Affective and Cognitive Aging Revisited: The Role of Metacognition

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THESE

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Statement

The present work is a cumulative dissertation based on three articles (*Thèse sur dossier d'articles*) representing three studies. It has been prepared as a self-contained work and all chapters were composed specifically for this thesis. Furthermore, I guarantee that these papers are the products of my personal work with the precious help, feedback and edits from my co-authors. This thesis includes the published papers of Studies 1 and 2, and the first version of the manuscript of the third study that is currently under review. Terminological and formatting inconsistencies may occur according to the different journal publishing policies.

This thesis includes the three following articles:

Study 1 (Chapter 5)**:**

Da Silva Coelho, C., Joly-Burra, E., Ihle, A., Ballhausen, N., Haas, M., Hering, A., Künzi, M., Laera, G., Mikneviciute, G., Tinello, D., Kliegel, M., & Zuber, S. (2021). Higher levels of neuroticism in older adults predict lower executive functioning across time: The mediating role of perceived stress. *European Journal of Ageing*. https://doi.org/10.1007/s10433-021-00665-z

Study 2 (Chapter 6)**:**

Da Silva Coelho, C., Zuber, S., Künzi, M., Joly-Burra, E., & Kliegel, M. (2023). The relationship between depressive symptoms, metamemory, and prospective memory in older adults. *Journal of Clinical and Experimental Neuropsychology,* 1–15. https://doi.org/10.1080/13803395.2023.2195618

Study 3 (Chapter 7)**:**

Da Silva Coelho, C., Hering, A., Zuber, S., Spurio, G., Bisiacchi, P., Kliegel, M. (under review). Exploring the Relationship Between Emotional Valence and Prospective Memory Metamemory in Younger and Older Adults. *Manuscript submitted to the Journal of Ageing and Longevity.*

Abstract

Prospective memory (PM) and executive functions (EF) are interconnected cognitive processes of particular importance in cognitive aging, given their central role in goal-oriented activities, planning, and executing everyday tasks — ranging from managing medication to regulating behavior. These tasks are essential to the functional autonomy and health-related quality of life for older adults. Both PM and EF are supported by the prefrontal regions of the brain and are fundamental contributors to an individual's overall well-being.

Different factors influencing EF and PM have been investigated, but demonstrated certain inconsistencies and it remains unresolved which factors are worth further investigations. The interplay between affect and metacognition can be of interest for cognition in older adults. Indeed, affect has been demonstrated to significantly influence different cognitive domains (e.g., retrospective memory), but the picture is not as detailed in the context of EF and PM, where inconsistent results have been demonstrated. These inconsistencies suggest that other factors may be at play such as metacognition, which has been linked to affect in healthy and clinical populations (e.g., depression). The main aim of this thesis is to investigate the interplay between affect, metacognition and cognitive performance in older age.

Previous studies indicated that the influence of neuroticism – emotional instability – on EF is inconsistent in cross-sectional studies and largely unexplored in longitudinal studies. In fact, a deeper understanding of the underlying mechanisms is lacking, which is an important knowledge gap considering that personality changes precede cognitive decline in older age. Thus, Study 1 investigated in a six-year longitudinal design the dynamics between neuroticism and EF through Bayesian analyses, with a focus on 768 older adults (M_{age} = 73.51 years; *SD* = 6.09 at Wave 1). A cross-lagged analysis was used to examine the data. Wave 1 revealed no correlation between neuroticism and Trail Making Test (TMT) scores. Interestingly, Wave 1

neuroticism did predict TMT performance in the at Wave 2, indicating that the more neurotic participants were, the lower they performed on the TMT six years later. Further examination indicated that this association was fully mediated by individuals' perceived stress. These findings indicate that higher neuroticism in older adults may amplify perceived stress over time, which adversely affects their EF performance. Thus, the study uncovers a potential causal path where neuroticism can impair EF over a span of six years, highlighting perceived stress as a key mediating factor. The study concludes by exploring potential interventions that could mitigate these negative outcomes.

Neuroticism increases risk of developing psychological affective disorders, such as depression, which is one of the most common mental health issues experienced by older adults. Unfortunately, the relationship between depressive symptoms and PM in older adults has only been investigated in two studies which demonstrated inconsistencies, not allowing to draw solid conclusions. These inconsistencies may stem from the neglection of underlying factors such as metamemory representations, as depressive individuals experience distorted metacognitive beliefs. Thus, Study 2 explored how depressive symptoms relate to PM in young-old and old-old adults, and assessed the role of potential underlying factors such as age, education, and memory-self efficacy. Performing Bayesian analyses on data from 394 older participants, with an average age of 80.10 years (*SD* = 6.09), highlighted a three-way interaction among depressive symptoms, age, and metamemory representations, suggesting that the link between depressive symptoms and PM performance was moderated by the individual's age and their metamemory representations. Among individuals with lower depressive symptoms, old-old adults with higher metamemory representations showed comparable PM performance to young-old adults, regardless of their metamemory representations. Conversely, within the group of individuals with higher metamemory representations and higher depressive symptoms, older adults exhibited weaker PM performance than younger adults. The present findings suggest that higher metamemory representations are protective against the detrimental effects of aging on PM, but this protective factor appears to be effective only for older adults with lower depressive symptoms.

Surprisingly, no study was conducted on the influence of stimuli valence on both PM metamemory representations and PM performance in older adults, nor focused on their ability to monitor their PM metamemory representations across the trials. Thus, it does not allow understanding whether older are able to modify their metamemory representations which is necessary to implement effective strategies accordingly to these representations. Thus, Study 3 examined older adults' ability to predict their PM performance and to adjust their metamemory representations after experiencing the task. In a sample of 25 younger (M_{age} = 22.12 years; *SD* = 2.47) and 19 older adults' (M_{age} = 73.37 years; *SD* = 4.40), results indicated that younger adults underestimated their PM performance for neutral and negative cues. They adjusted their metamemory representations more accurately for neutral cues, suggesting an effective metacognitive monitoring process. On the contrary, older adults initially overestimated their PM performance for tasks associated with negative cues and demonstrated no significant adjustment in their metamemory representations after completing the task. This suggests a potential difficulty in effectively updating their PM abilities, which is of crucial relevance to implement effective strategies and offer interventions to older adults.

The present findings indicate a complex interplay between affect, metacognition and cognitive performance, specifically for EF and PM, in older age. More precisely, the results presented in this thesis indicate that older adults are particularly sensitive to negative affect, which disrupts their metacognitive representations and is detrimental for their cognitive performance. As inconclusive results are brought up regarding the ability of older adults to monitor their metacognitive representations, the present findings highlight the need to further investigate this domain of research. Such knowledge will help to understand which metacognitive process is impaired in older adults and allow researchers and clinicians to offer tailored interventions to support cognitive performance, but also daily-life activities related to EF and PM that support autonomy and independent living.

French Abstract – Résumé en français

La mémoire prospective (MP) et les fonctions exécutives (FE) sont des processus cognitifs interconnectés de grande importance dans le vieillissement cognitif, étant donné leur rôle central dans les activités orientées vers un but, la planification et l'exécution des tâches quotidiennes — allant de la gestion des médicaments à la régulation du comportement. Ces tâches sont essentielles pour maintenir l'autonomie et la qualité de vie liée à la santé des personnes âgées. La MP et les FE sont soutenues par les régions préfrontales du cerveau et contribuent au bien-être global d'un individu.

Les facteurs influençant les FE et la MP ont été étudiés, mais ont montré certaines incohérences et des questions non résolues demeurent, ce qui nécessite des investigations supplémentaires. L'interaction entre l'affect et la métacognition peut être d'intérêt pour la cognition chez les personnes âgées. En effet, il a été démontré que l'affect influence de manière significative différents domaines cognitifs (par exemple, la mémoire rétrospective), cependant nous n'avons un tableau clair dans le domaine des FE et de la MP, car il y a des résultats incohérents. Ces incohérences suggèrent que d'autres facteurs peuvent être en jeu, tels que la métacognition, qui a été liée à l'affect dans les populations saines et cliniques (par exemple, la dépression). L'objectif principal de cette thèse est d'étudier l'interaction entre l'affect, la métacognition et la performance cognitive dans le vieillissement.

Des études antérieures ont indiqué que l'influence du névrosisme - instabilité émotionnelle - sur les FE est inconsistante dans les études transversales, et largement inexplorée dans les études longitudinales, et manque d'une compréhension plus profonde car les mécanismes sous-jacents n'ont pas été étudiés, ce qui est une lacune importante des connaissances, considérant que les changements de personnalité précèdent le déclin cognitif avec l'âge. Ainsi, l'étude 1 a investigué, dans un design longitudinal de six ans, la dynamique entre le névrosisme et les FE chez 768 adultes plus âgés (âge moyen = 73,51 ans ; SD = 6,09 à

la vague 1), en utilisant le Trail Making Test (TMT) et des analyses bayésiennes. La vague 1 n'a révélé aucune corrélation entre le névrosisme et les scores au TMT. Le névrosisme de la vague 1 a prédit les résultats au TMT à la vague 2, indiquant que plus les participants étaient névrosés, plus leurs performances au TMT étaient faibles six ans plus tard. Un examen plus approfondi a indiqué que cette association était entièrement modérée par le stress perçu des individus. Les résultats indiquent que le névrosisme plus élevé chez les adultes plus âgés peut amplifier le stress perçu au fil du temps, ce qui affecte négativement leur performance en FE. Ainsi, l'étude démontre un lien causal où le névrosisme peut altérer les FE sur une période de six ans, mettant en avant le stress perçu comme un facteur médiateur clé. L'étude conclut en explorant des interventions potentielles qui pourraient atténuer ces effets négatifs du névrosisme et du stress perçu.

