report difficulties with time management (e.g., being late, having a reduced sense of time) or with the organization of activities (e.g., homework being forgotten or not completed; APA, 2000). These difficulties have been related to deficits in prospective memory (PM; Mackinlay, Charman, & Karmiloff-Smith, 2006). PM refers to the self-initiated execution of intentions after a delay (Brandimonte, Einstein, & McDaniel, 1996; Kliegel, McDaniel, & Einstein, 2008), and PM tasks are ubiquitous in everyday life. For example, the organization of one's daily routine and most occupational and social demands strongly require PM (Einstein & McDaniel, 2005).

Importantly, these everyday problems can be linked to the neurocognitive profile of ADHD described above. It has

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been argued that successful prospective remembering (while being identifiable as a separate construct; see Zeintl, Kliegel, & Hofer, 2007) strongly relies on executive functions such as inhibition, switching, and planning abilities (e.g., Kliegel, Jäger, Altgassen, & Shum, 2008). For example, planning is needed during the formation of the intention, whereas inhibition and switching are involved in the initiation and execution of the intended action (e.g., inhibiting other ongoing activities and switching to the planned action). Hence, cognitive functions are required by PM tasks that are impaired in individuals with ADHD (e.g., Barkley, 1997; Boonstra, Kooij, Oosterlaan, Sergeant, & Buitelaar, 2010) and, thus, (general) PM impairments have been predicted before (Kliegel, Ropeter, & Mackinlay, 2006; Siklos & Kerns, 2004). However, surprisingly, despite its importance for everyday functioning, studies on proper PM performance and its underlying executive functions are scarce in individuals with ADHD. Moreover, despite the assumption of a general PM deficit in ADHD, the few available studies suggest an interesting differential pattern which is reflected by the two task types of PM. Specifically, experimental cognitive research on PM differentiates between two major types of tasks on the basis of the cue that signals the appropriate moment to re-instantiate the planned action. This cue may be an event (event-based tasks, for example, remembering to pass a message to a friend when seeing him) or a specific time (time-based tasks, for example, remembering to go to football at 3 o'clock; Einstein & McDaniel, 1996).

Until now, the only three studies that have explicitly targeted PM in ADHD (Brandimonte, Filippello, Coluccia, Altgassen, & Kliegel, 2011; Kerns & Price, 2001; Zinke et al., 2010) suggest a differential deficit across the two task types. Kerns and Price (2001) applied both an event-based and a time-based task. Within the event-based task, children were asked to perform specific actions during the course of the experiment (i.e., remembering to walk to the door and turn the doorknob when the experimenter snapped their fingers). Here, children with ADHD were as good as controls. In the time-based PM task that was a computerized task, children had to drive a car on a busy street while remembering to fill up the gas tank at specific times. Children could check the remaining filling level by pressing a predefined key. Time-based PM performance was lower in children with ADHD as compared with typically developing controls, whereas there was no difference in total number of gas checks. Zinke et al. (2010) only investigated time-based PM performance in children with ADHD using a standard computer-based paradigm (here, as ongoing activity individuals had to work on a one-back picture task, and for the PM task, children had to remember to press a target key every 2 min). Children with ADHD had fewer correct PM responses than control children, who in turn showed very similar performance as children in

previous studies using the PM task applied (Mackinlay, Kliegel, & Mäntylä, 2009). Neither differences in overall ongoing task performance nor, remarkably, but consistently with Kerns and Price's findings on gas checking, differences in overall frequency and accuracy of time monitoring were found between groups. Brandimonte and colleagues (2011) investigated only event-based PM (and response inhibition abilities) in children with autism spectrum disorder (ASD) and those with ADHD. Children worked on a categorization (ongoing) task and, simultaneously, either an event-based PM task (i.e., remembering to press a specific button when one of the two PM target cues were presented) or a Go/No Go task (i.e., remembering not to press any buttons when one of the two target items were presented). Results showed that, as compared with their matched controls, ASD children's performance was more impaired in the PM task than in the Go/No Go task, whereas the reversed pattern of performance was observed in ADHD. Children with ADHD performed as good as controls on the PM task but were impaired in the Go/No Go task. Regarding the ongoing task, ASD children were as accurate as controls, but significantly slower, independently of conditions. In contrast, ADHD children did not differ from controls in the presence of a concurrent PM task, whereas they were less accurate than controls in the presence of a Go/No Go task. Thus, overall, ASD and ADHD children manifested opposite patterns of performance in the realization of delayed intentions involving remembering to execute or to inhibit an action.

