COMENIUS UNIVERSITY IN BRATISLAVA
FACULTY OF MATHEMATICS, PHYSICS AND INFROMATICS

INFLUENCE OF WORKING MEMORY LOAD AND TASK IMPORTANCE ON PROSPECTIVE MEMORY PERFORMANCE

Master’s thesis

2019

Bc. Marek Sokol

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Study Programme: Cognitive Science
Field of Study: 2503 Cognitive Science
Department: Department of Applied Informatics
Supervisor: PhDr. Ing. Tomáš Gál, PhD.

2019

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Univerzita Komenského v Bratislave
Fakulta matematiky, fyziky a informatiky

ZADANIE ZÁVEREČNEJ PRÁCE

Meno a priezvisko študenta:	Bc. Marek Sokol
Študijný program:	kognitívna veda (Jednoodborové štúdium, magisterský II. st., denná forma)
Študijný odbor:	kognitívna veda
Typ záverečnej práce:	diplomová
Jazyk záverečnej práce:	anglický
Sekundárny jazyk:	slovenský

Názov: Influence of working memory load and task importance on prospective memory performance
Vplyv zaťaženia pracovnej pamäte a dôležitosti úlohy na výkon prospektívnej pamäte

Anotácia: Mnoho aspektov každodenného života do veľkej miery závisí od výkonu prospektívnej pamäte. ovplyvňuje prospektívnu pamäť. Dotetajší výskum poukázal na dôležitosť dvoch faktorov, vyťaženia pracovnej pamäte a dôležitosť úlohy, ale nikdy sa nezameral na súhru medzi nimi. Diplomová práca by mala viesť k lepšiemu pochopeniu výkonu prospektívnej pamäte, možným zlepšeniam tohto výkonu u zdravej populácie a taktiež môže priniesť užitočný vhľad do tréningu prospektívnej pamäte pre ľudí s poškodenou pamäťou.

Cieľ: Preskúmajte vzťah medzi pracovnou pamäťou, dôležitosťou úlohy a prospektívnou pamäťou. Na základe teoretickej časti realizujte behaviorálny experiment zameraný na testovanie vplyvu pracovnej pamäte a dôležitosti úlohy na výkon prospektívnej pamäte.

Literatúra:
Uttl, B., White, C. A., Cnudde, K., & Grant, L. M. (2018). Prospective memory, retrospective memory, and individual differences in cognitive abilities, personality, and psychopathology. PLOS ONE, 13(3), e0193806. https://doi.org/10.1371/journal.pone.0193806
Walter, S., & Meier, B. (2014). How important is importance for prospective memory? A review. Frontiers in Psychology, 5. https://doi.org/10.3389/fpsyg.2014.00657

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Dátum zadania:	01.02.2019

Dátum schválenia: 02.02.2019

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THESIS ASSIGNMENT

Name and Surname:	Bc. Marek Sokol
Study programme:	Cognitive Science (Single degree study, master II. deg., full time form)
Field of Study:	Cognitive Science
Type of Thesis:	Diploma Thesis
Language of Thesis:	English
Secondary language:	Slovak

Title: Influence of working memory load and task importance on prospective memory performance

Annotation: Many aspects of everyday life largely depend on prospective memory performance. Recent research pointed out to importance of the two factors, working memory load and task importance, but did not focus on their interplay. The thesis should lead to better understanding of prospective memory performance, its possible improvements in healthy people and also might provide insight into prospective memory training for people with impaired memory.

Aim: Examine the relationship between working memory, task importance and prospective memory. Based on the theoretical part, conduct a behavioral experiment focused on testing the impact of working memory and task importance on the performance of prospective memory.

Literature:
Uttl, B., White, C. A., Cnudde, K., & Grant, L. M. (2018). Prospective memory, retrospective memory, and individual differences in cognitive abilities, personality, and psychopathology. *PLOS ONE*, *13*(3), e0193806. https://doi.org/10.1371/journal.pone.0193806
Walter, S., & Meier, B. (2014). How important is importance for prospective memory? A review. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.00657

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Approved: prof. Ing. Igor Farkaš, Dr.
Guarantor of Study Programme

Student

Supervisor

Declaration

I hereby declare that I elaborate this diploma thesis by myself, independently using the cited literature.

Bratislava, 2019

Acknowledgement

I would like to thank my supervisor PhDr. Ing. Tomáš Gál, PhD. for his helpful insights and guidance he gave me. I would also like to thank all the people that helped me with recruitment of participants and of course to all the people that were willing to help me with my research.

Abstract

Prospective memory is special type of memory, oriented into future intentions. This type of memory enable humans to function effectively within the environment. However, prospective memory is prone to errors and can fail under various circumstances. Theoretical part unfolded the nature and of prospective memory using knowledge from psychological experiments, neuroimaging studies, psychophysiological experiments and also computational modelling approach. Experimental part tried to explore the unknown influence of interplay between factors of working memory load and task importance on prospective memory performance. The performance measure was meant to reflect the naturalistic way of assessing prospective memory. Our sample (N = 55) was separated by working memory load and task importance manipulation with 2x2 design, resulting in total of 4 groups. At the beginning of experimental procedure, participants were told to remind experimenter of completing form of participation after the experiment, which was our real performance measure. Also task importance manipulation happened there, when experimenter put different emphasis on reminding of the form. Participants then performed working memory digit span task as a secondary task where working memory load manipulation was employed. After evaluation of our data, the results showed no significant difference in interplay of working memory load and task importance factors. However, we observed significance of importance manipulation factor alone, this was not a concern of our thesis. Nevertheless, we provided possible interpretation of our results and discussed possible gains from our thesis to prospective memory research.

Keywords: prospective memory, working memory load, task importance, event-based prospective memory

Abstrakt

Prospektívna pamäť je špeciálny typ pamäte, orientovaný na budúce zámery. Tento typ pamäte umožňuje ľuďom efektívne fungovať v prostredí. Prospektívna pamäť je však náchylná na chyby a za rôznych okolností môže zlyhať. Teoretická časť odhaľuje povahu prospektívnej pamäte využívajúc poznatky z psychologických experimentov, neuro-zobrazovacích štúdií, psychofyziologických experimentov a prístupom výpočtového modelovania. Experimentálna časť sa pokúsila odhaliť neznámy vplyv interakcie faktorov zaťaženia pracovnej pamäte a dôležitosti úlohy na výkon prospektívnej pamäte. Meranie výkonu v experimente malo odrážať prirodzený spôsob hodnotenia prospektívnej pamäte. Naša vzorka (N = 55) bola rozdelená podľa rôznej manipulácie pracovnej pamäte a dôležitosti úlohy s 2x2 dizajnom, výsledkom čoho boli celkom 4 skupiny. Na začiatku experimentálnej procedúry bolo účastníkom povedané, aby pripomenuli experimentátorovi vyplniť formulár participanta po experimente, čo bol náš skutočný meraný výkon. V tom mieste nastala aj manipulácia dôležitosti úlohy, keď experimentátor dal iný dôraz na pripomenutie formulára. Účastníci potom vykonali úlohu zameranú na pracovnú pamäť ako sekundárnu úlohu, kde bola použitá manipulácia s úrovňou vyťaženia pracovnej pamäte. Po vyhodnotení našich údajov výsledky nepreukázali žiadny signifikantný rozdiel v súhrne faktorov záťaže pracovnej pamäte a dôležitosti úlohy. Zaznamenali sme však signifikantný rozdiel vo faktore dôležitosti úlohy osamote, čo však nebolo predmetom našej práce. Každopádne, poskytujeme možnú interpretáciu našich výsledkov a prediskutovali sme možné prínosy z našej práce pre výskum perspektívnej pamäte.

Kľúčové slová: prospektívna pamäť, vyťaženie pracovnej pamäte, dôležitosť úlohy, prospektívna pamäť založená na udalosti

Contents

Introduction and brief history of Prospective memory research

In everyday life, people come across many manifestations of prospective memory (PM). Recycling, locking doors, taking medication, taking right exit while driving on highway and millions of other activities in our everyday lives, that are very essential for us, require prospective memory. PM is part of human memory, different from retrospective memory. Straightforward and simple definition could be “remember to recall”, so it is memory for our future intentions (Cohen & Hicks, 2017). This applies not only for information to be recalled, but also for actions of different complexity to be carried out. As a phenomenon, prospective memory embodies many sub-domains of different tasks such as planning or multitasking. What is more, PM as ability cooperates with many other cognitive functions, for example working memory, attention, executive functions, time perception, imagination etc. Prospective memory research started in the middle of last century, but only in form of questionnaires and natural experiments. Modern approach to PM, as author sees it, began in mid 80’s when Harris (1984) made review, in which re calls for reinstatement of this topic in scientific area. Of course he didn’t stated PM directly, there have already been some research on this topic, but name of this function was different. In early 90’s two authors, McDaniel and Einstein, took closer look at PM and started deep research into this area. They developed experimental paradigm in order to empirically test the PM dynamics. These two pioneers are still active and respected in this field. From existing PM research and real-life experience, we can derive several important claims, that emphasize the motivation why we are focusing on this topic in our thesis. One such claim can be, that without proper functioning of PM live as we know won’t exist. On the other hand, another claim about PM is, that PM often fail, and these fails are from minimum importance errors up to catastrophically important disasters. Last but not least, one claim is, that although PM is very similar process to retrospective memory and even some components are the same, they are different in their nature. All these claims provided motivation for our thesis and led our course of investigation in this topic, and we will challenge them later on.

Prospective memory essentials

In the first part of our thesis, we provide all the information needed for readers to understand what PM means and how scientists approach PM research. We will state PM definitions, categorization and main models of PM.

1.1 Definition of Prospective memory

As we mentioned before, PM can be summed up in phase “remember to remember”. However, scientific definition of PM is more elaborate than this. PM is specific type of memory, when individual has to perform intention in future, and has to remember at what specific occasion or time and what intention he meant to perform. PM is usually triggered by some environmental cues, but one important criterion is, that it is self-initiated (Einstein & McDaniel 1990). As this brief definition points out, retrospective and prospective memory are not separated and actually, they are the basic two components of prospective memory. Prospective component is active when the right cue or moment is encountered, and we should recall some information or perform some action. Retrospective component enables us to recall the specific information or action, as we intended (Cohen & Hicks, 2017). In other words, prospective component is “when” and retrospective component is “what”. This is very crucial for PM research, especially when investigating why PM task failed.

PM, as its definition indirectly unfolds, consists of different stages, where prospective and retrospective components are represented. Dismukes (2010) identify three stages of prospective memory:

Encoding - or formation of intention. On this level we form what to do and also where/when/after what we should carry out the intention. This stage may also contain how we carry out the intention, but this part is usually somehow implicit in the “what” part.

