Masterthesis

The Role of Executive Functioning and Age in Prospective Memory Performance

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Nijmegen, 3rd February 2018

Abstract

On the basis of recent prospective memory research, the present study was conducted to examine whether executive functions and age are predictive of prospective memory performance. For that purpose, both executive functions as well as prospective memory performance were assessed. In total, 26 subjects participated. The target group were Dutch citizens of different ages and socio-economic backgrounds. The study was divided into two parts in which executive functions and prospective memory performance were tested respectively. The results of the stepwise multiple regression analysis showed that none of the proposed factors were significant predictors of prospective memory performance. This was the case both in a model containing executive functions only as well as in another one with age as an additional predictor. The lack of predictive ability was mainly attributed to methodological limitations. Further implications are discussed.

Keywords: prospective memory, executive functions, cognitive flexibility, working memory, inhibitory control, aging

Thinking about memory, the first association usually is the purpose of remembering past events, for example recollecting what one ate this morning. It is, however, proposed that this "retrospective memory" differs from an additional process referred to as Prospective Memory (PM; Brandimonte, Einstein, & McDaniel, 1996). The latter enables you to remember tasks or activities which are intended to be performed in the future, for instance attending a meeting tomorrow at 8 o'clock. This example describes a time-based PM event as it has to be remembered at a certain point of time. So its recollection is not triggered by any cue other than time. This cue is considered to be internal though since one has to monitor it by oneself. Such tasks are distinguished from event-based PM tasks which do involve an external trigger and have to be performed as soon as a certain event occurs. An example would be that one remembers to give a friend somebody's regards as soon as you see that friend. Here, the encounter with the friend is the cue triggering the memory to greet him or her from the other person. The basic difference between these two types of memories is the amount of self-initiated retrieval with time-based ones being more effortful in that regard (Einstein & McDaniel, 1990). Yet, for the sake of comparability with previous research conducted in this area, the focus of the present study lies on event-based PM.

Up to the present day, several assumptions have been made to explain deficits in PM and underlying processes. It is claimed that executive functions (EF) are linked to PM. They are defined as effortful cognitive processes enabling controlled behavior. It is reasonable to assume that such cognitive effort is needed to not only remember the intended task but also to interrupt an ongoing activity in favor of initiating and executing the task. In line with this reasoning, it was found that individuals with lower than average scores on EF tests perform worse on PM tasks than participants with high EF scores (McDaniel, Glisky, Rubin, Guynn, & Routhieaux, 1999). Such a link has also been established in clinical studies in which brain-damaged patients suffering from dysexecutive symptoms are compared to people with unimpaired EFs. Here, the performance of the impaired patients on PM tasks is worse as opposed to both the other group of patients without any EF complaints and healthy controls (Kopp & Thöne-Otto, 2003).

However, a problem with the mentioned and various other studies is that they neglect the fact that EFs are by definition a *set* of cognitive processes (see e.g. Diamond, 2013). Without a specification of which EFs are involved, it remains unclear which individual processes contribute to PM and to what extent. Kliegel, McDaniel and Einstein (2000) addressed this issue by investigating different EFs and their contribution to PM performance separately. It was concluded that working memory (i.e. a type of short-term memory helping to manipulate information for a current activity) and inhibitory control (i.e. the ability to focus on relevant and to ignore irrelevant information) play a crucial role in initiating the task. Only the latter predicted actual PM performance though. This finding was extended by a study which not only identified other EFs involved in PM but also disentangled four different phases of the PM process more extensively (Kliegel, Martin, McDaniel, & Einstein, 2002). In spite of the provided multiphasic model, only the result for the execution phase will be regarded since its measure is most comparable to general PM performance measures. For the execution of the PM task, cognitive flexibility (i.e. task-switching ability) turned out to be most crucial. This result is in line with the notion that this mental flexibility shares several parallels with PM as for instance similar developmental changes during childhood (Mahy & Munakata, 2015). Schnitzspahn, Stahl, Zeintl, Kaller and Kliegel (2013) also found that shifting reliably predicts PM performance whereas inhibitory control was an even stronger predictor in this case. Another study with elderly adults found that especially inhibitory control is of importance for PM (Scullin, Bugg, McDaniel, & Einstein, 2011) while yet another study emphasized the role of working memory (Mahy & Moses, 2011).