Taken together, the few available results on PM in ADHD do not support a general deficit in PM but seem to suggest a differential impairment only in time-based PM. Yet, the available evidence is limited in several ways, which motivated the present study. First, only three studies have examined this issue and thus, the empirical basis is much smaller than for many other cognitive domains possibly impaired in ADHD. Second, the differential impairment hypothesis rests on cross-study comparisons. Third, the only study using both task types in one sample has used tasks that differed in many respects (e.g., computerized or not, contextualized explanation or not, multiple/repeated vs. single PM responses, delay times etc.). Fourth, no study investigated PM in adults with ADHD despite empirical evidence of persisting symptoms and cognitive deficits into adulthood (Seidman, 2006). The present study, therefore, set out to address these open issues and, consequently, the primary goal of the present study was to compare time- and event-based PM performance in adults with ADHD within the same task setting using parallel task constraints. To this end, we applied a complex contextual task that allowed to keep participants' attention busy and to integrate both time- and event-based tasks in the same setting without having to introduce the task as two different procedures.

Method

Participants

A total of 25 adults with ADHD and 25 typically developing participants took part in this study. Controls were parallel for age (ADHD: $M = 40.00$, $SD = 11.20$, range = 20–57 years; controls: $M = 41.16$, $SD = 10.74$, range = 20–56 years; $F < 1$) and gender (ADHD: 13 women, 12 men; controls: 14 women, 11 men; $\chi^2(1) = .08$) to the ADHD group. Diagnoses were established through expert clinical evaluation in accordance with International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10) criteria. Individuals with ADHD were recruited through self-help groups and a local clinic specialized on ADHD treatment. Controls were recruited through advertisements and the participants' pool of the department. All participants with ADHD were medically treated. A total of 19 individuals were on stimulants (Methylphenidate/Ritalin, Concerta, and/or Medikinet), 4 on antidepressives (Strattera, Elontril, and/or Paroxetin), 1 on both stimulants and antidepressives (Methylphenidate and Paroxetin), and 1 participant was treated with antipsychotics (Zeldox). Participants treated with stimulants were requested to refrain from taking medication 24 hr prior to testing. Exclusion criteria were any history of other psychiatric or neurological disorders as well as drug and alcohol abuse. Any human data included in this manuscript were obtained in compliance with the Helsinki Declaration. Each participant was tested individually, and before testing, all participants gave written informed consent.

Materials and Procedure

Individual difference variables. Participants completed the Matrices Reasoning test of the Wechsler Adult Intelligence Scale–III to measure their cognitive ability (German version, Von Aster, Neubauer, & Horn, 2006; Wechsler, 1997). This test presents participants with a sequence of groups of designs, and the participant is asked to choose the missing design from a number of patterns. The test increases in difficulty. Raw scores are transformed into age-related normative scores.

To assess attentional dysfunctioning, hyperactivity and impulsivity participants were requested to fill in the Diagnostic Checklist-Hyperkinetic Disorders/ADHD (DCL-HKS), which is part of the Diagnostic System for Mental Disorders in Childhood and Adolescence (DISYPS-II) and is based on the international classification systems ICD-10 and *Diagnostic and Statistical Manual of Mental Disorders* (4th ed., *DSM-IV*; APA, 1994; Döpfner, Görtz-Dorten, Lehmkuhl, Breuer, & Goletz, 2008). The DCL-HKS consists of 18 items with a four-stage response format

that target symptoms of attention deficits, impulsivity, and hyperactivity.