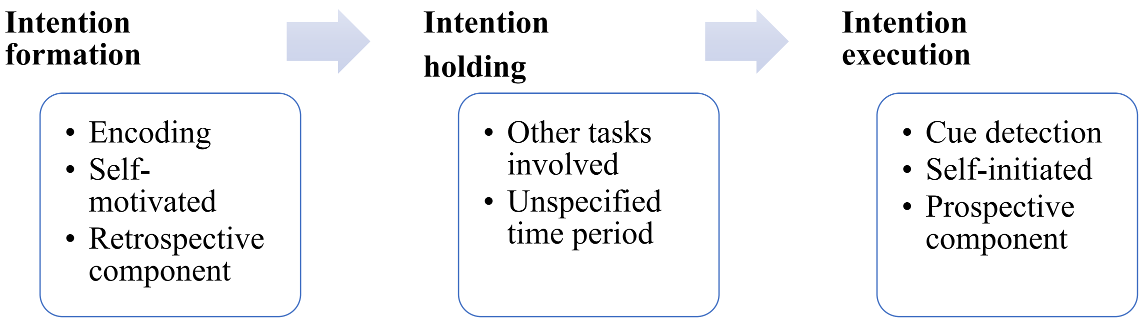
Retention - this part is of unspecific duration and usually contains one or more unrelated tasks, activities or thoughts. These ongoing tasks demands attention, working memory, executive functions and other cognitive resources, so person is not aware of prospective task at this stage.

Retrieval - recognition of specific cue that leads to carrying out intention formed in encoding phase. Intention is put back to conscious awareness.

All these phases contribute to prospective memory performance and they carry same names as stages of retrospective memory, but there are several differences. Among all, the actual identification of cue, or retrieval stage affect success of prospective tasks the most since the prospective component is present there.

As described above, PM process in practice can look like this example. Tom would like to recycle plastic bottles in his home. He will form intention like this – if my empty bottle is plastic, then I will put it to designated trash can (encoding). After some time (retention) he will eventually have a plastic bottle in his hand. After successful identification of cue (empty plastic bottle) Tom will put his bottle to the right bin (retrieval). This is example of PM phases and its successful execution that occur in real-life scenario, based on information provided above.

We created this simple flowchart of common steps in PM, in order to have definition summarized as a process:



This simple process is summarization of time steps in PM tasks. For the rest of the thesis we accept the definition of PM stated above, that it is memory oriented to the future, where individual has to form intention, hold it for a period of time and then retrieve it when specific cue appears. This process is always self-initiated and includes both prospective and retrospective component. This information is important, since we are using this definition also for our experiment. To move on, we will continue with categorization of PM and we will list all the different types of PM.

1.2 Prospective memory categorization

In everyday life, people come across many manifestations of prospective memory. All the manifestations look similar, but it is crucial to distinguish them. In a previous definition , we stated that the prospective component is triggered only by the cue itself. So prospective memory is very internal to agent, and any intervention from other agents avoids the prospective component, since we do not have to “remember to remember” and goes straight towards retrospective component (Dismukes, 2010). So the cue is very important for PM since the prospective component relies on detection of cues. Because of this, we can identify different types of prospective memory, based on cues for retrieval. Since the common mechanism for prospective memory holds in every type, the only distinction is cue. Basic types are time-based, event-based and action-based prospective memory (Walter & Meier, 2014). In time-based, time is a cue for intended action, e.g. taking medicine at 6 a.m. In event-based intention is carried out when certain event happens, e.g. leaving highway after desired exit sign. Action-based type can be seen as specific subset of event-based type, in action-based intention is performed after action, e.g. locking the doors after closing them. Usually in experimental practice, two types are mentioned, event-based and time-based, since action-based might be easy to confuse with event-based in experimental scenarios. We encounter all these types of PM in real-life, but some of them are more prone to errors. In general, we can say that, the more are cue and intention associated, the easier is retrieval with less errors (Dismukes, 2010). However, the categorization above does not explain much about this observation and we need different categorization for PM, which is based on automatic or effortful processing of cues.

One advanced classification is based on how cues help retrieval. Einstein et al. (2005) proposed cue categorization by level of relevancy or association to PM task, they distinguish two types, focal and non-focal PM cues. In experiments, focal cues encourage processing of features that are relevant to encoding and help the PM performance. Non-focal cues, on the other hand, are not relevant to encoding and do not ease the retrieval in general. According to authors (McDaniel, Umanath, Einstein, & Waldum, 2015) spontaneous retrieval increase with increased focal processing. This assumption was tested and there is empirical evidence, that for focal clues less or no monitoring is needed to retrieve intention. This distinction helped to develop Dual-pathways model of PM, which is easy, versatile and holds for majority of PM findings. This model is part of Dynamic multiprocess framework or simply Multiprocess framework, but we will cover this later on. Nevertheless, focal and non-focal categorization carry vast importance for PM research and will be contained in many experiments we will mention.

Another, less mentioned types of prospective memory are remembering to continue with previously stopped action and remembering when to switch between two concurrent tasks. They fit well to the definition of prospective memory, but are not specifically stated in research papers, although some authors argue (Loukopoulos, L. D., Dismukes, R. K., & Barshi, I., 2009) that these two types might be crucial in some specific professions (e.g. pilots) but also in specific tasks in daily living (e.g. cooking). Research often overlook these two types of PM, maybe because they are not that well established. Anyway, we will describe some research experience also with these types.

Distinctions we made above are important for understanding why people fail in prospective tasks and what is the best strategy to success. The success of PM is inevitably linked to cue detection. Hand in hand with cue detection comes intention formation, where we establish what is desired cues. Failures of PM are huge experimental agenda, since some authors argue, that PM errors are more prominent and also more critical in social environment (Penningroth et al., 2011; Dismukes, 2010; McDaniel, Umanath, Einstein, & Waldum, 2015). In the next part, we will discuss how the PM fails and what factors have contribution to successful or unsuccessful PM task.

1.3 Monitoring vs. spontaneous retrieval Prospective memory models

One big issue about PM is how the retrieval is supported by top-down and bottom-up processes. Research in general provides good evidence for top-down process of attentional control and maintaining of intention or active searching for cues in environment. Preparatory attentional and memory (PAM) process is model of PM monitoring by Smith (2003). Motivated by experimental finding Smith (2003) suggested, that given PM instructions, participants monitor their behavior towards PM stimuli and therefore lower their performance in concurrent task when compared with performance without PM parallel task. There is also evidence for performance decline even after participant complete intention, or cancel the intention during task (Marsh, Hicks, & Cook, 2006; West, McNerney, & Travers, 2007). For participants might be hard to disengage from PM task once it was emphasized by experimenter, also after completed or cancelled intention. Smith and Loft (2014) found another evidence for PAM, where participant had ON and OFF blocks with PM task and without and their results showed cost to ongoing task also during OFF blocks. Monitoring costs differ significantly among experiments (e.g., Cohen, 2013; Lourenço & Maylor, 2014; Marsh et al., 2006). This may depend on stimuli features and of course the whole context of experiment.

Constant monitoring of prospective cues can be nicely seen in experiments, where participants usually perform worse than the baseline when prospective component was added to experimental run. However, this constant monitoring is highly implausible for real world experience, where we have to maintain many prospective memory tasks during unspecified and sometimes very long time periods. PM depends on cognitive resources and other tasks we are engaged. Thus, it is evolutionary inefficient to lower our performance and keep track of one prospective memory act. If PM would rely only on monitoring and intentional retrieval, then people would either have serious problems to do concurrent tasks (driving, studying, working) while holding any intention or would be prone to forget every intention when engaged in concurrent tasks. This theory has support from huge amount of experimental data, but experiments are not usually design like real-life PM tasks. Some researchers tried to look at PM from other point of view and figured out so called Multiprocess theory, later called Dynamic Multiprocess framework.

Multiprocess theory suggest, that retrieval may also be spontaneous. Bottom-up or spontaneous retrieval occurs when intention is activated without monitoring (McDaniel, Umanath, Einstein, & Waldum, 2015). Thus, this kind of retrieval does not draw from the limited resource and performance of other tasks is not reduced. Such a formulation poses a challenge for experimenters, since experimental design usually differ from real world experience and many experimental paradigms directly encourage participants to monitor PM tasks. In short, experimental design for PM almost every time demands participants to be vigilant and maintain PM intentions. Scullin, McDaniel, Shelton, (2013) suggests that PM in everyday life might be interplay between strategic monitoring and spontaneous retrieval. Since retention may vary in duration, monitoring would be implausible solution for maintaining simple intention over long period of time. This interplay is enabled by focal/non-focal cues. At the beginning, it was meant for focal cues to have only spontaneous retrieval without monitoring. Most recent update of Multiprocess theory (Scullin et al., 2013) suggests, that monitoring and spontaneous retrieval can be recruited in same task, but at specific times. So the same task in different conditions may elicit monitoring or not. Exact criteria for monitoring are hard to define because of complexity of PM tasks, especially out of laboratory. But this framework was later completed by Dual-pathways model, which we cover in neuroscience part.

Performance of Prospective memory

In this chapter, we will provide results from various experiment in order to understand what factors may influence PM performance. First of all is important to understand why and how prospective memory can fail. Then, we will discuss several influential factors and finally importance of PM task among them.

2.1 Failure of Prospective memory

We can identify two basic types of errors in PM. Believe that someone already completed the intention, but the intention was not fulfilled at all is omission error. Second type of error is completely the opposite of first one, when someone believe that the intention was not fulfilled but it actually was (Cohen & Hicks, 2017). These two types of errors are more important for real life than laboratory. Imagine someone who cannot decide whether he should take his pills or not. If he commits omission error, he might suffer from not taking the medication. If he commits commission error, he could be in danger for excessive use of medicine.

Omission errors in experimental way can be seen as errors in monitoring of intention and commission errors may be understand as errors in monitoring of outcome (Marsh, Hicks, Hancock, & Munsayac, 2002). Based on this distinction, we can identify specific situations, where person can be more prone to omission or commission error. For example in routine situation omission error should be more pronounced and some new unexplored situation commission error may happen more easily. Scullin et al. (2013) suggest, that commission errors might be more likely when PM cues are salient and ongoing task and PM task have high overlap, for example in target features. Still, there may be difference between experimental and real-life errors and their causes. Anyway, we will cover many of possible contributing factors to PM performance and how these factors cause or prevent PM errors.

2.2 Personality traits, cognitive abilities and individual differences

Firs of all, for better understanding why and when can prospective memory fail, we may take a look at individual differences in prospective memory performance. There are several good predictors for retrospective memory such as intellectual or cognitive abilities, although they are not always reliable. In recent study consisting of almost 1200 participants, Uttl, White, Cnudde & Grant (2018) examined many variables, that may explain individual differences in prospective memory. They found that best predictors for prospective memory are processing speed, intelligence, working memory performance and also retrospective memory performance. They further examined personality traits and psychopathological factors and gender, but these factors demonstrated no predictive value for prospective memory performance. As we stated before, prospective memory has retrospective component, and share features with retrospective memory, in a light of this information retrospective memory as good predictor for prospective memory is a very intuitive finding. For the rest of cognitive abilities, intelligence have the best correlation with prospective memory performance, then comes working memory and processing speed with somehow lower correlation. But we would argue, that continuous assessment of prospective memory they used in their study is similar to some tasks in intelligence tests. All in all, cognitive abilities proved to be good predictors of prospective memory performance. Good working memory may facilitate processing of prospective memory encoding and retrieval (Uttl, White, Cnudde, & Grant, 2018). On the other hand, individual with better working memory may have better distribution of cognitive resources and therefore more may be spent on prospective tasks. Correlation of these specific cognitive abilities and prospective memory may have several causes and we are not certain what is the most plausible one. Also, personality traits may be more influential in real life or more natural setting, where these factors may interfere with PM task. Personality traits could play role in natural setting, but cognitive factors seem to be superior predictor of prospective memory after all.