Le névrosisme augmente le risque de développer des troubles affectifs psychologiques, tels que la dépression, qui est l'un des problèmes de santé mentale les plus courants chez les personnes âgées. Malheureusement, la relation entre les symptômes dépressifs et la MP chez les adultes plus âgés n'a été étudiée que dans deux études qui ont démontré des incohérences, ne permettant pas de tirer de conclusions. Ces incohérences peuvent découler de la négligence de facteurs sous-jacents tels que les représentations en métamémoire, car les individus dépressifs font l'expérience de croyances métacognitives déformées. Ainsi, l'étude 2 a exploré comment les symptômes dépressifs se rapportent à la MP chez les adultes jeunes-âgés et âgés-âgés, et a évalué le rôle de facteurs sous-jacents potentiels tels que l'âge, l'éducation et l'auto-efficacité en mémoire. Suite à l'analyse bayésienne des données de 394 participants d'un âge moyen de 80,10 ans (*SD* = 6,09), les résultats ont mis en évidence une triple interaction entre les symptômes dépressifs, l'âge et les représentations en métamémoire, suggérant que le lien entre les symptômes dépressifs et la performance en MP était modéré par l'âge de l'individu et ses représentations en métamémoire. Parmi les individus avec des symptômes dépressifs plus faibles, les adultes âgés-âgés avec des représentations en métamémoire plus élevées ont montré une performance en MP comparable aux adultes jeunes-âgés, indépendamment de leurs représentations en métamémoire. À l'inverse, au sein du groupe avec des symptômes dépressifs plus élevés, les participants plus âgés qui avaient des représentations en métamémoire plus élevées ont montré une performance en MP plus faible que les plus jeunes qui avaient également des représentations en métamémoire élevées. Les résultats suggèrent que des représentations en métamémoire plus élevées sont protectrices contre les effets délétères du vieillissement sur la MP, mais ce facteur de protection semble être efficace uniquement pour les adultes plus âgés avec des symptômes dépressifs faibles.

Étonnamment, aucune étude n'a été menée sur l'influence de la valence des stimuli à la fois sur les représentations en métamémoire de la MP et sur la performance de la MP chez les adultes plus âgés, ni ne s'est concentrée sur leur capacité à monitorer leurs représentations en métamémoire de la MP à travers les essais. C'est regrettable car cela ne permet pas de comprendre si la moins bonne performance des adultes plus âgés en MP par rapport aux adultes plus jeunes découle de représentations inexactes ou d'un processus stratégique altéré. Ainsi, en utilisant des indices émotionnels de MP dans une tâche de MP basée sur des événements, l'étude 3 a examiné la capacité de 25 adultes plus jeunes ($M_{\text{âge}}$ = 22,12 ans ; *SD* = 2,47) et de 19 adultes plus âgés ($M_{\text{âge}}$ = 73,37 ans ; *SD* = 4,40) à prédire leur performance en MP et à ajuster leurs représentations en métamémoire après avoir expérimenté la tâche. Les résultats ont indiqué que les adultes plus jeunes sous-estimaient leur performance en MP pour les indices neutres et négatifs. Ils ont ajusté leurs représentations en métamémoire plus précisément pour les indices neutres, suggérant un processus de surveillance métacognitive efficace. Au contraire, les adultes plus âgés ont initialement surestimé leur performance en MP pour les tâches associées à des indices négatifs et n'ont démontré aucun ajustement significatif dans leurs représentations en métamémoire au cours de la tâche. Cela suggère une difficulté potentielle à mettre à jour efficacement leurs capacités en MP, ce qui est d'une pertinence cruciale pour mettre en œuvre des stratégies efficaces et offrir des interventions aux adultes âgés.

Les résultats actuels indiquent une interaction complexe entre l'affect, la métacognition et la performance cognitive, spécifiquement les FE et la MP, dans le vieillissement. Plus précisément, les résultats présentés dans cette thèse indiquent que les adultes plus âgés sont particulièrement sensibles à l'affect négatif, ce qui perturbe leurs représentations métacognitives et est préjudiciable pour leur performance cognitive. Comme des résultats non concluants sont soulevés concernant la capacité des adultes plus âgés à monitorer leurs représentations métacognitives, les présentes découvertes soulignent la nécessité d'investiguer davantage ce domaine de recherche. Ces recherches aideraient à comprendre quel processus métacognitif est déficitaire chez les personnes âgées, et permettraient aux chercheurs et cliniciens d’offrir des interventions sur mesure pour soutenir les performances cognitives des adultes âgés, mais également les activités quotidiennes liées aux FE et à la MP essentiels pour l’autonomie et l’indépendance.

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1 General Introduction

Historically, psychologists' interests were focused on children's cognitive functioning and development, while cognition in older age did not trigger interest and was neglected because of the idea that it was only characterized by cognitive losses (Baltes et al., 1999). However, as the global population is rapidly increasing and aging, understanding trajectories of older adults' cognitive processes has become crucial. Indeed, the number of individuals aged 60 years and older should reach 2 billion by 2050, which raises age-related cognitive decline as a major challenge of our century (Kramer, 2012; World Health Organization, 2017, December).

Cognitive functioning encompasses diverse mental abilities like memory, reasoning, processing speed, and problem-solving (Horn & Cattell, 1967). While investigating cognitive processes in older age, researchers demonstrated that they are divided in two concepts which are crystallized intelligence (knowledge acquired over time) and fluid intelligence (like processing speed and working memory; Baltes et al., 1999). While the former remains relatively stable, the latter often shows a decline with age (Baltes et al., 1999; Hedden & Gabrieli, 2004; Tucker-Drob et al., 2019). This decline manifests because of a slower processing speed in older adults, which affects tasks requiring fast responses (Salthouse, 1996; Verhaeghen & Salthouse, 1997). Executive functions (EF) and prospective memory (PM), included in fluid intelligence, have been demonstrated to be particularly relevant in the context of cognitive aging as they are interconnected cognitive processes crucial for goal-directed behavior, planning, and the accomplishment of daily tasks such as medication intake and behavioral regulation, which are essential to older adults' daily-life autonomy and health-related quality of life (Hering, Kliegel, Rendell, et al., 2018; Laera et al., 2021). They are both supported by prefrontal brain structures and contribute significantly to overall well-being (Zuber, 2017).

Affect has been demonstrated to influence both EF and PM performances. Indeed, a meta-analysis revealed that positive emotional cues improve PM performance across age groups, with older adults demonstrating more benefit compared to younger ones (Hostler et al., 2018). However, these findings are inconsistent across studies. Indeed, the interplay between affective states and cognitive performance in older adults is multifaceted. For instance, certain research highlighted the benefits of stress on EF and PM performances when perceived as a challenge and when appropriately timed (Piefke & Glienke, 2017; Shields et al., 2017; Travis et al., 2020). Conversely, other studies associated high and long-time stress with decline in EF and PM performances (Aggarwal et al., 2014; Hidalgo et al., 2019; Piefke & Glienke, 2017). Such intricate relationships between affect and cognition are also observed for emotional instability and psycho-affective disorders such as depression. Indeed, a bidirectional relationship exists in older adults between EF and depressive symptoms, indicating that these symptoms can lead to poorer EF abilities, but also that diminished EF abilities can trigger depressive symptoms. However, in PM, only two studies investigated depression and PM in older adults, demonstrating inconclusive results (Albiński et al., 2012; Alexopoulos, 2003; Livner et al., 2008). The state of the art on the relationship between affect and cognitive performance indicates inconsistent findings, suggesting that other factors might be at play.

Metacognition - how individuals perceive and control their cognitive abilities—is an emerging field and might be an interesting factor to investigate at the intersection between affect and cognitive performance in older age (Nelson & Narens, 1990). Indeed, previous research demonstrated that affect plays an important role in shaping, not only cognitive performance, but also metacognitive representations. Indeed, positive affect has been linked to higher representations of one’s own memory abilities and to enhanced actual memory performance (Sidi et al., 2018). Conversely, negative affect, such as those elicited by neuroticism and depression, can trigger lower metacognitive representations and reduced cognitive performance (Balash et al., 2013; Boyle et al., 2010; Cipolli et al., 1996). Accurate metacognitive representations help to implement efficient strategies, thereby promoting higher cognitive performance and daily-life autonomy (Hertzog & Dunlosky, 2011). Additionally, concerns regarding subjective cognitive decline, which can be considered as inadequate metamemory representations, sometimes tied to anxiety or personality traits, are considered as a potential preclinical sign of neuropsychological disorders (such as Alzheimer's disease), reinforcing the need to further investigate metacognition in older age (Ávila-Villanueva & Fernández-Blázquez, 2017; Bouazzaoui et al., 2016).

Even though, it is of great importance in older adults for their autonomy, research on the interplay of affect, metacognition and cognitive performance is still scarce and certain questions remain unanswered. For instance, the relationship between negative affect and EF is inconsistent, with a noticeable absence of longitudinal investigations. While metacognitive representations are important to implement effective strategies, its relationship with negative affect, particularly depressive symptoms, and PM has not been thoroughly examined in older adults. Additionally, the relationship between emotional stimuli, metacognitive representations and PM has never been studied altogether in older adults, revealing a lack of knowledge. Investigating these questions will not only benefit scientific understanding in the field of cognitive aging, but can have implications for daily-life automomy of older by offering therapeutic and interventional possibilities. Thus, the aims of the present thesis will be to examine how emotional instability affects EF in aging, to investigate the relationship between depressive symptoms, metacognition and PM in older adults, and to explore the age-related differences and the emotional influences on PM metamemory representations and actual PM performance.

The following chapters of this thesis will provide details on previous findings on EF, PM, affect and metacognition in older adults.