Hence, attempts to disentangle different EFs contributing to PM functioning were in fact made but there is no consensus on the respective extent to which each function predicts PM performance. The mentioned studies do not always focus on the same EFs and correspondingly neglect others which might just as well be involved in PM. So the diversity of results can mainly be attributed to the mere fact that only one or two EFs were focused on at a time. Also, many studies conducted so far investigated only a single measure of EFs. These shortcomings do not allow a proper comparison between the contributions of different processes. However, looking at the various findings that have been provided by now, at least three EFs seem to be associated with PM: inhibition, working memory and cognitive flexibility. Correspondingly, the present study aims to counteract the inconsistency in the literature and to clarify if and in how far the most commonly studied EFs predict PM functioning. The relevance of studying PM and clearly identifying underlying mechanisms should not be underrated though as it improves our understanding of cognitive processes that facilitate everyday life. In addition, a clarification makes it possible to discern opportunities to improve PM in impaired individuals.

An aspect that should be taken into consideration in PM research is the fact that both PM and EF are shown to decline with age (Martin, Kliegel, & McDaniel, 2003). As for PM, age effects have been studied extensively as can be seen in several meta-analyses (Henry, MacLeod, Phillips, & Crawford, 2004; Uttl, 2011). These meta-analyses allowed the conclusion that increasing age affects PM negatively. Acknowledging age-related declines in both EF and PM, the present study incorporates the factor age as well.

Since EFs, age and PM were shown to be related in various studies, it can be expected that PM functioning can be predicted by all of the mentioned factors. Based on previous findings, it is hypothesized that inhibitory control and cognitive flexibility predict PM performance beyond working memory. The former two are found to be crucial predictors in most of the studies conducted so far. Also, working memory is presumed to play an inferior role due to its association with initiation of PM rather than with actual execution. However, proper execution relies on initiation which is why working memory is expected to still be a significant predictor of PM performance. Regarding the direction of the relationship, it is expected that positive outcomes on EF tests are accompanied by proper PM performance. In particular that would mean that less time needed for a cognitive flexibility and inhibitory control task and a higher working memory capacity result in higher PM performance scores. In conformity with the results of the mentioned meta-analyses, age is also expected to be significantly predictive of PM performance. To investigate the proposed relations, EF tests were carried out as well as an additional task to determine PM functioning.

Method

Participants

For the current study Dutch participants were approached using flyers and word of mouth. Participation was voluntary. The compensation involved a 10 euro gift coupon for the first part of the study, the EF assessment, and another 15 euro coupon for the second part which involved the PM test and a brain scan. The sample comprises 26 subjects (16 female, 10 male) with a mean age of 48.69 years (*SD* = 19.15). The ages ranged from 19 to 79 years and all socio-economic groups were included. The exclusion criterion for this study was the diagnosis of a (neuro-)psychiatric disorder which has an evident impact on executing a cognitive task such as in this study. This did not apply to any of the subjects. Initially, 29 subjects took part in both parts of the study, however data of 3 subjects were excluded from the analysis due to missing values.

Materials

To measure cognitive flexibility, the Trail Making Test (TMT) was used. The TMT has a high interrater-reliability with $r = .94$ for TMT-A and $r = .90$ for TMT-B (Fals-Stewart, 1992). Construct validity is also given (Gaudino, Geisler, & Squires, 1995). The test comprises two parts: in the first one, TMT-A, participants have to connect numbers through drawing lines as quickly as possible. This part mainly measures visuospatial abilities. In the second part, TMT-B, subjects have to connect numbers and letters alternately. If the time that was needed for TMT-A is subtracted from the time on TMT-B, one receives a relatively strong indicator of executive functioning and more specifically, task-switching ability (Sánchez-Cubillo et al., 2009). Hence, the latter was used as a measure for cognitive flexibility in this study.