2.3 Role of context

Researchers (Godden & Baddeley, 1975) showed how important is the role of context in retrospective memory, people were more successful in memory task recall when the context was the same, or similar, as during learning phase. Prospective memory is also strongly bound to contextual information. When performing prospective memory task, we usually move thought different spaces and contextually different situations, depending on the nature of the task. Moving from one room to another may mean different contextual information and we can easily forget what we intended to bring from bedroom to kitchen. In experimental setting, context is used to either enhance or mitigate PM performance. Context can also ease the allocation of attention resources and reduce costs to the ongoing parallel task (Smith, Hunt, & Murray, 2017) . Context supporting setting have usually positive effect on prospective memory and also concurrent task, depending on experimental setting and also type of PM task. One plausible explanation for this effect is, that context provides predictive information for the upcoming stimuli. In other words, the attention allocation cost in predictable environment is not constant and may vary, based on context predictability (Smith, Hunt, & Murray, 2017). This is valuable information for real-life setting, we can form intentions in the way, that the context will support them. Also, this can be used in complex experiments, where participants move through different spaces. The performance measure in such experiments should be prepared in the way to cope with context influence on PM. Moving through different context is also one possible reason why is so hard to make continuous experimental measures of PM, it is very difficult to cover all effects of all different contexts.

2.4 Interruptions and Prospective memory

Interruptions play huge role in PM failures. There are certain reasons why interruptions pose such threat for PM. Interruptions draw attention away from target, so at encoding of intention and plan forming interruptions may cause incomplete intentions. New task after interruption may be not properly evaluated, especially the cues. And of course people often forget what they were doing when they had been interrupted (Dodhia & Dismukes, 2009). Interruption may of course prolong the retention phase and during retrieval, they may disrupt attention as mentioned above. Interruptions are very attractive for research of PM, especially for continuous real-life experiments. We can argue, that interruptions are very frequent in real-world and they are namely one of the causes behind huge difference between experimental and real-life PM.

2.5 Dual-task vs. task-switching

In experimental practice, PM tasks can be twofold- one type demand participant to switch from one task to PM task, the other is preforming PM task in parallel with concurrent task (Bisiacchi, Schiff, Ciccola, & Kliegel, 2009) . Examples of this Dual-task and Task-switching paradigms can be linked to event and time-based PM tasks in real world. Time-based can be more dual-task related, for example to call a friend at 1. pm. Event-based PM is more of task-switching nature. This somehow comes from the definition of event-based PM, example from practice can be stopping on red light with car, you have to release the gas pedal and step on brakes. Of course time and event-based PM can be both and the dynamics described above are just suggestions to think. More important finding by Bisiacchi, Schiff, Ciccola, & Kliegel (2009) is, that there might be difference in performance for dual-task and task-switching conditions. Behavioral data from their experiment suggests, that task-switching can be harder to perform, because involved tasks are usually in opposition and task-switching explicitly needs participants to interrupt ongoing activity. As we discussed, interruptions can cause many troubles in PM, ether in PM task or other ongoing task. Many experiments didn’t take this to account and this finding can explain some of the contradictory findings. And if we combine focal/non-focal cues with dual-task and task-switching PM we can explain huge spectrum of PM fails.

2.6 Importance manipulation and Prospective memory

Importance of PM task, or the motivation added to the task is in the focus of our study and also one major contributor to PM performance. Therefore, proper investigation of previous findings is necessary for setting our research goals and hypothesis. Usually, we have multiple prospective memory tasks running at one time. Prioritization can help us remember the most important tasks. On the other hand, we often forget to do tasks with low importance. Going to the store for milk is less important than reservation of hall for wedding. Still, we can forget both of these tasks, but forgetting to buy milk is more possible and also rated less seriously as a fail.

We will take a look on how importance is important in prospective memory tasks. Several ways of adding importance to prospective memory task have been used in experimental setting, summarized by Walter & Meier (2014):

- Providing reward
- Relative importance manipulation
- Absolute importance manipulation
- Social importance (special part of absolute importance manipulation)

Providing reward means usually monetary reward or attractive goods, either after successful prospective memory task or as a part of a task itself, showed contradictory results in previous experiments (Walter & Meier, 2014). Rewards may vary in subjective value and previous studies showed only some effect of reward vs. no reward and didn't compared specific types of rewards. What is important, in naturalistic experiments monetary reward led to better performance because of better strategies or reminders participants used, compared to no reward. Relative importance means to stress out the importance of prospective memory task against the other concurrent task, this type of manipulation works only in parallel task paradigms and have drawbacks in the sense of costs in concurrent tasks (Walter & Meier, 2014). Absolute importance is emphasizing of prospective memory task, as there is no comparison needed, this works with all paradigms of prospective memory experiments (Walter & Meier, 2014). Although, this manipulation may have its benefits, it's not used often in prospective memory experiments.

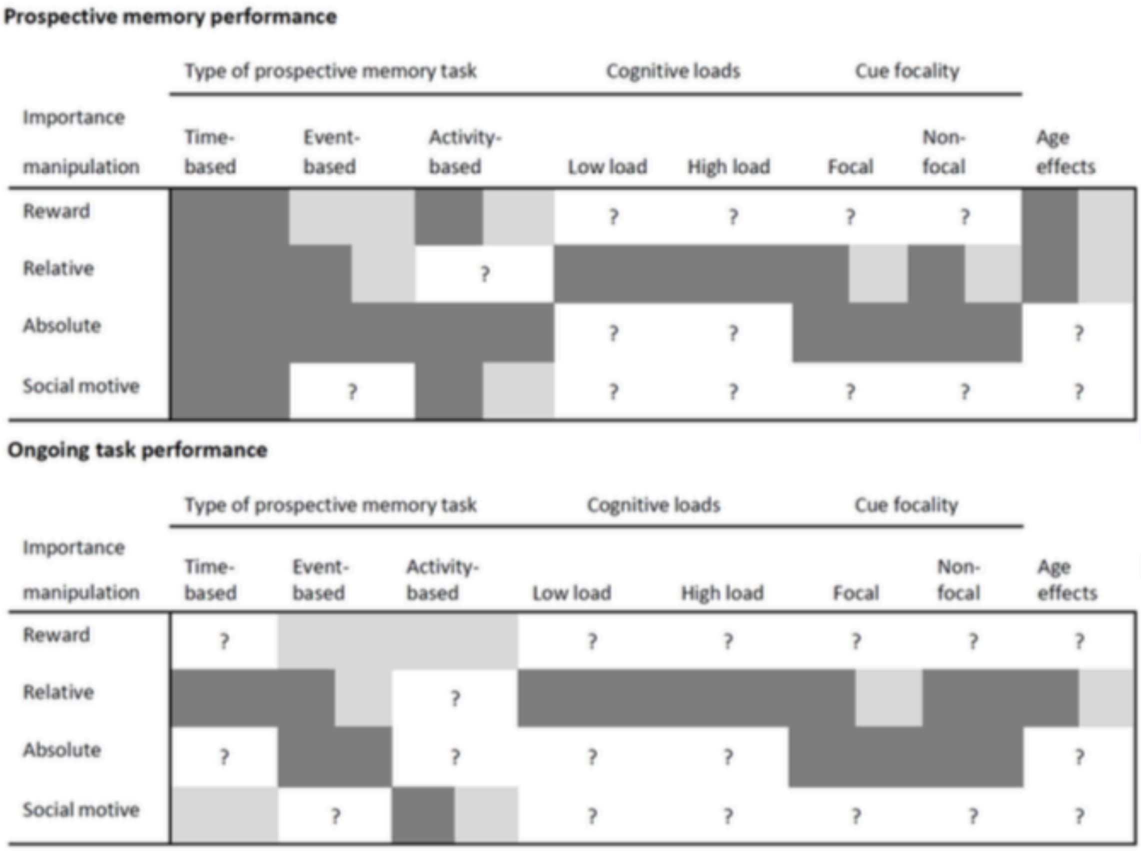


Figure 1. Prospective memory performance based on importance manipulation. Dark gray is where importance actually enhance performance, light gray shows no changes and question marks symbolize unknown effects (from Walter & Meier, 2014).

Social importance is used in our experiment. Many previous studies point out, that in real life and also experimental setting, social motives are strong motivators and can enhance performance of various tasks (Walter & Meier, 2014). Prioritization of socially important tasks provide some evolutionary advantage, for example ten thousand years ago, when people humans lived in tribes and every minute of their lives depended on each other. Prosocial behavior is seen as more automatic, compared to incentive-based behavior, which is thought to start top-down control (Bargh, Chen, & Burrows, 1996; Small et al. 2005). This might be plausible interpretation for social importance enhancement of PM. But if this is true, the social importance should enhance only focal cues, which was never been tested directly before. This is where our thesis may provide some preliminary data. However, it is not in our focus to support this assumption. We chose to work with social importance manipulation because there has never been direct interplay with this manipulation and working memory load manipulation. Real-life prospective memory scenarios include social context in majority of time. In this view, failures of retrospective memory are perceived less negative that prospective memory failures. Base on this, Penningroth, Scott, & Freuen (2011) explored that social PM tasks are more likely to be remembered, because they are rated as more important than non-social tasks.

D'Angelo, Bosco, Bianco, & Brandimonte (2012) examined how social collaboration influence PM. They surprisingly found out, that participants performed worse when collaborating, both on PM and ongoing task. This might be due to some "shared responsibility" and that participants rely on others too much. However, if the intention was carrying social motive, it somehow helped participants to perform better in both tasks.

Walter and Meier (2014) suggested, that extrinsic motivation increase strategic monitoring and intrinsic motivation leads to more spontaneous retrieval. There are many knowledge gaps in the figure 1, but we found working memory load and importance manipulation combination the most interesting, because of possibility to utilize our results in real-life setting. Also, actual research is using PM tasks with for example lexical decisions, where is hard to naturally induce social importance. Therefore, our methodology is trying to address social importance issue from more naturalistic and ecologically valid point of view.

2.7 Effect of emotions, alcohol, other stimulants on Prospective memory

Klieger et al.(2005) revealed, that sad mood had some effect on PM performance. Although, the effect was strong only right after they primed participants. Possible interpretation of PM decrease is, that sad participants reduced monitoring over their task, and it is worth more investigation. For example how mood intervene with focal/non-focal cues, importance manipulation and so on. Another interesting research can be how mood affects different phases of PM, retention phase for example can be completely unaffected, but we can imagine that encoding and retrieval can be crucially disrupted by mood. It is also important to mention, that mood in general affects many aspects of cognition and human life. We are often not certain about all the factors influencing some cognitive phenomena and mood is often one of the factors working at the background of almost every task, especially when it comes to extremes.