2 Theoretical Background

2.1 Executive Functions

2.1.1 Definition

EF are defined as top-down processes, embedded in the control executive of working-memory (WM), including a lot of different components which relate to one another, but also have their unique specificity, such as planning, information selection, and solution-seeking (Diamond, 2013; Miyake et al., 2000). However, the most commonly referred to and investigated EF are inhibition, shifting and updating (Miyake et al., 2000). Inhibition refers to individuals' ability to suppress automatic and dominant responses or impulsive behaviours when they are inappropriate or not needed anymore. Shifting is also known as cognitive flexibility or task-switching. It is the ability to switch between tasks or mental operations or to adopt a new perspective. Finally, updating is the monitoring process of information, which enables individuals to replace old non-relevant information by new and more relevant ones.

2.1.2 Executive Functions Development

EF are fundamental cognitive processes for reasoning, planning, organization and adaptation. They emerge around the age of 3, with children demonstrating basic working-memory skills and beginning to exhibit improved inhibition, such as resisting to take a forbidden toy (Diamond, 2013). EF development continues during school years, with children using better strategies and improving their capacity to perform more complex tasks (Best et al., 2009). By mid-adolescence, inhibition and shifting abilities reach their peak levels and are maintained into adulthood, while updating still develop beyond adolescence (Best et al., 2009; Carriedo et al., 2016).

EF seem to decline in older age, when they undergo several changes. For instance, research observed a decline in processing speed which influences EF components (Salthouse, 1996). Diminished cognitive flexibility is observed with older adults having difficulties to shift between tasks (e.g., multitasking), or to adapt to new rules and routines (Diamond, 2013; Lindenberger et al., 2000). Inhibition also weakens with age, with older adults being more susceptible to interference and influencing the speed of their decision-making, leading them to difficulties in performing cognitive tasks correctly (Ferguson et al., 2021; Lustig et al., 2007).

The importance of EF goes beyond cognitive tasks as they are crucial for daily-life autonomy and activities (Diamond, 2013; Engel-Yeger & Rosenblum, 2021; Suchy et al., 2020; Vaughan & Giovanello, 2010). Indeed, stronger EF correlate with improved medication management, a broader range of daily activities being performed, and reduced impairment in these activities (Engel-Yeger & Rosenblum, 2021; Suchy et al., 2020; Vaughan & Giovanello, 2010). Thus, previous studies investigated the potential factors influencing EF to help older adults maintaining autonomy in their daily-life. While certain factors like education, cognitive reserve, physical activity, social relationships and health conditions influence the trajectory of EF, several factors remain understudied and not entirely understood (Stern, 2002). In later sections of this thesis, I will briefly describe the influence of gender, education, cognitive reserve, and personality traits' influences on EF performance in older age.

Noteworthy is the fact that EF relate with other cognitive domains also crucial for maintaining daily-life autonomy, such as PM. Indeed, EF and PM are closely linked as they are both located in the (pre)frontal regions of the brain and they both involve goal-oriented actions and planning (Zuber, 2017).

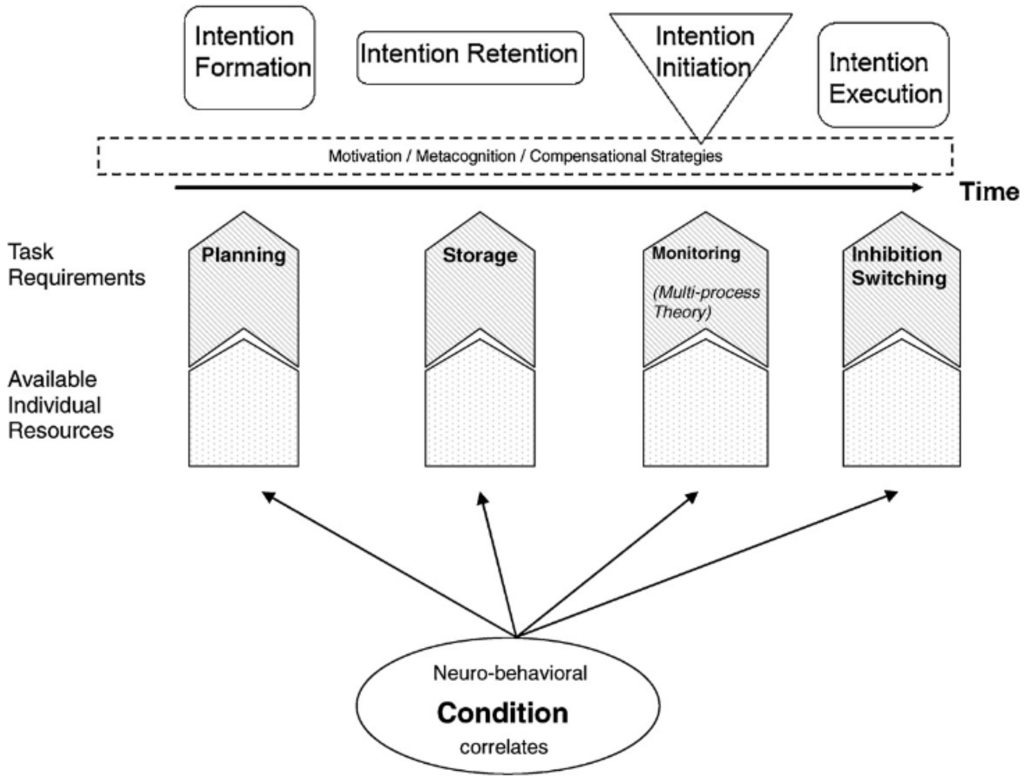
2.2 Prospective Memory

2.2.1 Definition

PM is the ability to execute intended actions in the future (Kliegel et al., 2008; McDaniel & Einstein, 2000). It is divided in two types of tasks, 1) the event-based PM tasks, which consist of executing the actions when a specific event occurs (e.g., taking your medication during dinner), and 2) time-based PM tasks, which consist of executing the intended actions at a specific time or when a specific amount of time has elapsed (e.eg., taking the cake out of the oven after 20 minutes; Kliegel et al., 2008; McDaniel & Einstein, 2000). PM is also divided in two components which are the prospective component (i.e., remembering that we have to execute an intended action; e.g., “I remember that I need to call someone after lunch”), and the retrospective component (i.e., remembering the content of the intended action; e.g., “I need to call the dentist to schedule an appointment”; Kliegel et al., 2008; McDaniel & Einstein, 2000). PM tasks include different phases through which the PM intention is processed: a) the intention formation, that is the phase in which individuals are planning the intention; b) the intention retention, which consists of maintaining the intention until the appropriate moment while performing other tasks (such as an ongoing-task); c) the intention initiation, the moment at which the execution of the intention is initiated; d) the intention execution, the execution of the PM intention as previously planned (see Figure 1; Kliegel et al., 2011).

Figure 1

PM Process Model and Underlying Mechanisms from Kliegel et al. (2011)



2.2.2 Prospective Memory Development

The performance of PM across the lifespan follows an inverted u-shape, informing researchers on its development, that is an increase in performance during school-age years, a stabilisation during adulthood, and a decrease in older age (Ballhausen et al., 2019; Kliegel et al., 2008; Zuber, 2017). Indeed, during early childhood, PM abilities emerge, with two-years old showing improved recall for high-interest tasks over lower-interest ones (Ballhausen et al., 2019; Zuber, 2017). PM consistently increases from preschool through primary school, with a culmination around the end of adolescence or early adulthood, attributed to the full maturation of the brain, especially the frontal lobe (Ballhausen et al., 2019; Zuber, 2017). Regarding age differences between younger and middle-aged adults, research is still scarce and unclear as certain studies demonstrated a superiority of younger adults over middle-aged ones, while other studies did not report this difference (Ballhausen et al., 2019). In laboratory settings, multiple previous research demonstrated that younger adults outperform older adults on both event-based and time-based PM tasks (Ballhausen et al., 2019). A reason evoked to explain these differences refers to the decline of EF abilities in older age. Indeed, with greater age comes a cognitive slowing that impacts EF abilities, leading to impairments in other cognitive domains related to EF, such as PM (Salthouse, 1996; Zuber, 2017). However, when considering PM performance of older adults in naturalistic settings, studies indicated that this age-difference in favour of younger adults is not replicated, and even sometimes older adults outperform their younger counterparts (Ballhausen et al., 2019; Henry et al., 2004). Such contrasting findings between laboratory and naturalistic settings suggest that certain factors may influence PM performance, leading to these differences. Previous studies indicated that the importance of the task and motivation can influence participants' involvement and subsequently improve their PM performance, meaning when the PM tasks' importance is stressed in the instructions compared to the ongoing-task, when there is a social importance provided such as helping the experimenter, or when there is a reward such as money (Walter & Meier, 2014). Moreover, commitments in real life also influence PM performance. Indeed, younger adults, engaged in education, employment, and social activities, prioritize these activities over the execution of PM tasks, while older adults, with potentially fewer obligations, consider ecological PM tasks of greater social importance (Altgassen et al., 2010; Maylor, 2008). Thus, it indicates that older adults seem to be able to use effective strategies to succeed at PM tasks when the right conditions are reunited, stressing the importance to investigate metacognitive processes as they are responsible of the implementation of strategies (Nelson & Narens, 1990). Even though older adults perform as well as younger adults for PM tasks in ecological settings, PM failures represent more than half of every day memory failures, potentially exerting negative influences on daily-life activities and autonomy (Crovitz & Daniel, 1984; Haas et al., 2020). Thus, researchers emphasize the need to understand the many factors influencing PM performance to counteract potential loss in autonomy (Einstein & McDaniel, 1990; Kliegel et al., 2008).