PM measures. Following Craik and Bialystok's (2006) suggestions to study planning and task coordination in a contextual setting, we developed a new computerized task in which we asked individuals to prepare breakfast for four people (Altgassen, Koban, & Kliegel, 2012; Dresden Breakfast Task). Specifically, participants were required to set the table in a predefined way (see Figure 1) and to prepare certain foods (e.g., eggs, bread) and drinks (e.g., tea, orange juice). The task comprises simple table-setting tasks (e.g., putting salt, cheese, etc. on the table) and more complex time- and event-based PM tasks. Time-based tasks are remembering to take the tea-bag out of the tea after 4 minutes or to put the butter on the table 5 min prior to guests' arrival. Responses were scored as correct if participants completed these tasks ± 60 s around the target times. Event-based tasks are remembering to prepare the tea after the kettle went off and changed its color from blue to red and to switch off the egg cooker when it gives an acoustic signal. Responses were scored as correct if participants completed these tasks within 20 s after occurrence of these events.

Participants were asked to prepare breakfast for four people at the computer. They were required to complete all tasks within 7 min following certain rules, which closely mirrored restrictions that also exist in daily life (e.g., first putting down the tablecloth, then setting the table). Participants were able to change between two screens (kitchen and dining room). Participants could check the elapsing time by clicking on a timer icon in the dining room, whereupon the experimental time was presented for 2 s (starting time was 09:53, end time 10:00). The task was explained first and then the participant was guided through all functions on the PC and was required to try them. In a next step, the participant was asked to develop a plan on how and in which order he or she wanted to perform the subtasks. Participants were explicitly encouraged to switch between tasks to complete all tasks on time and were informed that some tasks are more important than others (e.g., having the table ready when guests arrive and having the tea and eggs just ready before the guests arrive). Participants were asked to write their plans down and then tell it to the experimenter who digitally recorded it for later scoring. Plans were then taken by the experimenter and participants did not have access to them again before or during task performance. After having completed some filler tasks, participants performed the Dresden Breakfast Task.

The software measured when and which tasks participants began and completed. Main dependent variables were *event-* and *time-based PM performance* (number of completed event- and time-based tasks, respectively), and *time monitoring* (number of clock checks).

Figure 1. Dresden breakfast task.

Ongoing Breakfast Task performance (cf. Craik & Bialystok, 2006) was evaluated using several indicators; besides the overall measure of *general task performance* (number of completed breakfast task items in percentage, excluding PM tasks), we also explored *rule adherence* (number of rules participants adhered to during testing), *flexible switching* (sum of number of task switches and room switches), *efficiency* (i.e., participants' efficiency such as not taking more things to the living room than needed, following implicit order constraints such as first putting the tablecloth and then setting the table), and *plan quality* (composite score of prioritization [number of important tasks that were mentioned in the plan], rule adherence [number of rules that were mentioned in the plan], specification of actions [number of specified subtasks and number of specifically elaborated orders of tasks that were mentioned in the plan]). Plans were rated by two independent, trained raters. Moreover, *plan adherence* was assessed, that is, how closely partici-

pants followed their original plan while performing the paradigm. Interrater reliability was high (planning performance $r = .94$; plan adherence $r = .92$).

Results

Individual Difference Analyses

There were no significant group effects with respect to the matrices test (ADHD: $M = 12.24$, $SD = 2.31$; controls: $M = 12.76$, $SD = 1.76$; $F < 1$). In contrast, as expected, the ADHD group reported more symptoms of attention deficits (ADHD: $M = 1.81$, $SD = .48$; controls: $M = .50$, $SD = .40$; $F(1, 42) = 95.21$, $p < .01$), impulsivity (ADHD: $M = 1.87$, $SD = .66$; controls: $M = .75$, $SD = .59$; $F(1, 42) = 34.71$, $p < .01$), and hyperactivity (ADHD: $M = 1.20$, $SD = .64$; controls: $M = .56$, $SD = .53$; $F(1, 42) = 12.71$, $p < .01$) than controls.

Figure 2. Prospective memory performance.

PM Performance

ANOVAs were conducted to examine group differences with respect to PM performance. Groups differed significantly in time-based PM, $F(1, 48) = 9.52$, $p < .01$, $\eta_p^2 = .17$, but not in event-based PM, $F(1, 48) < 1$, $p > .05$, $\eta_p^2 = .00$. Individuals with ADHD performed significantly less time-based tasks correct, whereas event-based PM task performance was spared (see Figure 2). Groups did not differ in time monitoring (ADHD: $M = 2.48$, $SD = 4.42$; controls: $M = 2.63$, $SD = 2.65$; $F < 1$, $p > .05$, $\eta_p^2 = .00$).