Acute alcohol intoxication may cause several impairments in various cognitive functions such as memory and executive functions. So we also can expect it will have impact on PM. As we mentioned, PM failures are quite prominent in daily living . Thus, PM failures can also be very important for rehabilitation of clinical patients (e.g. alcoholics). Experience shows, that the errors in PM for alcoholics can be twofold, forgetting that something should be done and forgetting the content of intention so both prospective and retrospective component are affected. In controlled experiment, Leitz, Morgan, Bisby, Rendell, & Curran (2009) showed how alcohol intake in normal population influence PM remembering. They used computerized version of game Virtual week, which allows for assessment of 4 different task types of PM, those are event-based, time-based, regular and irregular tasks. Virtual week game is used as assessment test for PM and also as training for elderly people or people with impaired PM. It is useful tool because of its ecological validity. Authors of the study found significant decrement of PM performance in experimental vs. control group across all types of tasks. The amount of administered alcohol was 5 units (1 unit is about 10 ml of pure alcohol), and it had no effect on executive functions. Participants also tried future episodic simulation (as a form of implementation intention which we cover in later part), but that strategy was inefficient in experimental group.

In a study by Hutten et al. (2018), single dose of cocaine enhanced PM performance, in comparison with cannabis and placebo. There was very low correlation between attention, arousal an PM, which is something contra-intuitive. Attention to the cue in retrieval part is directly connected to PM success, however their results shouldn't be generalized, since the whole group was one third stimulated by cocaine and one third inhibited by cannabis. Anyway, these are quite recent findings and PM and attention correlation may be explored in near future. Our opinion is, that there might be correlation between PM and attention, or arousal, but it may depend on focal/non-focal targets.

Neuroscience and psychophysiology of Prospective memory

In this part, we will present findings from various neuroimaging and psychophysiological studies. We will start with two main models of brain PM activation, mostly based on functional Magnetic Resonance Imagining (fMRI) and enrich the knowledge from psychophysiological studies.

3.1 Attention to delayed attention model

This model was first contribution to PM research in terms of categorizing activation of different brain regions into PM phases by authors Cona, Scarpazza, Sartori, Moscovitch, & Bisiacchi (2015). This model was later criticized and marked as not precise, nevertheless we find it worth mentioning, since this model might be useful to sum up various information from PM brain research and also provides clear overview of how PM is distributed over brain areas. We will briefly describe how PM phases activate brain areas by using figures taken directly from the authors of this model. We decided to use these figures for two main reasons, they cluster brain areas with corresponding phase of PM and they also point out the path, or how the intention or cue is distributed over time.

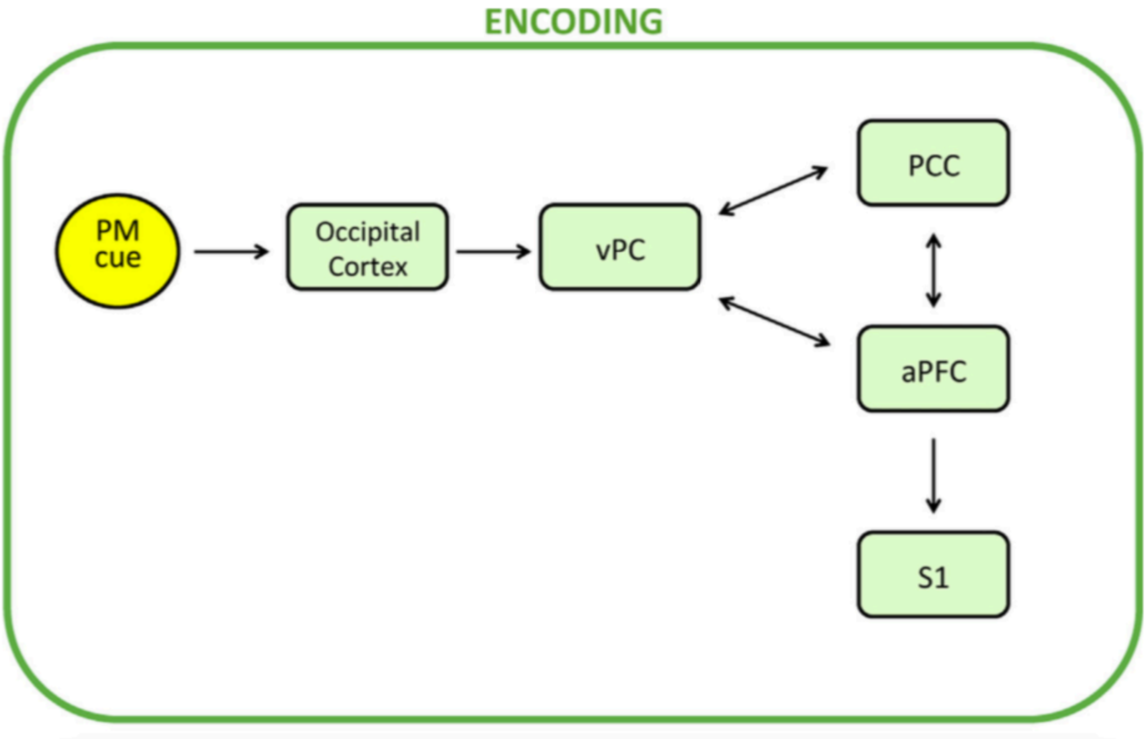


Figure 2. Encoding phase of PM and its related brain areas. Abbreviations: vPC- ventral parietal cortex, PCC- posterior cingulate cortex, aPFC- anterior prefrontal cortex, S1- primary somatosensory area (from Cona et al., 2015)

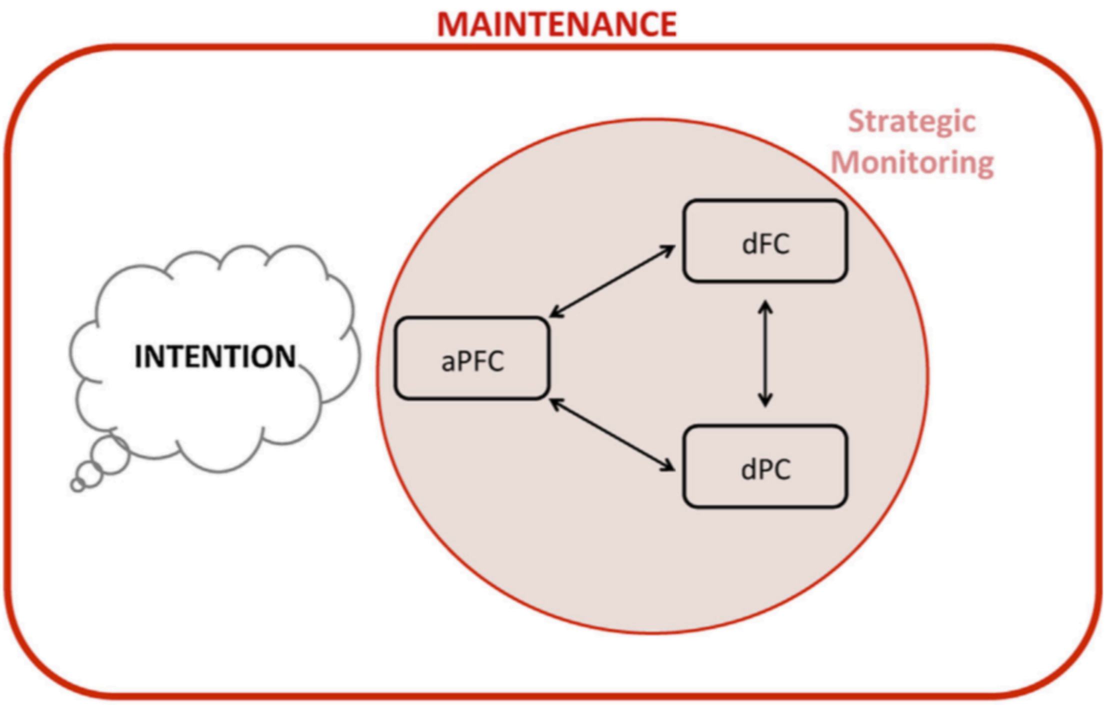


Figure 3. Maintenance phase of PM and its related brain areas. Abbreviations: aPFC- anterior prefrontal cortex, dPC- dorsal parietal cortex, dFC- dorsal frontal cortex (from Cona et al., 2015)

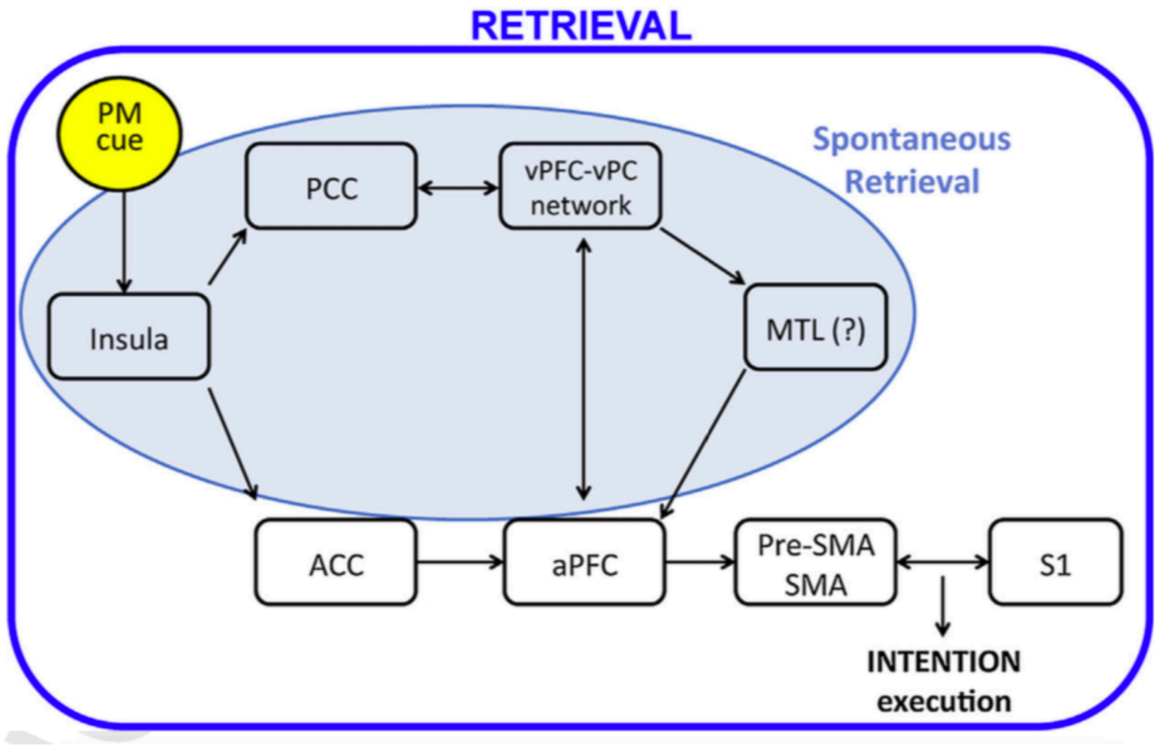


Figure 4. Retrieval phase of PM and its related brain areas. Abbreviations: vPC- ventral parietal cortex, PCC- posterior cingulate cortex, aPFC- anterior prefrontal cortex, vPFC- ventral prefrontal cortex, ACC- anterior cingulate cortex, MTL- medial temporal lobe (present but not sufficiently explained), Pre-SMA/SMA- pre/supplementary motor area, S1- primary somatosensory area, (from Cona et al., 2015)

As we can see in the figures, Cona et al.(2015) emphasized not only how the PM is processed in frontal area of brain, but also how is that part connected with other parts and what is the possible flow of the information. Cona et al. (2015) combined something unusual in figures for maintenance and retrieval. In maintenance, they specified only strategic monitoring and in retrieval they focused only on spontaneous retrieval. This is where the model starts to get mixed up and its explanation power is significantly decreased. To complete knowledge gaps for PM brain areas, we will present different model from authors that criticize this model.