2.3 Socio-Demographic Factors Influencing Cognitive Aging

In the literature, certain factors have been brought up to be extremely relevant to consider when investigating cognitive aging as they explain differences in EF and PM performances. For instance, previous studies indicated that men have an advantage in EF-related flexibility, but are more susceptible to PM impairment than women (Huppert et al., 2000; Parsons et al., 2005). However, these findings are still debated, with certain authors arguing that gender stereotypes, in opposition to gender itself, may influence cognitive assessments (Hyde, 2005; Jäncke, 2018) (Hyde, 2005. When focusing on older adults, educational inequalities may also contribute, as men historically had better access to education than women (Sundstrom, 2004). Indeed, education, as another critical factor, has shown to be positively correlated with cognitive performance. Indeed, the Trail Making Test, a standard test for EF assessment, reveals that those with higher education levels tend to perform better (Tombaugh, 2004). Research highlighted the significant influence of education on cognitive flexibility and inhibition across the lifespan (Best et al., 2009; Rhodes, 2004). Huppert and Beardsall (1993) and Simard et al. (2019) have highlighted that older adults with higher educational attainment generally have improved PM performance. This higher PM performance for individuals with higher education stems from the concept of "cognitive reserve" which links higher education to healthier cognitive functioning (Künzi et al., 2021; Simard et al., 2019). Thus, these factors are now commonly integrated in cognitive research, either as dependent or control variables to consider their potential effect on cognitive abilities.

However, other factors, such as personality traits and affect, may be of great importance for EF and PM in older adults. Indeed, it has been demonstrated that personality influences the maintenance of health-behaviours, and that affect modulates cognitive performance (Booth et al., 2006; Gallo & Matthews, 2003). I will explore these dynamics further, with a specific focus on the intricate relationship between personality traits, neuroticism and cognition in the upcoming sections.

2.4 Personality Traits

The relationship between personality traits and cognitive functioning has been repeatedly examined in cross-sectional settings for extraversion, openness to experience, conscientiousness and agreeableness demonstrating that they are positively associated with cognitive functioning, and particularly with EF and PM tasks, meaning that higher levels on those traits are associated with higher EF and PM performances (Bell et al., 2020; Cuttler & Graf, 2007; Hall et al., 2014; Ihle, Zuber, et al., 2019; McCabe et al., 2018; Schretlen et al., 2010; Uttl et al., 2013; Williams et al., 2010a).

While most studies indicated that personality is quite stable across the lifespan, several other studies demonstrated significant changes (Aschwanden et al., 2017; Costa et al., 2018). In their review Costa et al. (2018) reported results of longitudinal studies indicating that well-established personality traits such as extraversion, openness to experience, agreeableness and conscientiousness decrease with age, while neuroticism increases. Several studies indicated that these changes in personality may be a precursor of cognitive decline and impairment (Balsis et al., 2005; Donati et al., 2013; Luchetti et al., 2016). Indeed, Balsis et al. (2005) indicated that, in certain healthy participants demonstrating changes in personality, postmortem autopsy revealed the presence of neurological markers of Alzheimer’s disease, suggesting that the occurrence of personality changes may be the first indication of future cognitive impairments. Moreover, studies demonstrated that conscientiousness and extraversion levels decrease in MCI participants overtime, while neuroticism increases (Balsis et al., 2005; Donati et al., 2013; Luchetti et al., 2016).

The literature on neuroticism presents a complex picture, with its impact on psychological well-being, life satisfaction, and autonomy in older age well-documented, it constitutes a crucial personality trait to understand, yet its influence on cognitive functioning remains unclear (Anglim et al., 2020; Hansson et al., 2020; Wettstein et al., 2018). Indeed, its relationship with EF appears inconsistent in cross-sectional studies and largely unexplored in longitudinal research, highlighting an area in urgent need of further investigation (Waggel et al., 2015). The following section will provide more detail on neuroticism's interplay with cognitive and affective domains.

2.4.1 At the Intersection Between Personality and Affect: Neuroticism

Neuroticism refers to the measurement of emotional instability, encompassing a general tendency to experience negative emotions such as fear, sadness, anger, guilt, and disgust, as well as a tendency for distress (Costa & McCrae, 1992, p.14). Individuals with elevated neuroticism scores display tendencies toward irrational thinking, impulsivity, difficulties with stress management, and higher susceptibility to psychiatric disorders (Costa & McCrae, 1992). Conversely, those with low neuroticism scores appear to exhibit emotional stability, demonstrating a relaxed and structured behavior when confronted with stressful situations (Costa & McCrae, 1992).

Several studies suggested that neuroticism may impair cognitive performance because of an increased impulsivity, task-related anxiety, stress, and intrusive thoughts (Andrews & Thomson, 2009; Bell et al., 2020; Chapman et al., 2017; McCabe et al., 2018; Munoz et al., 2013). However, contrasting findings also emerged, indicating no effect or even an amelioration of cognitive performance with higher levels of neuroticism (Anderson & McDaniel, 2019; Beckmann et al., 2013; Boyle et al., 2010; Cuttler & Graf, 2007; Hill et al., 2015; Uttl et al., 2013; Waggel et al., 2015). This enhancement of cognitive performance may arise because individuals with higher levels of neuroticism ruminate, which, at a certain level, may help them maintaining tasks instructions and goals (Andrews & Thomson, 2009). Perceived stress, often elevated in individuals with high neuroticism, may act as a mediating factor that exacerbates cognitive difficulties, suggesting a potential mechanism underlying the relationship between neuroticism and cognition (Aggarwal et al., 2014; Pereira-Morales et al., 2019). Following on the importance to understand whether personality changes are related to cognitive decline, a 2-year longitudinal study demonstrated that neuroticism impairs EF cross-sectionally, but not longitudinally (Waggel et al., 2015). The authors posited that the absence of observable longitudinal relationship between neuroticism and EF might be attributed to the short time-interval between baseline and follow-up. Indeed, they suggested that longer time-interval may be needed to allow the relationship to fully develop. Following on (Balsis et al., 2005; Donati et al., 2013; Luchetti et al., 2016) findings that personality changes precede the emergence of cognitive decline and the uncertainty revealed by studies on neuroticism and EF, it seems essential to investigate this relationship in a longitudinal setting to better understand how they are associated.

In conclusion, the influence of neuroticism on cognitive functioning in aging is not well understood yet, moreover, the mechanisms underlying this relationship are still unexplored, with only speculative hypotheses rather than actual empirical findings. This is unfortunate because figuring out how neuroticism interact with EF in older adults, cross-sectionally and longitudinally, can provide insights into the understanding of cognitive decline and have implications for daily-life autonomy. Moreover, research into how perceived stress could mediate the link between neuroticism and cognitive performance is essential, particularly since it could offer a target for interventions to support cognition in older adults.

On another level, clarifying the relationship between neuroticism and cognitive performance can have important implications for mental health in older adults. Neuroticism has been associated with increased risks of affective psychological disorders, such as post-traumatic stress disorder, anxiety, and depression, across all age groups (Banjongrewadee et al., 2020; Borja et al., 2009; Costa & McCrae, 1992; Jorm et al., 2000; Kendler et al., 2004). Thus, affective disorders related to neuroticism may also be worth considering in the investigation of cognitive health in older age. Further research into this relationship is not only academically interesting but could lead to practical applications that enhance the mental health and quality of life of aging populations. In the following section, I will explain associations between affect and cognitive aging and highlight remaining knowledge gaps when considering older age, starting with a definition of affect, its influence on cognition in older adults, and an examination of how depression interacts with cognitive processes.

2.5 Affect and Cognitive Aging

2.5.1 Definition of Affect and Emotions

Affect includes a diffuse and long-lasting positive or negative state that can persist for hours or days (Clore et al., 2018; Forgas, 2008), while emotions are brief processes triggered in response to a specific cue or event which include two steps: a) an activation based on relevance detection, and b) a multidimensional emotional response (Sander et al., 2005). Two dimensions characterize emotions, the valence (i.e., positive or negative) and arousal (i.e., the activation that the emotion elicit; Sander et al., 2005).

Storbeck & Clore (2007) indicated that research should integrate both emotion and cognition together instead of considering emotions independently from cognition. They argued that emotions are deployed based on a combination of affective and cognitive processes as emotions arise based on a cognitive appraisal. This appraisal approach indicates that to elicit an emotion, a stimulus must undergo a cognitive evaluation on different criteria, such as the relevance for oneself (e.g., will this event affect me?), the implication (e.g., what consequences will have this event?), the coping mechanism (e.g., am I able to adapt myself to these consequences?), the normative significance (e.g., what does this event mean for my internal standards, and for the external ones?; Sander et al., 2005). Once the stimuli or event underwent the appraisal, other components of emotions are triggered such as the autonomic physiology (e.g., heart rate increase), the action tendencies (i.e., usually – but not always, an approach tendency for positive stimuli, and an avoidance tendency for negative stimuli), motor expression (e.g., facial expression such as smiling), and the subjective feeling of the emotion (Sander et al., 2005). Nowadays, most researchers consider the existence of six basic emotions, which are fear, happiness, disgust, surprise, anger and sadness (Sander et al., 2005).

Affective and emotional well-being play a crucial role for maintaining a high quality of life and autonomy, particularly among older adults as it prevents from stroke, and promotes healthcare (Baernholdt et al., 2012; Gao, 2018; Ostir et al., 2001). On the contrary experiencing negative emotions and affect such as stress, anxiety and depression can impair cognitive performance in older adults (Aggarwal et al., 2014; Almondes et al., 2016; Beaudreau & OHara, 2008). However, contrasting findings emerged in the literature, suggesting a need for further investigations.