For the measurement of inhibitory control, the Stroop test (Stroop, 1935) was used. The test-retest reliabilities of all the versions of the Stroop test are good ($r > .80$) and construct validity has been established in various clinical as well as in neuroimaging studies (Homack & Riccio, 2004). The test consists of three tasks. The first one (Stroop 1) is to read a list of words, which name colors, as fast as possible. In the second part (Stroop 2) a list with such words is presented again with the difference that they are congruently inked in the color they name. Here, the task is to name the ink color of the words. In the third part (Stroop 3), the words in the list are inked in an incongruent color but the task to name the *color* of each word stays the same. So here, the urge to read the word has to be inhibited. The outcome measure that is used as an indication for inhibitory control is the commonly used interference effect, also called Stroop-effect. It is derived by comparing the times that were needed to complete Stroop 2 and Stroop 3 (i.e. Stroop 3 - Stroop 2).

Working memory capacity was quantified by making use of the Digit Span Task (DST; Wechsler, 1987) which is a core subtest in the Wechsler Intelligence Scales. Its test-retest reliability values range from .65 to .71 (Blackburn & Benton, 1957). In this task, participants have to recall a series of digits beginning with two continuing to the maximum of nine digits. For each series length, there are two trials with differing digit series respectively. In the *digits forward* part (DST-F), subjects have to repeat the digits in the same order as presented whereas the *digits backward* (DST-B) requires them to repeat the memorized digits in reversed order. Participants receive one point for each correct trial. The sum of all correct trials of both the forward and the backward task is the score that will be used as a measurement for working memory.

The ongoing task (OT) in this study is a visual 2-back task. Therein, participants see a series of images. For each image, the picture shown two images ago has to be remembered and matched to the currently presented one. So the task is to indicate whether the image on the screen is the same as the second last one seen. Answers are administered by two different buttons on a button box that have to be pressed if the image is either the same (button left index finger) or not (button right index finger). Each of the images is presented for 1.5 seconds with an interstimulus interval of 0.5 seconds. In all task blocks about 25% are 2-back hit items. Four blocks are presented in total. The first one contains 120 OT items, each item being an image. The PM task is added in blocks 2, 3 and 4 and its purpose is to note whether the border of the images has a particular color. For one half of the participants this color is red and for the other half it is blue. Hence, if the target border colors are presented, the 2-back task has to be interrupted and the presence of the border color has to be noted by pressing a different button (left middle finger). So blocks 2, 3 and 4 are dual-task blocks and they will comprise 36 PM cues and 444 OT items. A correct answer (a hit) is the correct identification of images with a red or blue border respectively. To measure PM, first of all the proportions of hits vs. all responses (including misses) to PM cues were calculated. This is done for each dual-task block. Then, the mean of these three calculated proportions was computed to obtain an averaged proportion of hits in the PM task as an indicator of overall PM performance.

Procedure

The study was divided into two parts. On the first part the participants completed a series of behavioral tests, including the EFs tests mentioned above and additional tests which are irrelevant for the present research questions. Demographic data (i.e. age, gender, nationality, type of education, years of education) were assessed as well.

For the second part of the study another appointment was made with the participants. Therein, they completed three tasks in a functional magnetic resonance imaging (fMRI) scanner. The three tasks were a baseline task, the OT and the PM task. The baseline task was unrelated to the critical measurements for the present matter of interest, as was the fMRI. These two measures were thus negligible. For instructions and practice of the (baseline and) OT, the participant was first brought to a separate cubicle. After practicing, the subjects were brought to the fMRI scanner where the performance on the three tasks was actually assessed. The PM task was not explained to the subjects until they completed the first out of the four task blocks. Then, the first block was presented which only included the baseline and OT, just like in the practice beforehand. After completion, the participants received an oral instruction on the upcoming PM task while still lying in the scanner. The communication with the subjects was enabled by headphones. After checking if the instructions are understood, the second, third and fourth blocks were presented one after another. In each of these three blocks all of the three tasks–including the added PM task–had to be executed. To prevent potential fatigue, which might affect performance, a break was offered to the participants after finishing the first dual-task block.