3.2 Dual-pathways model

Authors McDaniel, Umanath, Einstein, & Waldum (2015) came out with interesting ideas about PM neural correlates, based on previous studies, criticizing previous model Attention to delayed attention. Model by Cona et al. (2015) emphasized active maintenance during retention part and retrieval process in more bottom-up fashion. These two parts of the model are quite contradictory to behavioral research about focal and non-focal cues, and the model oversimplifies PM process (McDaniel et al., 2015). Dual-pathways model describes PM differently. First, we will mention what areas are involved in PM. Now, the encoding phase is out of focus, because previous model got flaws mostly in maintenance and retrieval phases.

For the active maintenance of intention, several areas exhibit sustained activity. Many areas of sustained activity may also represent activation of attentional processes, this can be caused by paradigm used in the various experiments, where usually PM task resembles multitasking. Another problem might be, that PM itself is complex process and it is only natural that it involves activation of many brain areas. Therefore isolated area that represents sustained monitoring activity of PM is hard to identify. Now, we will focus on transient activity, the distinction based on transient and sustained activity motivated authors to create Dual-pathways model.

Transient activity in brain is demonstrated in retrieval part of PM. This transient activity may be better in representing the areas of brain involved in PM, namely because there are recognizable patterns for PM cues than for all other cues. However, research point out that there are different regions active for focal and non-focal PM. This is somehow in line with Dual-task model of PM. For better overview of all these areas, I will provide figure summarizing activation areas during PM phases based on focal/non-focal cues.

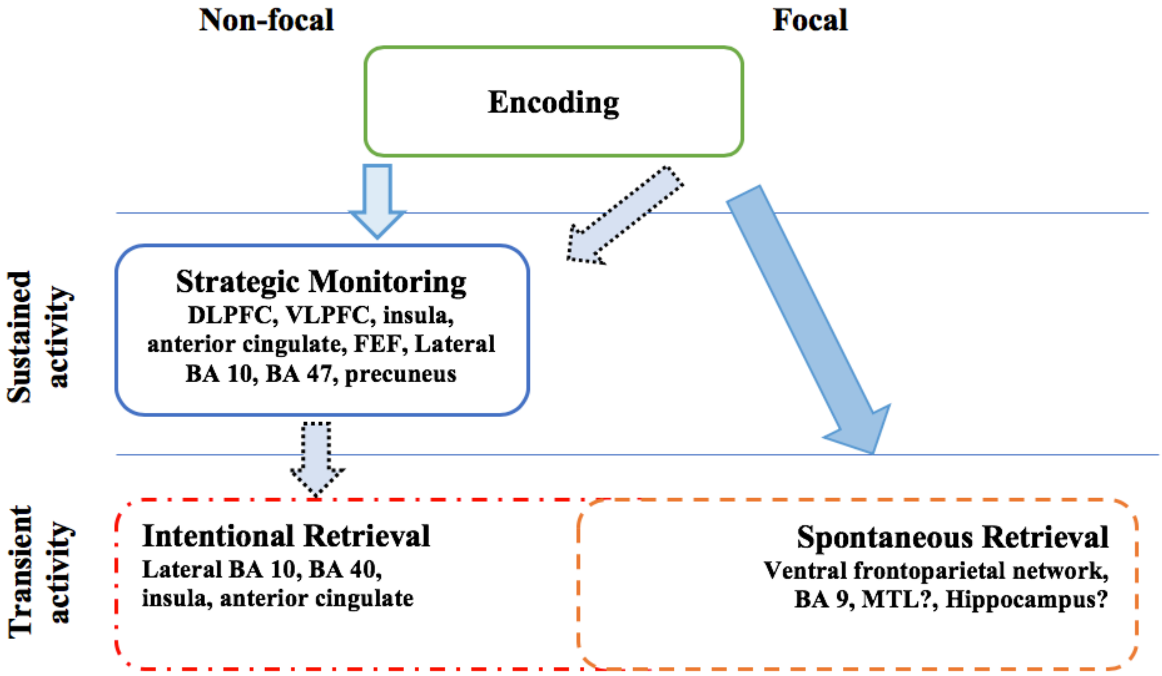


Figure 5. Representation of brain areas of sustained and transient activity based on focal/non-focal cues distinction. Abbreviations: DLPFC- dorso-lateral prefrontal cortex, VLPFC- vetro-lateral prefrontal cortex, FEF- frontal eye fields, BA- Broadman area, MTL- medial temporal lobe (adapted from McDaniel et al., 2015).

Line framed arrows suggest the default way of processing for focal/non-focal cues. On the other hand, dotted framed arrows suggest another possibility, that also focal cues may recruit strategic monitoring and intentional retrieval. These improvements are based on both, neuro-imagining and behavioral data, and help the model to be more flexible than Attention to delayed attention model. Thanks to its flexibility, it has outstanding explanation power for many research data and also real-life PM performance. Namely because of the possibility to include strategic monitoring for focal cues.

Areas that correspond to PM are quite similar to previous Attention to delayed attention model, whereas the pathways are different. Here, the MTL or more specifically hippocampus is also part of the model and are also better explained. Possible interpretation of hippocampus role in PM comes from one research focused on structure of brain and PM correlates. They found out positive correlation with gray matter volume in medial temporal brain area, especially pronounced in hippocampal area, with focal PM tasks (Gordon, Shelton, Bugg, McDaniel, & Head, 2011). Hippocampus is usually associated with spatial and episodic memories (Head, Rodrigue, Kennedy, & Raz, 2008; Erickson et al 2009) . So it seems natural, that gray matter volume in hippocampal area is linked with better PM for cues enabling spontaneous retrieval. Nevertheless, hippocampus might be important link between retrospective and prospective memory (Gordon et al., 2011). Lateral rostral prefrontal cortex (rPFC) exhibits greater activity during trial when people have PM intention, and medial rPFC is relatively less active. Based on dissociation of lateral and medial PFC, Broadman area 10 seems to coordinate stimulus dependent and independent parts (Burges, Dumontheil, Gilbert, 2007). Evidence from these experiments supports authors previous research about dissociable paths for PM in brain. McDaniel, LaMontagne, Beck, Scullin, and Braver (2013) investigated 2 distinct patterns of activation in anterior prefrontal cortex. This brain area is in general strongly associated with monitoring and active top-down control. In fMRI study, authors found transient and sustained activation of this area. This is in support of their hypothesis, that PM might use both spontaneous retrieval and monitoring. Because transient activity in aPFC points to lower or no top-down control of PM. Dual-pathways model is direct part or addition to Dynamic multiprocess framework, which explains PM performance in experiments and also in real-life.

One main implication of this Dual-pathways model is for PM and ageing. There is, or better there was a general consensus, that ageing disrupts PM performance. Based on new findings (Mullet et al., 2013) ageing disrupts only PM with non-focal cues, or PM where active monitoring is needed. This seems to be very natural, with ageing come decline of most cognitive abilities, especially when they simultaneously draw from same resource. PM with focal cues seems to be less impaired by ageing. Therefore the retention part is crucial for elderly people in PM. PM performance and ageing is crucial example where PAM model of PM does not hold.

3.3 Neural correlates of cognitive load

In our experiment, we are manipulating working memory (WM) cognitive load. WM enables humans to utilize and manipulate some sort of information, visual, auditory or abstract. It is important to state that WM, like PM, is very complex cognitive phenomenon and involves many brain areas. WM is usually associated with DLFPC, but as Rottschy et al. (2012) stated this area may serve many other higher cognitive functions. As we are working with cognitive load, activation by such tasks are most prominent in caudal area of

DLPFC, but still the activation may vary based on load used in the studies examining this activation (Rottschy et al., 2012). The active brain areas for WM and PM are both located in frontal cortex, since both are higher cognitive functions, and they share also the process stages (encoding, retention, retrieval). However, during retention in WM, the information can be actively manipulated by the set of rules, which puts more resources into this part. This is the actual WM cognitive load we are invoking in our experiment. We are trying to load maximum capacity in both groups, since it disables the option for participants to effectively monitor PM task, but we make it even more difficult for one group with adding more rules.

We tried to compare WM and PM corresponding brain areas or at least point out, that both of these cognitive processes are mainly happening in frontal and prefrontal part of a brain. As we stated above, that is where the top-down monitoring happens in the brain, and if we load WM, there might be less monitoring over intention of PM. These are just assumptions, because there never was direst study about WM load modulation of PM in brain, but based on behavioral results, this may be the mechanism behind PM performance decrease under high WM conditions.

3.4 Psychophysiology and Prospective memory

Now, we will focus more on arousal and psychophysiological changes during PM tasks. There is general consensus, that significant stimuli elicit Skin conductance response (SCR- change in skin conductance). Kliegel, Guynn, & Zimmer (2007) had hypothesis, that SCR for PM cues should be higher and PM misses should be similar as rejected concurrent task cues, if primary cause of forgetting PM in failure of noticing a cue. They conducted experiment in which they provide evidence for their theory. However, they used many PM cues. This may not hold for real life, where we have usually only one PM cue. To be more ecologically valid, Rothen & Meier (2014) conducted similar experiment with only one PM cue. They used aversive stimuli for comparison with PM stimuli, because aversive stimuli are well known to elicit more reliable SCR. They also tested cues specificity. According to previous line of research (Marsh, Hicks, Cook, Hansen, & Pallos, 2003; Meier, von Wartburg, Matter, Rothen, & Reber, 2011), the more is intention specified, the better the PM performance is. Authors conducted 2 experiment co verify these assumptions. They found PM to elicit similar SCR as aversive stimuli and this SCR is connected only to one PM cue, so it is likely for real life PM cue to elicit same response. PM misses showed substantially lower activation than hits, but still somehow higher SCR responses than baseline. What is more, their behavioral findings showed better PM performance with specific intentions, compared to categorical intentions. On SCR level, this have no effect on data. This may support theory, that PM retrieval may rely on different strategies (spontaneous vs. intentional) and not only physiological activation. What is interesting, that research found evidence for more negativity in ERP N300 (elicited for congruent/incongruent stimuli) component when people see PM cue than ongoing task cue (West & Wymbs, 2004). So there is different activity in brain, but not in physiological arousal.