Ongoing Breakfast Task Performance

No significant group differences were revealed in general task performance (ADHD: $M = 64.56$, $SD = 17.18$; controls: $M = 69.30$, $SD = 18.62$; $F < 1$, $p > .05$, $\eta_p^2 = .02$). To investigate plan quality and plan adherence, ANOVAs were conducted. Results indicated significant group differences in plan quality (ADHD: $M = 13.32$, $SD = 1.93$; controls: $M = 14.72$, $SD = 2.42$; $F(1, 48) = 5.10$, $p < .05$, $\eta_p^2 = .10$) and plan adherence (ADHD: $M = 7.72$, $SD = 3.16$; controls: $M = 10.92$, $SD = 2.89$; $F(1, 48) = 14.00$, $p < .01$, $\eta_p^2 = .23$). Overall, controls planned more accurately and followed their own plans more closely than ADHD individuals. No significant group differences were revealed for rule adherence (ADHD: $M = 1.60$, $SD = 1.04$; controls: $M = 1.56$, $SD = .65$; $F < 1$, $p > .05$, $\eta_p^2 = .00$), flexible switching (ADHD: $M = 28.88$, $SD = 10.19$; controls: $M = 33.64$, $SD = 8.08$; $F(1, 48) = 3.35$, $p > .05$, $\eta_p^2 = .07$), and efficiency (ADHD: $M = .24$, $SD = .60$; controls: $M = .64$, $SD = 1.08$; $F(1, 48) = 2.64$, $p > .05$, $\eta_p^2 = .05$).

Exploratory Correlational Analyses

In a final step, correlational analyses were carried out to explore possible links between plan quality and plan adherence and between the two planning variables and participants'

PM performance. A significant correlation was revealed between plan quality and plan adherence within the control ($r = .41$, $p < .05$) but not within the ADHD group ($r = .23$, $p > .05$). Event-based PM correlated significantly with plan adherence within the control ($r = .40$, $p < .05$) and ADHD group ($r = .49$, $p < .05$). The correlations between plan adherence and time-based PM were not significant (control group: $r = .01$, $p > .05$; ADHD group: $r = .20$, $p > .05$). No significant correlations were revealed for event- and time-based PM and plan quality (event-based control group: $r = .20$, $p > .05$; event-based ADHD group: $r = .02$, $p > .05$; time-based control group: $r = -.30$, $p > .05$; time-based ADHD group: $r = -.06$, $p > .05$) or for plan quality and impulsivity as measured through the impulsivity scale of the DCL-HKS in individuals with ADHD ($r = .02$, $p > .05$).

Discussion

The aim of the present study was to compare, for the first time, time- and event-based PM performance in adults with ADHD within the same procedure using tasks with parallel task constraints. In line with the cross-study evidence from previous studies (Brandimonte et al., 2011; Kerns & Price, 2001; Zinke et al., 2010), we observed a marked dissociation, namely impaired time-based PM but spared event-based PM in individuals with ADHD. Importantly, the time-based deficit was a substantial and large-scale effect, and ADHD individuals had less than half correct time-based PM responses in comparison with controls. In contrast, there was no sign of any impairment in the event-based tasks despite similar task constraints. Here, individuals with ADHD performed at a similar level as controls.¹

In conclusion, the task dissociation across PM task types in the neurocognitive profile of ADHD was corroborated in the present study. Hence, the next step for clinical neuroscience research in this regard will be to delineate the cognitive correlates of this dissociation. The present data may give first indications in this regard. Interestingly, no group effects were found for time monitoring. Although, overall, time monitoring was low for both groups, this pattern is in line with observations of two previous studies. Zinke et al. (2010) and Kerns and Price (2001) had also found no ADHD effects on time monitoring or gas-level checking, respectively. Thus, the deficit in time-based PM appears to manifest itself *without* the pathway of reduced strategic monitoring for the target time—at least in the way currently assessed in PM research. This is not only of interest for the clinical neuroscience of ADHD but also of conceptual importance for cognitive models of PM. This is because, usually, it is argued that inhibitory and working memory loads are rather high in time-based tasks, as they require the individual to frequently inhibit performing the ongoing activity *in order to* check the time to make sure