2.5.2 Effects of Affect on Cognitive Aging

Phelps (2006) explains that emotions may have an influence on three components of episodic memory: encoding, consolidation and subjective remembering. According to this paper, during the appraisal of stimuli, the amygdala evaluates their relevance and modulates the thresholds of attentional and perceptual processes in favor of emotional stimuli compared to neutral stimuli. Thus, presenting emotional PM cues may improve both their encoding and recognition compared to neutral ones, subsequently improving PM performance. A recent meta-analysis about PM and emotions demonstrated that positive cues seem to improve PM performance for both younger and older adults (Hostler et al., 2018). Moreover, the benefits encountered by older adults for positive PM cues is greater than for younger adults (Hostler et al., 2018). This can be explained by the socioemotional selectivity theory, which suggests the existence of a positivity bias in older adults as with greater age they would focus on “hedonic and meaningful” emotional goals rather learning goals (Carstensen & Mikels, 2005). Consequently, they would involve more cognitive resources toward relevant information matching these hedonic goals, such as stimuli of positive valence. However, this pattern of improved PM performance for positive cues in older adults is not replicated in most studies that Hostler et al. (2018) included in their analyses, suggesting that other factors may underlie this effect. Representations that individuals have about emotional stimuli may be interesting to consider, I will develop this idea later in this manuscript, when referring to metacognition and metamemory.

The relationships between affect and cognitive performance among older adults is complex. While certain studies demonstrated enhancing effects of stress on EF and PM, they indicated that these benefits may arise among those with a robust cognitive reserve (Hidalgo et al., 2019; Ihle et al., 2012; Plieger & Reuter, 2020; Schnitzspahn et al., 2022). On the contrary, other research indicated that higher stress levels correlate with accelerated cognitive decline and poorer EF (Aggarwal et al., 2014; Hidalgo et al., 2019; Ihle et al., 2014; Plieger & Reuter, 2020). A theory postulates that when individuals perceive stress as a challenge rather than a threat, it can increase their motivation, and improve effort and focus on cognitive tasks, highlighting the importance of metacognitive (and meta-affective) representations (Shields et al., 2017; Travis et al., 2020). Further, the timing of stress is crucial: stress experienced after the encoding phase of a memory task might facilitate memory consolidation, while stress during the encoding phase might impair the process and subsequently impair the performance (Shields et al., 2017). Similarly, the influence of anxiety on cognitive functioning presents contradictions. While some evidence suggested that higher anxiety levels can be detrimental to cognitive processes, other studies demonstrated a cognitive improvement or indicated a non-significant relationship (Beaudreau & OHara, 2008). These effects might be level-dependent:

while moderate levels of anxiety can enhance cognitive processes due to higher alertness, excessive amounts can impair them because of interference with working memory and increased rumination (Eysenck & Calvo, 1992; Mathews & MacLeod, 2005).

Therefore, if neuroticism and other affective factors, such as stress and anxiety, are associated with cognitive performance, it is relevant to consider whether this also applies to individuals experiencing affective psychological disorders. Beyond stress and anxiety, neuroticism is also a risk factor for depression, which is one of the most common mental health condition in older adults (Kendler et al., 2004; World Health Organization, 2017, December). Therefore, it is relevant to investigate whether associations between depressive symptoms and cognitive performance also arise in older adults.

2.5.3 Depressive Symptoms and Cognitive Aging

Depression is characterized by fatigue, anhedonia, lack of interest, difficulties with sleep, and rumination (American Psychiatric Association, 2013). The World Health Organization (2017) indicates that 15% of older adults are suffering from a mental health disorder, which, for half of them, is depression.

While most research on depressive symptoms in younger adults demonstrated a detrimental influence on cognitive performance across various domains, certain studies also investigated this relationship in older adults. They indicated that the direction of the link between depressive symptoms and EF is still to determine as some of them showed that older adults with depressive symptoms are impaired on EF (Almondes et al., 2016; Siqueira et al., 2022), while other suggested that their depression may arise from an EF dysfunction (i.e., the depression-executive dysfunction; Alexopoulos, 2003). Indeed, individuals may develop depressive symptoms if rumination processes are not inhibited, and everyday goals are not met because of a lack in inhibition and planning skills. Surprisingly, there is plenty of research available on the relationship between depression and retrospective memory, demonstrating a detrimental influence (for a meta-analysis see James et al., 2021), while research on PM is really scarce.

When considering the relationship between depressive symptoms and PM in older adults, findings remain inconsistent. Out of two studies on this subject, one indicated that depressive symptoms were associated with impaired performance on the retrospective component of PM, but there was no association with the prospective component (Livner et al., 2008). The second study revealed no association between depression and PM performance on an event-based PM task, while depressed participants were more accurate than control on a time-based PM task (Albiński et al., 2012). This suggests that the relationship between depressive symptoms and PM is not straightforward. Interestingly, previous research suggested that the relationship between depressive symptoms and cognitive outcomes is complex. Certain studies have found an inverted U-shaped relationship, meaning that individuals with moderate levels of depressive symptoms performed better on certain cognitive tasks compared to those with low or very high levels of depressive symptoms (Andrews & Thomson, 2009). This suggests that a certain level of depressive symptoms may enhance cognitive performance, possibly due to a phenomenon known as analytical rumination, which is a cognitive process associated with depressive affect. It involves two components: causal analysis (i.e., understanding the origins of depression-related problems) and problem-solving analysis (i.e., finding ways to solve these problems; Andrews & Thomson, 2009; Bartoskova et al., 2018; Sevcikova et al., 2020). Individuals with subclinical levels of depressive symptoms may rely on analytical rumination and reflection, which could explain why they outperform individuals with lower depressive symptoms and those with clinical depression on cognitive tasks. Thus, this phenomenon could explain Albiński et al.'s results (2012), in which participants with higher levels of depressive symptoms performed better on a time-based prospective memory task compared to those with lower levels.

To resume, even though depression is the leading cause of disability worldwide and is the most common psychological disorder encountered by older adults, the knowledge on its relationship with cognitive functioning in aging is still scarce and inconsistent. This inconsistency raises questions and suggests that researchers may not be understanding nor targeting the actual underlying mechanisms of this relationship. As individuals with depressive symptoms tend to have biased – and negative – representations about the world, others and themselves, including their cognitive performance, it may be interesting to include metacognitive processes in the study on the relationship between affect and cognitive aging (Beck, 1976; Wells, 2008a, 2008b).

2.6 Metacognition, Metamemory and Cognitive Aging

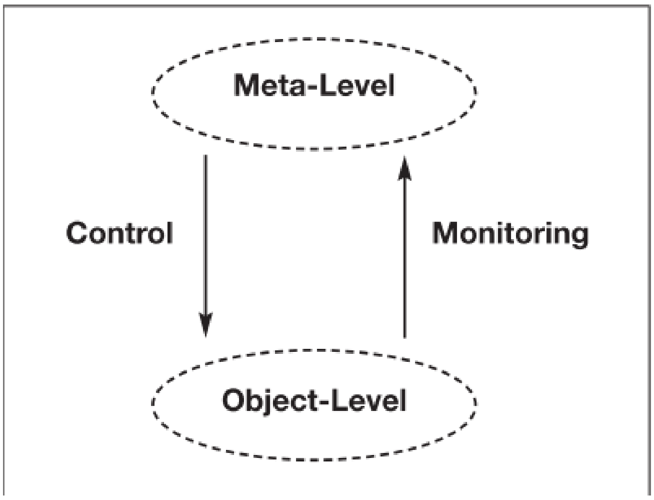
2.6.1 Definition

Metacognition is an umbrella term for the knowledge that individuals have about their cognitive functioning, development and capacities (Kuhlmann, 2019). Flavell (1979) modeled metacognition using four components, which are a) metacognitive knowledge, meaning ones' own beliefs about their cognition; b) metacognitive experiences, meaning the cues provided by the environment (or a task) that are relevant to better understand one's own cognition; c) goals, meaning the expected outcomes after having performed a cognitive task; and d) strategies, meaning the behaviors and strategies that individuals implement to achieve their cognitive goals. Previous research demonstrated that older adults suffering from aging stereotypes (i.e., negative metacognitive representations of their cognitive abilities because of greater age) exhibit impaired cognitive performance compared to older adults for whom these stereotypes were not activated (for a review and meta-analysis see Lamont et al., 2015). Common concerns and stereotypes encountered by older adults concern their memory abilities (Hertzog et al., 1999). The metacognition for memory is called metamemory.

Nelson & Narens (1990) explain that metamemory is composed of a meta-level, which includes metamemory representations (i.e., the representations individuals have about their memory abilities), and an object-level, (i.e., such as the environment or situation that we are in, and the observed component of metamemory such as the success or failure at a task). There are two processes working between these levels: a) the “monitoring” process which reflects the information about our memory performance, that comes from the object-level, to shape our representations; and b) the “control” process, which is a regulation process that individuals use to control their performance by implementing strategies (see Figure 2). Both processes are working together in a loop, meaning that the implementation of strategies depends on the representations that individuals have of their memory abilities.

Figure 2

Meta-Level and Object-Level with the Monitoring and Control Processes from Nelson & Narens (1990)



2.6.2 Measurement Tools

To measure individuals’ representations of their memory abilities, researchers target off-line or on-line metamemory representations. Off-line metamemory representations refer to global knowledge and representations that individuals have about their memory functioning and their memory failures in everyday life (Perrotin & Isingrini, 2010). They can be measured using metamemory questionnaires such as the Metamemory In Adulthood (Dixon & Hultsch, 1983b), Memory Functioning Questionnaire (Gilewski & Zelinski, 1988), or the Memory Self-Efficacy Questionnaire (Berry et al., 1989). On-line representations refer to individuals' representations about their memory abilities for a specific task that is simultaneously presented (Perrotin & Isingrini, 2010). To measure on-line metamemory representations, researchers usually ask participants to predict their performance using judgements of learning (JOL) in which they predict their performance during (or right after) the learning phase. It is also possible to measure metamemory after the execution of the task, in this case, researchers ask participants to do postdictions using judgements of confidence (JOC), meaning that participants evaluate their performance or indicate how confident they are about their performance. Comparing predictions and postdictions to actual performance helps understand whether individuals have accurate representations of their memory abilities, which may have implications for strategies' implementation and performance.