Computational modelling approach to Prospective memory

In this part, we present very unique computational modelling study, that utilized real-world data and inspired us to take a different look on how can PM research be conducted. We see this part important also because the study links PM and habit formation.

4.1 Recycling campaign and Prospective memory

One important and often overlooked variable considering PM performance is strength of the habits for some intended behavior. Strong habit is hardly to occur in experimental setting, where participants usually spend hour or two. In real-life, many PM tasks have form of habits and are driven by similar rules as habits.

Reminders or cues for prospective memory have their own dynamics – they are dependent on location and time. In real-world setting, cues for specific PM tasks are presented in various time series or occasions and the salience decrease over time. Same holds for the location, reminders are contextually based. One more assumption is, that the forgetting curve is approximately the same for retrospective memory and intentions (Tobias, 2009). These assumptions are crucial for research of PM. There is very unique computational modelling study by Tobias (2009), which works with real-life data from plastic recycling campaign. If we consider the data itself, it is very different from paradigms used in PM research. In research we either have continuous measures resembling multitasking and lasting no longer than one hour, or we have single measures in longer time span. This study utilizes continuous long-time measures to explain and predict PM behavior. Tobias (2009) draw 10 key principles from the data, which he later used in his PM modelling study. These are just abstract variables for purpose of authors research but are definitely worth mentioning. They have nice explanation power for real-life PM. These principles are:

- Determinants of behavior execution (possible, remembered, high preference)
- Determinants of behavior preference (norms, affective influences, needs)
- Determinants of remembering a behavior (time, resources, context)
- Forgetting
- Reminding by events

- Reminding by behavior execution (frequency)
- Reminding by situational cues (memory aids)
- Habit decay
- Habit gain (association)
- Habit gain for not executed actions (habit transfer)

There is roughly half of these parameters used in other PM research or each parameter is examined separately. For example, if we consider forgetting or habit decay, these two factors are observable only in long lasting experiments or real-life. So beside experimental result from this experiment, we have strong claims against typical paradigm used in PM research, because if we consider habit formation and decay, some non-focal cues can be automatized for some period of time. So someone would need less resources for originally non-focal cue. When habit can spare some resources and therefore compensate the difference between focal/non-focal cues in terms of processing, there is huge space for new research in terms of habit and PM interplay. However, the effect of habit formation may be two-fold, routine habitual actions are more prone to errors in monitoring and therefore more vulnerable to omission errors (Einstein et al., 1998).

Back to the actual study, authors draw several implications for PM from their modelling results. The increase (or decrease) of accessibility of intentions seems to play major role in PM performance. In also showed, that intentions decay in the same manner as retrospective memory. However, intentions can be more easily retrieved, depending on accessibility. PM research often do not take into account accessibility of intentions, but it is one important factor that should not be neglected.

Model confirms, that habits reduce need for resources and therefore ease the recall of intention. All the information is derived from equations used in modelling, but we would like to again emphasize its value for real-life PM research.

One important information that empirical research overlook is, that intentions are performed in very different situations and it is not possible to cover all the situations in laboratory. We mentioned this problem and how it is covered in PM and context chapter. In this point of view is also important to conduct longitudinal or at least long-lasting experiments, since we know, that reminder strength decrease over time and classical experimental setting is not sufficient to include this effect. This is where habits come in play. In real-life, habits might be the right compensatory mechanism for reminders strength decrease. It is pity, that this was one of a kind study and eventually performed long time ago and no other researchers follow this path.

According to Tobias (2009) commitment, as demonstration of importance, increases reminding of cues. This is strong claim and it might be interesting to see how the two factors such as very high importance and very subtle cues. This is particularly interesting for our experiment. We are using importance manipulation against high cognitive load, which draws attention away from cues. In a sense, we will somehow try to answer this question.

This computational modelling study is very unique in the data the author is using. The performance measure is very simple yet carries a lot of information. From our point of view, this study poses very important methodological challenges that we already mentioned for PM research. Many authors are using PM tasks that resembles multitasking or are based on lexical decisions that may be uncommon in real-life (e.g. Smith, Hunt, & Murray, 2017; Hutten et al., 2018). In the prospective memory performance section, we discussed how experimental design can influence PM performance, namely dual-task and task switching (Bisiacchi, Schiff, Ciccola, & Kliegel, 2009). If such difference is important for PM performance, then also approximation of PM tasks in laboratory to PM tasks in real-life has to be of vast importance for PM performance. This computational modelling study shows, how reminders works for PM in real-life and we would like our study to have performance measure with similar ecological validity.

How to improve Prospective memory performance

Here, we suggest strategies for possible improvement of PM. We list what is important to keep in mind when improving our PM performance, what research say about improving PM and finally what exactly do to increase the potential of PM performance.

5.1 Possibilities of Prospective memory improvement

In order to avoid performing the same intention twice, one must keep track of "to-do list" and scratch out already completed actions. On the other hand, one must also have active intention in mind, until it has been carried out, in order to avoid forgetting of intended action.

Here we take a look on how omission and commission errors affect real-life cases and strategies for overcoming omission and commission errors. For example, Scullin, McDaniel, & Shelton (2013) showed, that elderly people with hypertension were more prone to omission errors, when having non-focal compared to focal cues. To handle this, we can transform our cues from time-based to event-based types, perform the action immediately after we think of it to prevent interruptions and imagine the detailed performance of intention. Insel, Einstein, Morrow, Koerner, and Hepworth (2016) used intervention training for elderly people based on these rules and they found improvements for medication adherence, especially for participants with lower executive functions and working memory.

In aviation, many disasters are caused by PM failure, usually by pilots or air traffic controllers, when they believe they already performed action, but they didn't (Dismukles, 2010). This points out that PM errors can happen also to very skilled professionals with many years of experience. One possible explanation is, that series of actions become routine over time and yet more accessible for errors.

Interruptions pose big threat for PM in real life, since more interruptions may happen in longer time span than in laboratory. Dodhia and Dismukes (2009) suggest easy steps for overcoming drawbacks of interruptions. Useful advice is to stop at the beginning of interruption in order to form plan to continue with original task after interruption. Another possibility is to create extremely salient cues, that are easy to be encountered after interruption. Also in order to avoid commission errors caused by interruption, one also can at the beginning of interruption recap what actions he already finished.

It is hard to state one technique for general improvement of PM, although there have been some attempts to do so. For example, implementation intention is technique used for PM improvement in real-world, the term was coined by Gollwitzer (1999). This technique is simply formulation of intention in IF- THEN way. One example can be If I drink form plastic bottle, I will throw it to plastic recycle bin. One possibility how implementation intention can enhance PM performance is, that it actually enables us to automatize the intended action. What is interesting, study by McDaniel and Scullin (2010) implementation intentions enhanced PM, but it does not support automatization of PM. This was showed in high-demanding condition, where implementation intention caused worse performance than behavior practicing. So implementation intention may be not the best way to create automatic process compared to behavioral practice. This information only points out how thin is the line between habit formation pros and cons and that one improvement technique can help for one type of task and actually cause troubles in other. So far, we are not aware of some kind of improvement, that would have only positive result in all cases. Our advice for reader who wants to improve PM performance is, that creating strong and vivid intentions, cutting maintenance phase to minimum and some kind of practicing combined with implementation intention might help. Nowadays we have opportunity to utilize for example some mobile applications, that are design in the way to help PM performance.

Practical part

In practical part, we provide detailed description of our experimental design, hypotheses, research sample, procedure and results. At the end of practical part, we discuss our results and also list some possible limitations of our experiment.

6.1 Motivation for our experimental design

We derived our experiment based on knowledge we presented in theoretical part. As we mentioned in previous part of our thesis, state of the art research is now mostly focused on PM dynamics in laboratory. PM tasks are often designed in the way that they resemble multitasking. However, PM seems to be of different nature in real-life, it took longer time for cue to emerge, often PM is either success or failure, nothing in between and is in form of simple intention rather than complex rules. Typical example of PM task in real-life can be, when someone send regards through third person to someone. For the person who is messenger it means to form an intention of passing the regards, holding the intention for some time and finally give regards to the right person. If we take a closer look at the intention, it might look like this: “If I meet person B I will send regards from person A”. Maintenance period in this case can last from seconds to months or even years, but it is hard to say what is the limit of holding such intention. Cue for successful retrieval is in this case only encounter of person B, or let’s say a small conversation with person B. Since the intention is directly linked with cue, the prospective task might be seen as focal. Intention execution depends only on the person who has the intention and it is either executed or not. PM task as we just described it is slightly different from classic PM paradigm in experiments and for sake of ecological validity we stick to this example when designing our performance measure. We chose this example also because social importance and working memory load effects can be there clearly demonstrated here. If the intention is emphasized by very high social importance, the messenger would probably remember to send the regards. On the other hand, if the messenger is meantime engaged in some cognitive demanding activity, he may lose the track of his previous intention and fail in PM task. Of course there might be many more influential factors for this kind of task, but we used it only as an example why we tried to approximate our PM task to real-world PM tasks.

6.2 Participants and design

Our sample consisted of 55 people (28 male (M), 27 female (F) subjects) with mean age 23,33, ranging from 20 to 30 years. There were both students and non-students. Since our experiment takes into account social importance, our very close friend and family were excluded from the recruitment process. Recruitment process itself was designed to engage our participant to seek for another participants, like snowball sampling. We provided no reward for participation, but we offered reward for anyone who successfully recruited participants for us. We have 4 groups since our experiment has 2x2 design, where first manipulation was working memory load, either high or low and second manipulation was social importance of PM task, either high or no social importance. Participants were assigned randomly to the 4 groups at the beginning, but after half of the participants were tested, we moved to semi-random assigning procedure in order to have more balanced groups by age and sex. Ratio of participants among groups was as follows:

- high WM load and high importance, N= 13, (5 M, 8 F), age average 23,15
- high WM load and low importance, N= 14, (8 M, 6 F), age average 23,86
- low WM load and low importance, N= 14, (9 M, 5 F), age average 23,5
- low WM load and high importance, N= 14, (6 M, 8 F), age average 22,79

All the participants were naïve to the paradigm and showed no suspicion towards our experimental procedure and measures. All subjects declared to be physically and mentally healthy and took no psychoactive substances or alcohol at the day of testing or day before. We obtained written consents from all participants.