Data-analysis

The outcome measures that were used for the analyses were computed as follows: to quantify cognitive flexibility, the difference between the times (seconds) needed for each part of the task was calculated (TMT-B - TMT-A). The interference effect of the Stroop test was utilized to indicate inhibitory control. It was calculated by subtracting the time (seconds) that was needed for the second part of the test from the time needed for the third part (Stroop 3 - Stroop 2). Working memory performance is represented by the total number of correctly recollected digit series (DST-F + DST-B). Here, the highest possible score is 24 and 0 the lowest. Regarding age, no data preparation was necessary since division into different age groups did not occur in view of the sample size. For PM performance, the mean proportion of hits on the PM task was generated from the three dual-task blocks. This averaged hit-proportion served as the outcome variable for PM.

The data was analyzed by calculating correlations first to look at the relationships between the different variables. Then, for the main analysis, a multiple regression analysis was implemented. This was done in a similar manner to the study by Kliegel et al. (2002) by conducting a sequential analysis. First, the predictors cognitive flexibility (quantitative), working memory capacity (quantitative) and inhibitory control (quantitative) were analyzed. The criterion was PM performance (quantitative). In a second step, age (quantitative) was added as another predictor while the criterion and the other predictors stayed the same.

Results

Correlations

Table 1 shows the correlational data structure for the different cognitive constructs that were assessed as well as for the factor age. Therein one can see that all of the EFs are significantly related to one another. Also, there is a significant relation between age and cognitive flexibility (TMT) as well as age and attentional inhibition (Stroop). Working memory (DST) is not correlated to age though. With exception of working memory, all of the variables significantly correlate to PM. In all of these cases the relation is a negative one. That means that improvement in PM functioning is associated with less time needed both in the cognitive flexibility and the inhibition task. So the better these two executive functions are, the better the PM performance. Furthermore, increasing age is associated with worse PM performance.

Table 1

Correlations between Executive Functions, Age and Prospective Memory Performance

Measure	TMT	Stroop	DST	Age
TMT	-			
Stroop	.447*	-		
DST	-.414*	-.347*	-	
Age	.444*	-.434*	.041	-
PM	-.479**	-.355*	.108	-.357*

* p < .05, ** p < .01

Main analysis

A stepwise multiple regression analysis has been utilized to examine the degree to which EF and age predict PM performance. The results for each model are displayed in Table 2. For the first equation (Model 1) containing the EFs only, the analysis showed that the proportion of variance explained is not significantly larger than 0 ($F(3, 22) = 2.743$, $p = .067$, $R^2 = .272$). That means that PM performance cannot be predicted by the three EFs altogether. In Model 1, cognitive flexibility was found to be a significant predictor ($b = -.004$, $p < .05$). However, the entire model did not reach significance which is why individual predictive ability from either of the factors within this model is excluded.

When the predictor age was added to the equation (Model 2), the result was similar

($F(4, 21) = 2.025$, $p = .128$, $R^2 = .278$). So in both models none of the independent variables are shown to be predictive of PM performance. To exclude that multicollinearity has affected the regression estimates, variance inflation factors (VIF) were checked. The VIFs for each predictor stayed in a range between 1.44 and 1.66 (< 10) which suggests that there is no multicollinearity.

Table 2

Predictors of Prospective Memory Performance

Predictor	R^2	*B*	*p*
Model 1	**.272**		**.067**
TMT		-.004	.047
Stroop		-.002	.333
DST		.009	.471
Model 2	**.278**		**.128**
TMT		-.003	.102
Stroop		-.002	.463
DST		-.005	.607
Age		-.001	.677

Discussion

With the present study it was tried to investigate to which degree EFs–working memory, cognitive flexibility and inhibitory control in particular–as well as age predict PM functioning. Specifically it was expected that cognitive flexibility and attentional inhibition would be strongest predictors. Working memory was also expected to be a significant but relatively weaker predictor. Also, it was hypothesized that age significantly predicts PM performance. The analysis however did not show any of the expected results. When taken altogether, changes in EFs are not significantly associated with changes in PM performance. The same is the case, when age is added as an additional factor. Since both models were not significant, the individual contributions of each factor to PM performance are neglected. This falsifies all of the given hypotheses. It can be concluded that the present findings do not provide evidence for a prediction of PM performance based on executive functioning and age.