In more detail, if individuals consider that their performance is lower than their expectations, they may implement strategies to compensate for this discrepancy between their actual abilities and the expected ones. However, if individuals' metamemory representations are not accurate this may have consequences. Indeed, if individuals underestimate their memory abilities (meaning that they think their abilities are lower than they actually are), this might create anxious and checking behaviors about memory performance (Cuttler et al., 2013; Uttl et al., 2018). On the contrary, if individuals overestimate their memory abilities (meaning that they think they perform better than they actually do), they will not implement effective strategies to compensate for their forgetfulness as they are not aware that they forget (Scarampi & Gilbert, 2021). Not having accurate metamemory representations, keeping forgetting to do things such as PM intentions (e.g., forgetting to go to appointments, to take medication or to pay the bills), and not being aware of it, may finally impair autonomy in daily-life.

2.6.3 Metamemory and Prospective Memory

Research explored the relationship between metamemory and PM performance in both younger and older adults. They demonstrated significant positive relationship between memory self-efficacy and PM performance (Mcdonald-Miszczak et al., 1999; Rimmele et al., 2022). This relationship can be explained by the fact that memory self-efficacy is dependent of perception of internal control. Essentially, if individuals believe that they have control and power over their PM abilities, it may increase their motivation to invest effort in the task and to succeed (Mcdonald-Miszczak et al., 1999; Rimmele et al., 2022). In comparison, if individuals perceive themselves as not efficient and that their performance is out their control (and rather depend on external factors), they may easily be discouraged and invest fewer effort into succeeding at the task (Mcdonald-Miszczak et al., 1999).

Yet, when considering individuals' predictions' and postdictions' accuracy on PM performance, different patterns emerge depending on age. Indeed, while younger and middle-aged adults tend to underestimate their PM performance, older adults overestimate theirs (Cauvin et al., 2019a; Cauvin et al., 2019b; Kuhlmann, 2019). For instance, in Cauvin et al.'s study (2019a) younger and older adults were confronted to a lexical decision task in which was embedded an event-based PM task for which participants had to perform a specific action when they encountered a PM-target word that had been previously presented. Even though PM predictions were similar between younger and older adults, their actual performance was significantly different as younger adults outperformed older adults. Moreover, older adults were overconfident for the first block of the task and even demonstrated a greater overconfidence for the second block of the task. These results suggest that older adults may have inaccurate representations of their PM abilities and, even though it was not the main aim of the study, that these representations are not updated towards more accurate ones across the task. Two studies investigating the evolution of metamemory representations after having performed the task on younger adults and middle-aged adults demonstrated that both younger and middle-aged adults' underconfidence towards their PM abilities persisted from predictions to postdictions (Meeks et al., 2007; Ng et al., 2018). It is worth noting that, in Ng et al.'s study (2018), certain participants (at an individual-level, not group-level) were able to modify their PM representations towards more accurate ones. As it is not clear in this study whether the stimuli used were emotional or not, it can be a potential explanation on what may have impacted participants' monitoring of their metamemory representations.

While there is a lack of research on PM metamemory representations evolution across trials in older adults, existing studies on retrospective memory suggested that they are able to improve their metamemory accuracy (Hertzog et al., 1990; Perrotin & Isingrini, 2010; Tullis & Benjamin, 2012). As PM abilities are key to maintain older adults daily-life autonomy, and metamemory representations are essential to implement effective strategies to succeed at memory tasks, it is important to investigate whether older adults PM metamemory representations evolve across trials towards more accurate representations, and whether PM cues' valence may influence this metamemory monitoring.

2.6.4 Metamemory and Affect

As previously mentioned in the section about affect, Phelps (2006) indicates that emotions may influence subjective remembering. Indeed, highly emotional public events (e.g., such as bomb attacks) are usually described vividly and with great confidence even though details are actually often incorrect. Then it suggests that the emotionality of an event or stimulus may influence metamemory representations, eliciting high confidence in the memory without actual accuracy.

Indeed, research focused on retrospective memory consistently demonstrated that emotional valence influences metamemory predictions. Both younger and older adults tend to believe that they are more likely to remember emotional stimuli in comparison to neutral ones (Hourihan, 2020; Hourihan & Bursey, 2017; Sanders & Berry, 2021; Tauber et al., 2017; Tauber & Dunlosky, 2012, p. 201; Witherby & Tauber, 2018). However, participants' predictions for emotional stimuli do not always align with their actual performance. Certain studies revealed that while participants may predict better memory for specific emotional stimuli, such as positive ones, their performance was either a) influenced by a different valence or by neutral stimuli (Hourihan, 2020), or b) is unaffected by stimulus valence (Hourihan & Bursey, 2017; Sanders & Berry, 2021; Tauber & Dunlosky, 2012; Witherby & Tauber, 2018). This suggests that participants may have biased representations of their memory abilities when confronted with emotional stimuli. Furthermore, the presence of both negative and positive biases in different studies does not clarify whether participants' predictions are sensitive to specific valences, such as positive versus negative. These interesting findings have not been explored in the context of PM, leaving a gap in our understanding of the interplay between affect, metamemory and PM.

Regarding affective psychological disorders, such as depression, clinicians describe the development, maintenance and offer therapy for these disorders based on metacognition (Wells, 2000, 2008b). In these books, the authors described the Self-Regulatory Executive Function model (S-REF; Wells & Matthews, 1996) which suggests that psychological distress arises from higher neuroticism levels and a “maladaptive self-regulation”. Within this model, there are metacognitive beliefs which are categorized as positive and negative. Positive metacognitive beliefs consider rumination and worry as beneficial for problem-solving and emotional processing (e.g., “worrying helps me cope”), while negative metacognitive beliefs consider that one’s own thoughts might be uncontrollable and dangerous (e.g., “I can’t stop worrying and it is making me sick"). This dichotomy between metacognitive beliefs is a fertile ground for the activation of the Cognitive Attentional Syndrome. This syndrome is central in the S-REF model and includes cognitive components such as "worry and rumination", "threat monitoring", and "maladaptive coping behaviors". These components supposedly interact with the two types of metacognitive beliefs and may amplify symptoms, such as depressive ones. Indeed, increased rumination focuses the attention on depressive symptoms but also on the causes and consequences of distress, subsequently reinforcing negative affect. Threat monitoring exacerbates this by increasing perceptions of risk and vulnerability. Simultaneously, maladaptive coping strategies, such as avoidance, allow a temporary relief but, in the end, maintain or worsen depressive symptoms. The interplay between the Cognitive Attentional Syndrome and metacognitive beliefs creates a reinforcing feedback loop which is resistant to change. This relationship not only maintains depression, but may also lead to cognitive impairments as internal thoughts and symptoms occupy the central place in one's focus, leading cognitive resources to be disengaged from cognitive (external) tasks.

Consequently, depressive symptoms have been associated with higher memory complaints, lower metamemory representations and lower accuracy on retrospective memory tasks (Balash et al., 2013; Cipolli et al., 1996; Metternich et al., 2009; Zandi, 2004). Regarding PM, a recent study investigated the relationship between depressive symptoms and metamemory representations in younger adults, demonstrating higher PM complaints in depressed younger adults compared to the healthy group (Huber et al., 2022a). To our knowledge, this relationship has not been studied in older adults. This is unfortunate as depression is the leading psychological disorder experienced by older adults, as metamemory representations are essential for strategic behaviors, and as PM is highly related to daily-life autonomy. Moreover, this could help us understand further the underlying mechanisms at play between depressive symptoms and cognitive performance in aging.

3 Literature conclusion

Taken together, cognitive domains in older adults, such as EF and PM, are crucial for maintaining autonomy in older age, yet uncertainties and unanswered questions remain (Hering, Kliegel, Rendell, et al., 2018; Laera et al., 2021). Following on previous literature findings, the main aim of this thesis is to understand the interplay between affect, metacognition and cognitive functioning in older adults. Indeed, previous research investigated these domains separately, demonstrating interesting findings, however little knowledge is available regarding these domains combined together. Additionally, when previous studies focused on these domains combined, they reported inconsistencies. There is an important need to clarify this interaction as it may have potential opportunities and consequences for interventions and daily-life autonomy of older adults.

First, it appears that the impact of emotional instability -neuroticism- on EF is still not well understood in longitudinal designs even though it is necessary to assess whether it is a precursor for subsequent cognitive decline (Balsis et al., 2005; Luchetti et al., 2016; Waggel et al., 2015). Moreover, the mechanisms underlying this relationship are still undetermined. Perceived stress arises as a potential interesting mediator as it is considered as a combination of affect and metacognitive processes, referring to individuals' representations about their ability to manage stressful situations (Spada et al., 2008; Travis et al., 2020).

Second, as neuroticism has been related to numerous affective psychological disorders, and importantly to depression - one the most common psychological disorder, other affective variables such as depressive symptoms may also influence performance on cognition (Wells, 2000, 2008b; World Health Organization, 2017, December). Previous studies reported very scarce and inconsistent results when comparing older adults with and without depressive symptoms on PM performance (Albiński et al., 2012; Livner et al., 2008). This inconsistency may stem from the neglection of potential underlying factors, such as metamemory representations. Indeed, depressive individuals often experience distorted metacognitive representations, potentially affecting their involvement in a task and the implementation of strategies (Wells, 2000, 2008b).

Third, as metamemory representations influence effort engagement and strategies' implementation, understanding whether older adults can monitor their metamemory representations to use effective strategies for succeeding at PM tasks relevant to daily-life autonomy is crucial. However, and unfortunately, this area of research remains unexplored which does not allow to understand whether the monitoring process of metamemory is properly functioning in older adults (meaning that it is able to update representations), even though this is crucial to implement effective strategies and perform accurately on PM tasks. Furthermore, the emotional valence of stimuli has been shown to influence metamemory representations in memory tasks, suggesting that it could also influence metamemory representations in older adults' PM tasks and whether they monitor them or not (Hourihan, 2020; Hourihan & Bursey, 2017).