6.3 Research questions and hypotheses

We design our experiment in the way to describe and fit our research questions and hypothesis. We would like to examine influence of WM load and task importance manipulation on PM performance, and based on theoretical part we formed several questions and hypotheses. We take a look on WM load and task importance manipulation factors together, since WM load or task importance manipulation alone have exhibited to be of significant effect. Regarding the interplay of factors, we expect high WM load and low importance to have the greatest negative impact on PM. On the other hand we expect low WM load and high importance should have no negative or even positive impact on PM. Research question in our case can be how interplay between WM load and task importance manipulation impact PM performance. Based on our research question, we narrowed down our main hypothesis as follows:

H0: high WM load and low importance group will have no difference in PM performance compared with low WM and high importance group

H1: high WM load and low importance group will have significantly worse PM performance compared with low WM and high importance group

H0 is null hypothesis, that we won't reject when we will reject H1. If we will be able to answer this singe hypothesis, it will mean objective of our thesis was reached. Nevertheless, apart from our main hypothesis we have several side hypotheses, that are best represented in the order how successful we expect them to be:

H2: low WM, high importance > high WM, high importance

H3: high WM, high importance > low WM, low importance

H4: low WM, low importance > high WM, low importance

We can only assume that high WM, high importance group will perform better than low WM, low importance group. However this assumption is based on premise, that the social importance will have more important role in whether participant will remember to do it or not. We are not saying that WM load is unimportant, but the difference between WM loads is relative, but the task importance manipulation is absolute, so either high social importance or no importance at all. Anyway, this order of how we expect the groups to perform is only secondary objective and we do not expect it to be fulfilled. We did not exactly state null hypotheses to H2-H4, but we are focusing on our H1 and these other hypotheses are only supplementary.

6.4 Procedure

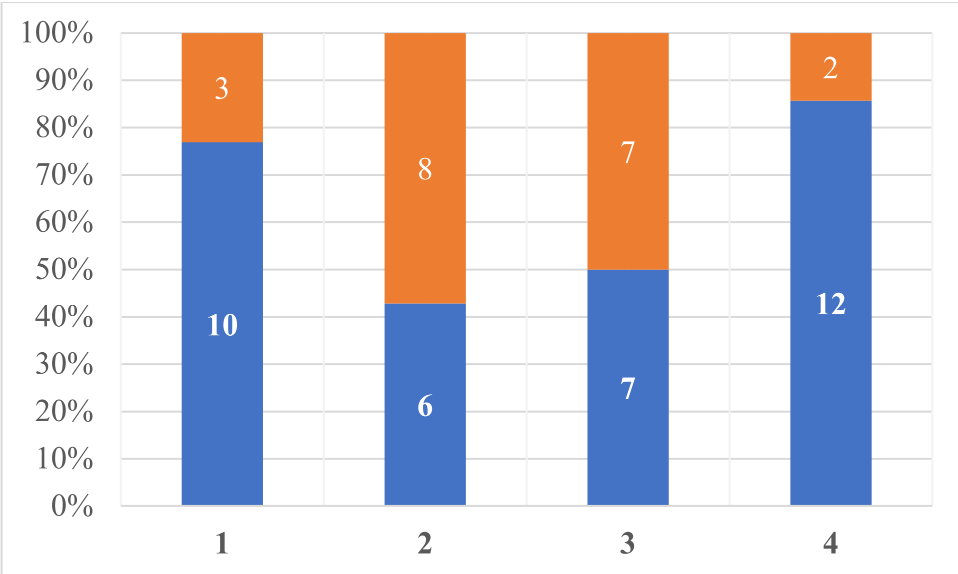
The nature of our experiment allowed us to test only one participant at time. At the beginning of testing procedure, participants have been told that it is performance test, we tried to focus them on the working memory test part. Then, they have to randomly pick their group from paper slips. After assigning them to one of the four groups, experimenter handed them form of participation, where they put consent with testing and wrote their personal data. The form had two sides, consent and personal data on first side and on the other side was agreement with usage of measured data. This form was clipped on paper holder writing board, so they saw only one side. This form was our actual performance measure and also part where task importance manipulation happened. After participants finished the one side of the form and handed the form to experimenter, experimenter told them two different phrases, based on which group the actual participant was. For participants assigned to high social importance, experimenter told them exactly this: “We will proceed to the testing part, but first of all, this form you just gave to me has also second part on the other side. It is extremely important for me that you will fill it out, please remind it to me after the experiment”. On the other hand, in the low social importance group, respectively no social importance group, experimenter told them exactly this: “We will proceed to the testing part, but first of all, this form you just gave to me has also second part on the other side. Please remind it to me after the experiment”. For both groups, experimenter told participants to remind him of the second part of the form, but there is obvious difference in the level of social importance. After this, participants began to be tested by working memory digit span task. In digit span task, a series of digits is presented to participant, one by one and participants should remember and later recall them. Digits from 1 to 9 were presented semi-randomly, so in the string of less than 9 digits none digit came up twice. The number of digits vary during the experiment, based on performance of participants. For every successful recall, the number of digits increased and for two consecutive errors it decreased. The manipulation with WM load here was provided by different means of recall. Low WM load group had to recall the string of digits in the same order as it was presented. High WM load group should recall digits in backward order, which is more difficult and embodies more rules than low WM load group. This task is very simple in instructions, yet very cognitively demanding. We chose this specific task, because it loads the maximum capacity for every person, so the individual differences are well handled. There is difference in actual cognitive load, but the capacity is always reached when the person is really engaged in the activity. The testing took from 17 up to 27 minutes, based on how fast they tried to do the task. This time difference is not big concern, since span of retrospective and prospective memory is different, and the forgetting curve is of different nature, especially for event-based PM. When the test finished a summary screen with results appeared and experimenter explained the data to participant. When the explanation was done, experimenter clearly said: ”Thank you for participation, the experiment is over”. This phrase was designed to explicitly end the experiment, so there was no ambiguity about the end of experiment. This phrase should also serve as cue for participants to remind experimenter about the second side of participant’s form. There was immediate response from some participants, that they were told to remind experimenter to fill out the form. If they did not respond immediately, experimenter accompanied participants to the exit. Some participants stopped before the doors and reminded experimenter the form, but if the participant stepped out of the room, experimenter stopped them. The participants who stepped out without reminding experimenter about the form were classified as unsuccessful in prospective memory task. From this design we get simple measure in the form of fail/success. For unsuccessful participants, experimenter made short investigation why they didn’t remind him of the form. This was done mainly because of possible retrospective memory fails, in the case they do not remember the instruction to remind him. Every participant remembered the instruction and we are therefore more certain that the failure was in PM. After success or fail of the PM task, experimenter provided full debriefing and explanation of real performance measure and experimental design and also collected consents from participants who failed in the task. The whole procedure took from 30 up to 40 minutes for one participant.

6.5 Results

Our results have a form of success/fail rate for each group. Since our performance measure was in nominal or binary form, for better overview of our results we provide corresponding table and graph.

	Group				Total
	1	**2**	**3**	**4**	
Fail	3	8	7	2	20
Success	10	6	7	12	35
Total	13	14	14	14	55

Table 1. Success rate for every group with marginals and grand total. Groups are represented as follows: 1 = high WM load & high importance, 2 = high WM load & low importance, 3 = low WM load & low importance, 4 = low WM load & high importance



Graph 1. Success rate for every group in percentage bar charts. Groups are represented as follows: 1 = high WM load & high importance, 2 = high WM load & low importance, 3 = low WM load & low importance, 4 = low WM load & high importance. Numbers in orange parts represent number of fails in PM task and numbers in blue indicate number of successes in PM task.

As we can see from this chart, there is clearly difference between the group. We tested whether the difference is significant or not by nominal data significance tests. All tests were made in IBM SPSS software version 23. In the following table, we summed up the most important results for clear overview. All other side results and significances are mentioned in the text.

	Value	Exact significance
Chi-square	7,678	0,053
Fischer's exact test	7,483	0,061

Table 2. Tests of statistical significances for our results. Significance is two sided for both cases.

We performed Chi-square analysis on our data, with value 7,678 and p = 0,053. The result points to no significant difference in our data. In Chi-square one cell had expected count less than 5, so by the rule of a thumb we decided to perform also Fischer's exact test, which may be more reliable in this case and with smaller samples. Fischer's exact test value is 7,483 and p = 0,061. The results of both show no significant difference in our data, based on the division into experimental groups with interplay of WM load and task importance factors. If we perform Chi-square analysis on the data sorted only by WM load apart from task importance, meaning low vs. high WM load, we have value of 0,439 and p = 0,582 (exact and 2-sided). This means no significant difference in our data based on WM load distinction. But when we sort our data based on task importance, no vs. high social importance, we have Chi-square value of 7,299 and p = 0,011 (exact and 2-sided), meaning that we have significant difference between groups when they are divided by task importance, namely participants with high social importance manipulation are more successful in the PM task than participants in no importance manipulation where 1-sided p = 0,007. Nevertheless, the only significant effect we observe on our data is not the one we were looking for.

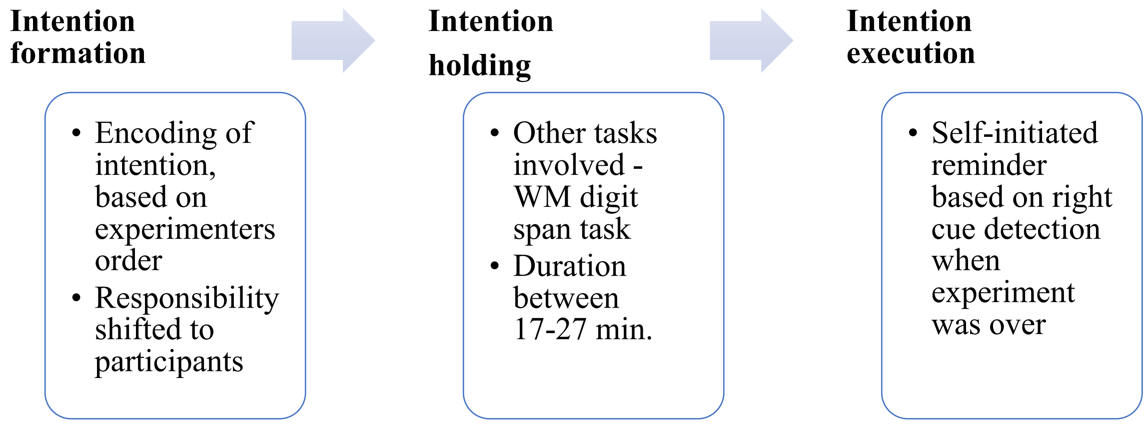
As a supplement to our PM task data, we examined how participants performed in WM digit span task. There we had two conditions, forward and backward recall of digits, in our words high and low WM load. By one-way ANOVA we found no significant difference in WM task in the experimental groups with p = 0,424. Moreover, we found no significant difference in the data split up by high or low WM load using t-test, with p = 0,633. The differences in WM task mentioned here have very little explanation value for our research question and we will very briefly mention why we also analyzed this data in later part.