These found lack of predictive capabilities in the mentioned EFs altogether is not consistent with results provided by previous PM research. A variety of studies did show that all of the investigated EFs predict PM functioning. Even though most of these studies focused on single EFs or used only one measurement for EFs as a whole, Kliegel et al. (2002) and Schnitzspahn et al. (2013) showed that single and combined effects are still present if a larger number of (inter-correlated) EFs is included in one model. So different EFs ought to affect outcomes in PM tasks both independently and jointly. Neither of these effects was found in the present study though, despite having applied a similar analytic procedure as Kliegel et al. (2002).

Since it was tried to replicate this approach, not only similarities but differences should also be regarded in order to explain the current results. One of these differences is that the present study did not make use of the multiphasic model of PM. It was introduced to disentangle a range of cognitive abilities involved in the PM process. These however were not measured individually in the present study. Instead, overall PM performance was assessed with only one corresponding total measurement. To make an estimate about the outcomes though, this outcome measure was equaled to the measure of the execution phase of the multiphasic model. Even though the nature of these two things seems to be the same, the measurements differ substantially. Execution is for example assessed by counting the number of subtasks executed that participants were instructed to initiate on their own at a certain point of the experiment (Kliegel, et al., 2000, 2002). Another established PM test however comprises a computerized paradigm which *introduces* a certain type of cue which the participant has to respond to (see e.g. Einstein & McDaniel, 1990). Even though both measures aim at assessing event-based PM performance, the amount of self-initiation varies. In the more naturalistic setting, the PM response is self-generated whereas it is triggered with a cue in the computerized paradigm. As a consequence, comparing results of studies with these two approaches can be problematic since correspondingly differing retrieval processes might have been used. So this makes it even more difficult to pinpoint possible causes of PM failures. Besides, the negligence of the multiphasic PM processes in itself might have masked EF effects in the present study. So it is thinkable that EFs actually affected PM, but not in every phase. In this case the question, which of the three EFs affects which phase also remains. So for more valid, comparable and accurate results, uniform measurements of the different PM processes, preferably considering the multiphasic model, should be applied.

Regarding the factor age, the results are surprising as well. Age is the most studied influencing factor with respect to PM functioning. In his meta-analysis, Uttl (2011) identified 62 studies comparing age differences in PM performance and concluded that an age-related decline does exists. However, one other study did find a lack of age-effects as well (Einstein

& McDaniel, 1990). Therein two experiments failed to find age-related deficits in an event-based PM task. A possible explanation, that the authors name, is the similarity between the OT and the PM task. If a PM cue is similar to the OT in terms of processing, the cue is referred to as *focal*. The focal stimulus might have disturbed the retrieval of the PM task by triggering other associations connected to it. The cue appeared within the 2-back items so the possibility to associate other things than the required response is given, for instance (mistakenly) continuing with the 2-back task. So the OT might have been salient and therefore too hindering for the recollection of the PM task. This could have distorted the results. Accordingly, the authors argue that a distinctive surrounding might facilitate PM functioning, making individual and actual age differences more detectable. Supporting this line of reasoning, it was found that the presentation focal PM cues eliminates deficits found in older age (Aderle, Rendell, Rose, McDaniel, & Kliegel, 2010). The explanation for this result was that focal retrieval is less demanding for elderly adults due to a more automatic and less resource-demanding type of processing. Meanwhile, younger adults seem to struggle with the differentiation of the two tasks. In order to prevent such phenomena from blurring out actual age differences, future research should consider comparing focal and non-focal PM tasks within the same sample.

Considering all of the presumed predictors of PM, it is also thinkable that there are other factors related to age that have influenced both executive functioning as well as PM. Socio-economic groups were not compared in this study, so one such factor could be education. Undoubtedly, increasing age allows more opportunities to receive education. According to the Cognitive-Reserve-Hypothesis (see e.g. Stern, 2009) certain occupations, such as exposure to education and engagement in leisure activities, benefit cognitive processes in the long run. They slow down age-related memory declines and can even protect from developing Alzheimer’s disease. So the more one is occupied with such activities, the stronger the resilience of one’s cognitive capacity to declines. Much of this type of research focuses on neural changes associated with memory loss or even dementia suggesting that PM could also be affected. But cognitive reserve is also shown to be associated with EFs. People with a higher cognitive reserve perform better in EF tests (Roldán-Tapia, García, Cánovas, & León, 2012). Resting upon these findings, it can be assumed that various confounding variables associated with cognitive reserve may have influenced the EF and PM measures of the present study. So controlling for such variables, through assessing and analyzing for example years of education and type and amount of leisure-time activity might be necessary.