4 Research Questions

The main objective of this thesis is to investigate and understand whether and how neuroticism, depressive symptoms and stimuli valence interact with metacognitive processes on cognitive abilities supporting daily-life autonomy, EF and PM. To do so, and based on the open questions raised by previous literature, I focused on three research objectives which are 1) understanding how emotional instability – neuroticism - longitudinally influences cognitive aging in EF, 2) investigating the relationship between depressive symptoms, metacognition and PM performance in older age groups, 3) exploring how age-related differences and emotional valence relate to PM metamemory representations and actual PM performance. The following objectives and hypotheses guided the three studies presented in this thesis.

4.1 Objective 1: Understanding How Emotional (In-)Stability Longitudinally Influences Cognitive Aging in Executive Functioning

Several studies demonstrated that neuroticism, characterized by emotional instability, is associated with poorer performance on global cognition and higher reaction times in older age (Jorm et al., 1993; Waggel et al., 2015). However, the association between neuroticism and specific higher order cognitive domains such as EF is understudied and the few existing studies showed inconsistent results in older adults compared to younger adults. Uncovering whether neuroticism and EF are associated is of great importance as several studies reported that neuroticism levels increase in older age (Kandler et al., 2015; Mõttus et al., 2012), while EF contribute to daily functioning and health-related behaviours of older adults, supporting successful aging and autonomy (e.g., Diamond, 2013; Laera et al., 2021; Miyake et al., 2000; Suchy et al., 2020).

Thus, the first major objective of the present thesis was to examine (a) whether neuroticism relates to EF performance in older adults, (b) which mechanism may be associated to this relationship, and (c) whether and how this relationship may develop over time. The existence of a link between neuroticism and EF was hypothesized, without specifying its direction as longitudinal studies are lacking in this research domain. Perceived stress was considered as a potential underlying factor in this relationship, as neuroticism would increase perceived stress, which may subsequently impair EF performance.

4.2 Objective 2: Investigating the Relationship Between Depressive Symptoms, Metacognition and Prospective Memory Performance in Older Age Groups

In the second study, we took a step further in our investigation of the relationship between affect and cognition by focusing on depressive symptoms, metamemory representations and PM performance. Indeed, neuroticism and stress are related to the occurrence of depressive symptoms, which in turn create distorted metacognitive representations of one's own cognitive performance that can be associated with actual cognitive performance (Beck, 1976; Costa & McCrae, 1992; Jorm et al., 2000; Kendler et al., 2004; Wells, 2008b). Despite extensive research on depression in older adults, only two studies have investigated the relationship between depressive symptoms and PM in the aging population – with inconsistent results (Albiński et al., 2012; Livner et al., 2008), which is unfortunate as PM has been previously related to daily-life autonomy and independence, especially in older adults (Altgassen et al., 2009; Chen et al., 2013; Hering, Kliegel, Rendell, et al., 2018; Laera et al., 2021). To disentangle these inconsistencies, we investigated this relationship in young-old and old-old adults as recent studies indicate that old-old adults differ from young-old adults in their cognitive and affective development (Escourrou et al., 2020; Henry et al., 2004; Mehta et al., 2008).

Thus, the second major objective of this thesis aims to (a) address the knowledge gap on depressive symptoms and PM performance in older age as the findings are scarce and inconsistent, and to (b) understand the underlying mechanisms that may influence this relationship, such as metamemory representations, education and gender. Considering that this is the first study to investigate depressive symptoms, metamemory, education, gender and age, we did not have specific hypothesis regarding the effects of all these variables together, especially because opposite effects may occur and compete.

4.3 Objective 3: Exploring How Age-Related Differences and Emotional Valences Relate to Prospective Memory Metamemory Representations and Actual Prospective Memory Performance

Previous studies investigating metamemory representations in PM indicated that younger adults are underconfident in their performance, while older adults are overconfident (Cauvin et al., 2019a; Cauvin et al., 2019b; Meeks et al., 2007). It is of particular interest to understand what may influence these PM representations, and whether they can be modified because if older adults are overconfident in their PM performance, they may not implement effective strategies. Research on retrospective memory indicated that metamemory representations are influenced by the valence of emotional stimuli, however this has not been investigated in the context of PM (see for examples Hourihan, 2020; Hourihan & Bursey, 2017; Tauber et al., 2017). Moreover, only one study of Ng et al. (2018) indicated that certain adults of 50 years old and more, at an individual-level, were able to modify their predictions for PM task. Thus, we decided to explore the relationship between age, metamemory representations (predictions and postdictions) and PM performance with emotional stimuli.

Thus, the third objective of this thesis was a) to explore whether cues' emotional valences differentially influence PM metamemory representations, and b) whether individuals were able to modify their PM metamemory representations after performing the task. We expected that younger adults would outperform older adults on the event-based PM task, we also expected that younger adults would be underconfident regarding their metamemory PM representations, while older adults would be overconfident. Regarding the effect of PM cues' emotional valence on metamemory representations and PM performance, we explored this relationship without specific hypotheses as the literature demonstrated inconsistencies.

5 Study 1: Higher Levels of Neuroticism in Older Adults Predict Lower Executive Functioning Across Time: The Mediating Role of Perceived Stress

5.1 Abstract

Neuroticism has been associated with individual differences across multiple cognitive functions. Yet, the literature on its specific association with executive functions (EF) in older adults is scarce, especially using longitudinal designs. To disentangle the specific influence of neuroticism on EF and on coarse cognitive functioning in old adulthood, respectively, we examined the relationship between neuroticism, the Trail Making Test (TMT) and the Mini-Mental State Examination (MMSE) in a 6-year longitudinal study using Bayesian analyses. Data of 768 older adults (Mage = 73.51 years at Wave 1) were included in a cross-lagged analysis. Results showed no cross-sectional link between neuroticism and TMT performance at Wave 1 and no longitudinal link between neuroticism at Wave 1 and MMSE at Wave 2. However, neuroticism at Wave 1 predicted TMT performance at Wave 2, indicating that the more neurotic participants were, the lower they performed on the TMT six years later. Additional analyses showed that this relation was fully mediated by participants' perceived stress. Our results suggest that the more neurotic older adults are the more stress they may perceive six years later, which in turn negatively relates to their EF. In sum, this study demonstrates that neuroticism may lead to lower EF in older age across six years. It further suggests older adults' perceived stress as mediator, thereby providing novel insights into the mechanisms underlying this relation. Possible intervention approaches to counter these effects are discussed.

5.2 Introduction

As the population's longevity is continuously increasing, age-related cognitive decline has become one of the main issues in the study of aging (Kramer, 2012). Indeed, it is well established that many cognitive abilities decline with increasing age, particularly those related to executive functions (EF; Clarys et al., 2009; Fjell et al., 2017; Isingrini et al., 2008). Thus, uncovering which factors contribute to the maintenance or loss of EF across the lifespan is crucial. Not only does this allow to understand which factors can lead to a decrease in EF, but also to set up possible interventions to support individuals in preserving autonomy in their daily life as long as possible. EF are defined as top-down cognitive processes that contribute to planning, reasoning, managing goals, dealing with unexpected challenges and self-regulation (Diamond, 2013). As they contribute to older adults' daily functioning and health-related behaviors (e.g., management of medication and chronic illness), EF are considered of major importance in successful aging and are crucial to maintain the autonomy of older adults (Engel-Yeger & Rosenblum, 2021; Suchy, 2020; Vaughan & Giovanello, 2010). In addition, EF are also indicators of subsequent neurocognitive diseases such as mild cognitive impairment and Alzheimer's disease (Allain et al., 2013; Espinosa et al., 2009; Storandt, 2008). Previous studies have gained important insights regarding factors that affect whether and to which degree EF decrease with age. For example, they have highlighted that lifestyle and socioeconomic factors (such as higher levels of education, higher socioeconomic status, or longer engagement in professional and non-professional occupations) can help preserve older adults' cognitive abilities in general and EF in particular (Delgado-Losada et al., 2019; Ihle et al., 2018a; Moorman et al., 2018; Roldán-Tapia et al., 2012). Of key interest for the present study, personality traits have also been associated with age-related changes in EF (Booth et al., 2006; Chapman et al., 2017; DeYoung et al., 2010; Hall et al., 2014; Waggel et al., 2015).

Personality traits can be defined as an individual's disposition to behave in a similar, consistent way across different situations (Costa & McCrae, 1980). According to the Big Five Model, the following personality traits can be distinguished: openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism (Costa and McCrae, 1992). The relationship to EF has been repeatedly examined for openness to experience, conscientiousness, extraversion, agreeableness (Bell et al., 2020; Buchanan, 2016; Campbell et al., 2011; Chapman et al., 2017; DeYoung et al., 2010; Hall et al., 2014; Ihle, Zuber, et al., 2019; Jensen-Campbell et al., 2002; Murdock et al., 2013; Roye et al., 2020; Schretlen et al., 2010; Unsworth et al., 2009; Williams et al., 2010b). In contrast, so far, very few studies investigated the association between neuroticism and EF, and particularly how EF develop as a function of neuroticism in old age. According to the Big Five Model, neuroticism is characterized by irrationality of thoughts, low ability to manage impulsions and stress, emotional instability, and consequently, a higher risk of developing psychiatric disorders (Costa & McCrae, 1992). However, while the negative relationship between neuroticism and EF seems well established in younger adults (Crow, 2019; Murdock et al., 2013; Purić & Pavlović, 2012; Schretlen et al., 2010), research on older adults is still inconsistent. Indeed, certain studies did not find a significant link between neuroticism and EF (Boyle et al., 2010; Hill et al., 2015; Turunen et al., 2020; Waggel et al., 2015), whereas others found that neuroticism was negatively associated with EF in older adults (Bell et al., 2020; Booth et al., 2006; Chapman et al., 2017; Denburg et al., 2009; Kim et al., 2022; Williams et al., 2010b). Except for Kim et al.'s (2021) study, which demonstrates that sleep quality moderates the relationship between neuroticism and EF, little is known about mechanisms through which neuroticism may be associated with EF.