6.6 Discussion

Our experiment was naturalistic PM task hidden behind demanding WM task. When designing the experiment, we shifted from the paradigm used in majority of experiment in PM research. While researching literature, we found many discrepancies in papers about PM. Namely, we found that in theoretical part or introduction, authors often address PM as very simple in terms of performance measure, yet in actual experiments they employ methods that stray far away from simple and realistic PM tasks. There is no debate about their contribution to knowledge about PM and its dynamics, but there is already a vast amount of such experiments and it's about the time to move experimental paradigm closer to PM in real-life.

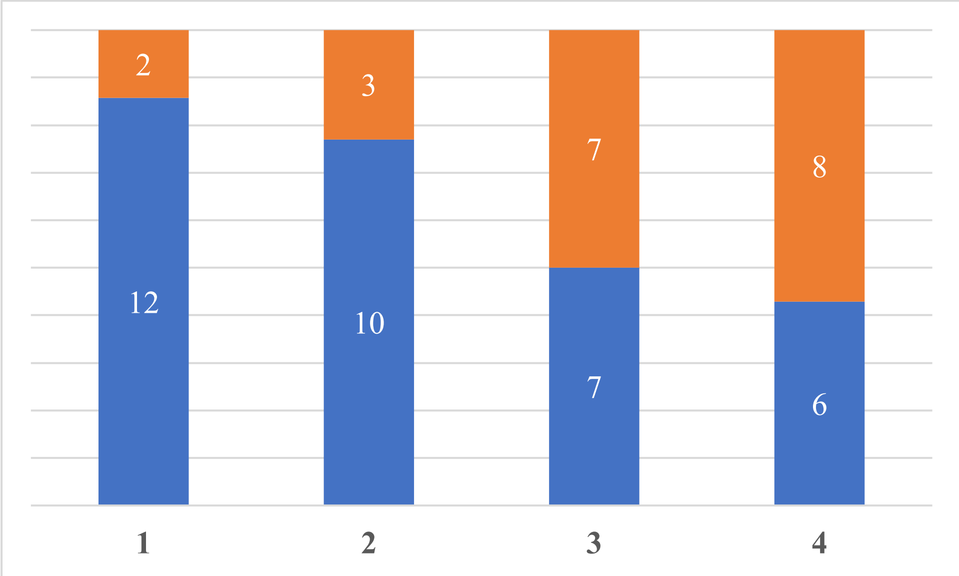
As recruitment tool, we used snowball sampling. As any other sampling method, it has its odds. We can see this directly in our sample, but we state more about sample in limits of our thesis. Important thing to mention about our sample is, that we tried to have homogeneous experimental groups, on the contrary we tried to have heterogeneous group participants in general. These two demands are difficult to achieve with snowball sampling and also with relatively small number of participants we had. So we resigned on having heterogeneous group, that covers let's say all adult age categories, in favor of having homogeneous groups in experiment for more reliable comparison among groups.

Testing procedure and paradigm used in experiments is somehow inspired by previous research and somehow new. We wanted to have more ecologically valid performance measure and to have replicable procedure with reliable measure of PM. In the sense of these requirements, we were quite successful. We would like to recapitulate the PM flowchart form the beginning of our thesis and adapt it to our experiment, so we can point out the PM process in our experiment.



Reminding somebody of something is very natural task and in everyday living we encounter this activity really often. Experimenter directly put this responsibility on participants, when he instructed them to remind him of the form. The maintenance phase was mediated by WM span task and the retrieval by experimenter explicitly finishing the testing procedure. All participants remembered the instructions by experimenter, yet not all of them were successful in the PM task. This just mean, that retrospective component was all right and prospective component was the one to blame. Therefore our designed task worked as PM performance task, with lot of similarities with real-world PM tasks. If there would be 100% success or fail rate, the task would be probably too easy or difficult to perform, but success rate as we have seemed to mirror suitable difficulty of the task.

Hypotheses we made are actually only our groups put into expected order and our main hypothesis came out from the strongest assumption, that opposite groups in WM load and task importance will have the most different results. In the result, we can see no statistical difference between any groups. Although, the result is reaching significance with $p = 0{,}061$, it is still mere trend that we can observe when we have split data according to groups. According to our analysis, we stick to H0 since we cannot reject it. For our secondary objective, we specified the order of groups in experiment. The order of the groups is exactly as we described in our hypotheses section, for better overview, we will provide a graph of groups sorted by success rate.



Graph 2. Groups ordered by success rate. In this graph, groups are represented as follows: 1 = low WM load & high importance, 2 = high WM load & high importance, 3 = low WM load & low importance, 4 = high WM load & low importance. Numbers in orange parts represent number of fails in PM task and numbers in blue indicate number of successes in PM task.

Groups are definitely ordered in the way we expected, but it is the statistical significance that results would need to be sound. Without statistical significance, order of the groups may be caused by some random factors that the WM and importance factors of the groups.

Regarding the results, we can say that there was no significant difference in the groups caused by interplay of WM load and task importance factors. When we examined WM and importance factors alone, we found out, that task importance manipulation had strong influence on PM performance. However, that is not the information we searched for. This only supports the previous line of research, as we stated in the theory, that importance manipulation has positive effect on PM performance. Interesting is, that we didn't find any effect of WM load manipulation. As previous research suggests, there should be a difference also for WM loads. So we decided to inspect how groups performed in WM digit span tasks. As we mentioned, we found no significant difference between groups. It may point out, that the difference is not that big in the terms of WM load between forward and backward recall of digits. In the case of importance manipulation, we used absolute manipulation, in other words all or nothing. For WM load, we used relative manipulation, so we had WM load present in all conditions, just in different amount. Well, it seems that the difference was too tiny to have significant effect on PM task. That is one thing that certainly shaped our results. Before experiment, we considered the difference between two WM loads satisfactory. However, now we would do absolute manipulation of WM load or make the difference between groups even greater. We maybe didn't catch the effect of WM load and importance manipulation interplay because of insufficient difference in WM loads, but that calls for another experiment to be sure is this assumption is right. Nevertheless, our main hypothesis came out to be rejected and we incline to null hypothesis. Further investigation is needed, since our research was limited by some factors, later listed in limitations of thesis.

In the previous paragraph, we tried to interpret our result or at least provide explanation for them. Here we would like to focus on how we connect our procedure and results with theory we wrote in the first part of the thesis. First of all, interesting for us is whether our cue was focal or non-focal. The cue as we designed it is probably focal, because the intention should be formed something like this: If the experiment is over, then I will remind experimenter about second page of the form. In this case, the cue is exactly when experimenter ends the testing. As we know, there might be space for spontaneous retrieval for focal cues. In the case that our cue was purely focal and enabled spontaneous retrieval, WM load might have little effect on the actual outcome of the task. This is another improvement we would employ, to style the cue little bit harder to engage active monitoring. Especially combination of focal cues and social importance might lead to very good PM performance, as we speculated in theoretical part. However, one might argue, that our task has non-focal cues. The argument may come from the fact, that the intentions has to be really form in the way we assumed above. To know this, we would have to ask all participants after experiment about their formulation of the intention. If the cue is not directly connected to the task, there is always a possibility for it to be non-focal. Nevertheless, we found factor of social importance influential, so as in other experiments within this area. Another interesting variable is, that our PM cue is definitely event-based. In real-life scenario, such task as remind somebody of something can easily be time-based. We argue, that making the task time-based would cause more monitoring of time and such monitoring won't reflect the nature of the task from real-life scenario and more elaborate or even long-lasting study would be needed to examine this effect. In computational modelling part, we mentioned how habit formations shapes the performance of PM. There is possibility, that some participants from our sample, especially those who live with elderly people, can have habit of reminding somebody of something. Therefore, our task we gave them was more of a habit kind. This is solely a speculation, but it can be useful to include some questions about habit in PM research in future experiments.

We tried to provide some novel findings into PM research field. Unfortunately, our results were not significant, but we can provide some useful insights and implications for PM research anyway. We can definitely say, that it is possible to design PM task that resembles real-life scenario. We are quite sure, that the fails in task were of prospective nature, because we questioned participants to find possible retrospective memory fails. We found none. We argue, that this paradigm, or some of similar kind, can be used also in longitudinal study or for example neuroimaging study. Another insight is, that when using WM load manipulation, it might be helpful to use absolute manipulation, like we used in the importance manipulation case. If there is need for relative manipulation of WM load, we suggest using some method that will show more difference among groups that WM digit span task.

To wrap up the results and discussion. Our results point to no significant effect of interplay between factors of WM load and importance manipulation on PM performance. We used our own paradigm for PM performance assessment, which we rate as successful. We presented possible explanation for our data and suggest methodological improvements for our experiment. Apart from results, we also provided helpful insight for those, who would like to explore dynamics of PM by themselves.

6.7 Limits of experiment

We declare several possible limits of the thesis. First of all, we used our own paradigm. It is always difficult to compare results among experiments with different paradigms, but we did it on purpose and for the sake of ecological validity as we mentioned above in the thesis. Anyway, our own paradigm might produce some limits to our experiment. Another limitation is relatively small sample. We determined by G*Power software, that in our case, with 3 degrees of freedom and small to medium effect size, we would need a sample 108 participants to obtain power of our experiment about 0,95. Another limit when it comes to generalization of our data is relatively homogeneous age group. As we stated earlier, we gave up on having diverse sample in favor of having homogeneous groups for reliable comparison. We also didn't perform any test of cognitive abilities before testing. Better cognitive abilities may lead to better PM performance and therefore influence the results. In this part we would also like to declare no conflicts of interest.

Conclusion

Our thesis was separated into two parts, theoretical and practical. In theoretical part, we provided definition of PM. With the definition we moved through chapters exploring various dynamics of PM. We stated two most important categorizations of PM, namely event vs. time based and focal vs. non focal cues. We also defined PM stages and similarities with retrospective memory. The distinction between focal and non-focal cues led us to two main theories behind PM, one emphasizing active monitoring and the other emphasizing spontaneous retrieval. After we discussed the main theories, we listed several factors influencing PM performance, for example context, importance and personality traits, and also took a look at how PM can fail. Moreover, we focused on neuroscience of PM and listed several neuroimaging studies as well as psychophysiological findings. We enriched our knowledge with interesting computational modelling study, that from our point of view challenged the classical PM experimental paradigm and inspired us to use naturalistic performance measure in our experiment. By the end of theoretical part, we provided some techniques for possible improvement of PM in real-life. In practical part we introduced our experiment, described the motivation behind our approach. Our main hypothesis was set according to assumptions based on theoretical part. We tried to provide as detailed overview of our procedure as possible, for better replicability. We used WM digit span task for WM load manipulation, for importance manipulation, we used different formulation of instructions before testing procedure. PM measure was design in very naturalistic way, in form of simple reminder to finish form of participation. After testing 55 participants, we obtained results, that were not significant when analyzed by experimental groups. The only significant effect was the one of social importance manipulation, but this was not in our focus and has already been investigated. This was in line with previous research, so in the sense our thesis provided more evidence for importance manipulation to cause significant differences in PM. In the last part of our thesis, we provided possible interpretation of our results and possible limits of our experiment.

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