A methodological aspect that should be noted is the fact that neither EFs nor PM assessment has a standard testing procedure. To give an example for the differences in EF assessment: in order to quantify shifting, Schnitzspahn et al. (2013) used both the category-switch as well as the color-shape task (see Friedman et al., 2006). On the contrary, Kliegel et al. (2002) used the Wisconsin Card Sorting Test (Heaton, Chelune, Talley, Kay, & Curtiss, 1993) for that same purpose. What is also noteworthy is that not only different tests are used to examine the same construct, but even if the same tests are used, the ultimate outcome measures still vary. For instance, Scullin and colleagues (2011) chose for the number of correctly named ink colors within 45 seconds in the Stroop 3 subtest as an outcome measure. Kliegel et al. (2000) however decided to consider all three subtest scores of the Stroop to calculate the relative increase of time needed for Stroop 3 in contrast to Stroop 2. Therefore, the Stroop 2 score was subtracted from Stroop 3 and the outcome was divided by the time from Stroop 1. Yet again others use the Stroop effect as in the present study. Hence, there still does not seem to be a consensus on what the most content-valid and reliable EF assessment is. So with such a large diversity in EF outcome measures, it is difficult to not only compare results but also to interpret individual findings in the first place.

Aside from these remarks, limitations of the current study and its consequences should be discussed as well. One issue is certainly the relatively small number of participants. Uttl (2011) provides an overview of PM studies examining age differences and there it shows that the majority included at least 40 subjects. In fact, a power analysis with G*Power 3.1 (Faul, Erdfelder, Buchner, & Lang, 2009) revealed that for a multiple regression in particular, a power of 80% and a medium effect size of .15 can only be achieved with a minimum of 85 subjects. So it can be assumed that the total of 26 subjects in this study does not seem to suffice for reliable results. This assumption can also be supported by the finding that in both investigated models, the coefficients of determination (i.e. R^2) were found to be quite high despite non-significance. The coefficients however do suggest a strong relationship with PM. Such a contradiction often indicates that the sample was too small to test the proposed hypotheses. The current results should therefore be interpreted with caution.

Despite all of the discussed issues, the present study contributed valuable insights to PM research and underlying processes. Even though age and EFs were numerously studied in connection with PM, there is an uncertainty as to what extent the different factors actually contribute to PM functioning. With an approach similar to Kliegel et al. (2002), it was tried to disentangle the effects that working memory, cognitive flexibility and attentional inhibition have on PM. Also, the unique contribution of age was examined to see if the effects of the EF remain important predictors. None of the expected predictions were found. This shows that a variety of factors have to be considered when PM research is conducted. PM performance cannot be attributed to a couple of simple, independent factors. Establishing underlying processes and finding reasons for impaired functioning is a complex matter requiring to consider intertwined concepts, like EFs and cognitive reserve. So further research is required to provide more certainty on what can improve or worsen PM. For that purpose, first of all psychometric evaluations of the assessment methods should be compared both EFs and PM. With consistent testing of the same constructs, results are more interpretable and comparable so that differences in measures can more confidently be attributed to actual variations in cognitive functioning. Also, the multiphasic model should be applied to pinpoint which EF affects which phase in the PM process. Besides, incorporating both focal and non-focal PM cues within one sample should be considered for comparison. Furthermore it is suggested that cognitive reserve effects should be controlled for by examining and controlling for crucial factors. Ultimately, a sample size of at least 85 for the data-analysis used in the present study is advised.

All in all it can be concluded that there is not enough evidence yet to weigh the importance of EFs differently when determining which processes affect PM. If the suggestions are applied, maybe also the role of age might reveal itself more clearly and less erroneous as well. If the involvements of certain processes are established, not only the understanding of PM benefits but potentially also individuals and patients suffering from PM deficits. Obstacles in everyday life might then be diminished by making use of and enhancing alternative cognitive resources.

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