not to miss the appropriate moment to execute the planned action (Einstein & McDaniel, 1996). The current data—together with the consistent evidence from the previous studies—challenge this functional relationship between time monitoring and time-based PM as there were consistent deficits in time-based PM without a corresponding effect in time monitoring. Hence, at least for the ADHD-related effects, the key mechanisms appear to be different. As for what may be relevant in this regard, the current data structure only allows for speculation, but one may assume that (a) the necessity to maintain the timing information in working memory and/or (b) inhibiting the ongoing task at target time may be potential candidates. Hence, this calls for more elaborate ways of assessing the underlying processes in time-based PM in general and in ADHD in particular. Future studies should directly manipulate inhibitory load of the PM task at specific task phases to assess its impact on PM performance in ADHD.

With respect to the spared PM performance in event-based PM, present data support conceptual arguments that suggest that (at least certain types of) event-based PM tasks with distinct and salient cues are very structured, and similar to cued (retrospective) recall provide explicit cues that may support retrieval of the intended action and put lower demands on inhibitory control processes, which are known to be impaired in ADHD (Barkley, 1997; Boonstra et al., 2010). This may enable individuals with ADHD to preserve event-based PM performance (Einstein & McDaniel, 1996; Kerns & Price, 2001).

Several additional findings merit consideration, although we consider them exploratory as no *a priori* hypotheses were formed. In the ongoing Breakfast Task, no group effects were found for general task performance, rule adherence, switching, and efficiency. In line with previous research on complex multitasks and planning tests (Chan et al., 2006; Kliegel et al., 2006; Siklos & Kerns, 2004), ADHD participants made poorer plans and adhered to them less closely than controls. For example, Kliegel et al. (2006) reported impaired planning abilities for multiple tasks and compared the poorer plan adherence in children with ADHD with a control group. Importantly in the present study, plan quality and plan adherence correlated significantly within the control group indicating that participants who planned more accurately in the run-up to Dresden Breakfast Task also adhered to their plans more strictly during the execution of the task. This relationship was not found for the ADHD group. Possibly, as suggested by Kliegel et al. (2006), individuals with ADHD tend to form their plans more impulsively and less strategically than controls which may lead to poorer encoding of these plans and less close plan adherence. In line with this assumption, using the Tower of London, Young, Morris, Toone, and Tyson (2007) found shorter planning times in ADHD. Moreover, only controls increased planning time with increasing levels

of task difficulty but not ADHD individuals. This may also indicate higher impulsivity during plan formation in individuals with ADHD, and indeed, planning time and impulsivity correlated negatively. Yet, the present study was not able to replicate this relationship. However, the impulsivity scale of the DCL-HKS used in the present study only consisted of four items and may not have been sensitive enough to assess impulsivity adequately. Future studies should address the question of a relationship between those variables using more sensitive scales for the investigation of impulsivity.

Somewhat surprisingly, the exploratory correlational pattern of time- and event-based PM with both planning variables (plan quality, plan adherence) was mixed. No significant correlations were found between plan quality and time- and event-based PM performance; neither for the control nor for the ADHD group. For plan adherence, a significant relationship with event-based PM was observed for both groups but not with time-based PM. As to why this differential pattern emerged, one possible explanation may be that it is easier to imagine a specific cue/situation in which the intended action is later performed and to plan accordingly than to imagine a certain time. Possibly, imagination of the cues/situation in which the task will later be performed leads to the formation of an association between these cues/situation and the intention, so that later these cues rather automatically prompt retrieval of the intended action.

In summary, the present study found a task dissociation in PM performance in ADHD with impaired time-based but spared event-based PM. This was the first study to investigate time- and event-based PM within one sample and task setting and the first one to explore PM in adults with ADHD. Hence, the present study provides further evidence for specific cognitive deficits in ADHD, namely, impairments in time-based PM and planning, which may underlie their everyday organization deficits. Conceptually, the current results call for further examination of the neurocognitive processes underlying time-based PM.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Note

1. A potential limitation of the present study is that there are no reliability and validity data available on the specific task version applied; however, other studies using similar PM tasks report satisfactory reliability and validity (e.g.,

Salthouse, Berish, & Siedlecki, 2004; Zeintl, Kliegel, & Hofer, 2007).

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