Thus, the potential mechanisms through which neuroticism may affect EF largely have yet to be examined. One possible mechanism involved in the relationship between neuroticism and EF might be stress. Indeed, higher levels of neuroticism have been associated with experiencing more negative affect, such as stress (Costa & McCrae, 1992; Curtis et al., 2015). Stress, in turn, has been associated with more intrusive thoughts, reduced levels of interference control, decreased attention, and thereby can impair performance on cognitive tasks and lead to everyday cognitive failures (Boals & Banks, 2012; Braunstein-Bercovitz, 2003; Caswell et al., 2003; Curtis et al., 2015; Lupien et al., 2009). Previous research on older adults further indicated that higher levels of stress are negatively associated with EF and positively to accelerated cognitive decline (Aggarwal et al., 2014; Diamond, 2013; Ihle et al., 2020; Liston et al., 2009; Oaten & Cheng, 2005; Orem et al., 2009; Wolff et al., 2021). So far, there has been no longitudinal study exploring whether the relationship between neuroticism and EF may be mediated by stress among older adults. This is unfortunate because if perceived stress indeed mediates the link between neuroticism and EF, targeting stress perception with interventions like mindfulness could reduce both the stress and the risk of adults' cognitive decline. Therefore, we aimed to explore this mechanism in the present study in a longitudinal design.

Indeed, research on neuroticism and EF in older adults also lacks longitudinal studies as most previous studies were cross-sectional (but see Waggel et al., 2015). One of the shortcomings of cross-sectional studies is that they do not provide information on how neuroticism and EF develop over time (Sedgwick, 2014). Moreover, discrepancies have been observed between the results of cross-sectional versus longitudinal studies that targeted other cognitive processes. Specifically, previous studies suggest cross-sectional studies usually depict a more negative image of older adults' abilities than results of longitudinal studies showed (Damon, 1965; Hedden & Gabrieli, 2004; Schaie, 1996; Schaie & Strother, 1968). Therefore, it is relevant to explore neuroticism and EF in a longitudinal design to explore whether cross-sectional effects are maintained over time or whether a different pattern appears longitudinally. It is noteworthy that, when assessing longitudinal mediation effects, it has been indicated that three waves of data collection should be favored over two. Specifically, compared to two waves, including three or more waves is more likely to avoid bias on the estimates of the mediation effects by accounting more precisely for previous values of the dependent variable (Cole & Maxwell, 2003; O'Laughlin et al., 2018). However, although examining data from even more waves does provide certain advantages, two waves longitudinal mediation analyses have been frequently used to examine potential links between different psychological constructs (Bilevicius et al., 2018; Butt et al., 2020, p. 202; Frazier et al., 2017; Ihle, Fagot, et al., 2019; Ju & Lee, 2018; Kwon et al., 2018; Royuela-Colomer & Calvete, 2016; Weber & Exner, 2013). Further, previous studies show that two waves can be sufficient to examine such links using structural equation modeling (Bilevicius et al., 2018; Frazier et al., 2017; Ihle, Fagot, et al., 2019; Ju & Lee, 2018; Kwon et al., 2018; Royuela-Colomer & Calvete, 2016). Indeed, previous research shows that two waves of data still provide results that go beyond cross-sectional analyses. For example, Jose (2016) applied both cross-sectional and longitudinal analyses to the same dataset and found that of six significant cross-sectional mediations only four remained significant when examined longitudinally. Thus, even two-wave longitudinal studies may provide important information on abilities' development over time and demonstrate that cross-sectional conclusions should be taken cautiously when considering long-term implications such as interventions.

To the best of our knowledge, only one longitudinal study focusing on older adults has investigated the relationship between neuroticism and EF in older adults. Waggel and colleagues (2015) investigated performance on the TMT (as key indicator of EF) in a longitudinal study design of two years among 493 older adults and demonstrated that higher neuroticism scores were cross-sectionally associated with poorer performance on the TMT but did not predict future decline among older adults (Waggel et al., 2015). The authors explained that longer follow-up periods may be more appropriate to examine potential associations between neuroticism and cognitive measures because neuroticism could start influencing cognition earlier in life and potential effects may thus be more difficult to detect within old age. Considering this empirical and theoretical framework, we longitudinally investigated the relationship between neuroticism and EF with perceived stress as a potential mediator. Specifically, the first goal of the present study was to examine whether neuroticism is associated with EF (as indexed by performance on the TMT) beyond its possible relationship with coarse cognitive functioning (as indexed by performance on the Mini-Mental State Examination; MMSE, Folstein et al., 1975) among older adults in a longitudinal study across 6 years. As previous studies are lacking longitudinal results to assess the joint development of neuroticism and EF in late adulthood, we hypothesized a link between neuroticism and TMT (and between TMT and neuroticism) across six years without specifying the direction (positive vs. negative) of this link. The second goal of the present study was to explore whether perceived stress mediates the link between neuroticism and TMT across our two waves of data. Related to this, we further aimed to test a potential reverse causation by examining possible evidence for EF mediating the relationship between neuroticism and perceived stress.

5.3 Method

Data stem from the first and second waves of the longitudinal study “Vivre – Leben – Vivere” (VLV), which investigated cognitive aging across the lifespan in Switzerland. Participants were assessed in 2011 and 2017 in a face-to-face computer-assisted personal interview (for more details on the procedure, see (Ihle et al., 2018a; Künzi et al., 2021; Mella et al., 2018; Vallet et al., 2020).

The initial sample consisted of 3080 participants at the first wave and 1059 at the second wave (six years later). For the subsequent analyses, we only included participants who completed both waves and who had at least one answer on TMT or Neuroticism at Wave 1 or 2, who completed at least half of the questions of the MMSE at Wave 2 and who provided data for age, gender, and education. Thus, our final sample for the present analyses consisted of 768 participants (49% females) with a mean age of 73.51 years (*SD* = 6.09; range = 64–91 years) at Wave 1, 79.51 years (*SD* = 6.10; range = 70.21–97.94 years) at Wave 2 and a mean level of education of 3.92 (*SD* = 1.54; range = 0–6) at Wave 1, which indicates that, on average, participants' educational level was between "professional apprenticeship" and "high school graduation." All participants gave their written informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki (World Medical Association 2000), and the ethics commission of the Faculty of Psychology and Social Sciences of the University of Geneva had approved the protocol (project identification codes: CE_FPSE_14.10.2010 and CE_FPSE_05.04.2017).

5.3.1 Measures

5.3.1.1 Mini-mental state examination (MMSE). Coarse cognitive functioning was assessed at Wave 2 with the MMSE (Folstein et al., 1975). The MMSE aims to assess cognitive functioning in the general population and represents one of the most used tests in research. It comprises subtests of spatial and temporal orientation, immediate and delayed recall, calculation and language. We calculated a total score of MMSE for each participant. The maximum score possible is 30 points. Higher scores reflect better coarse cognitive functioning.

5.3.1.3 Trail making test (TMT). EF were assessed at both waves with the TMT. It has been previously used in several studies to assess cognitive flexibility using a visual scanning task. It is subdivided into two subtests: the TMT-A and the TMT-B (Gallant, 2016; Godefroy, 2001; Ihle, Gouveia, et al., 2019; Moll et al., 2002; Oosterman et al., 2010; Perrochon & Kemoun, 2014; Senior et al., 2018; Zhang et al., 2019). Both subtests consist of twenty-five circles that participants have to connect to one another. In TMT-A, each circle contains a number (from 1 to 25) and participants have to connect the circles in ascending order as fast as possible. In TMT-B, there are numbers (from 1 to 13) and letters (from A to L) that participants have to connect in ascending order while alternating between numbers and letters as fast as possible. In detail, they have to connect 1 to A, A to 2, 2 to B, etc. Thereby, TMT-A provides a baseline in a simple condition, whereas TMT-B requires participants to alternate between numbers and letters and thus deploys EF (Reitan, 1958). The TMT provided completion times in seconds for both TMT-A and TMT-B. It is important to know that based on multiple studies (Ashendorf et al., 2008; Goul & Brown, 1970; Tombaugh, 2004), we used cutoff criteria for the results to include in our study to avoid unlikely and biased results. More precisely, for TMT-A, we included participants who scored between 15 and 180 s (as it is generally very unlikely to be able to complete the test in less than 15 s, and 180 s is the stop time used in the VLV study). For TMT-B, we included participants who scored between 29 and 180 s (for the same reasons as previously mentioned, also see Ashendorf et al., 2008; Goul and Brown, 1970; Tombaugh, 2004). For information, a higher score on both parts of the TMT represents a worse performance: the higher the score, the slower the participants performed the task.

5.3.1.4 Neuroticism. Neuroticism was assessed at both waves with two questions of the BFI-10, an abbreviated self-assessment version of the Big Five Inventory (BFI-44; Rammstedt & John, 2007). The two questions were "I see myself as a person who…" (1) "… is relaxed, copes well with stress" and (2) "… is easily anxious," and participants had to answer on a 5-point Likert scale ranging from 1 "strongly disagree" to 5 "strongly agree." On both items, participants' score could range from 1 to 5. The score of the first item was inverted.

5.3.1.5 Perceived stress. Perceived stress was assessed at Wave 2 with the PSS-4 based on the Perceived Stress Scale (Cohen et al., 1983). Its aim is to measure the perception of stress participants had during the last month in their daily life (how the participants felt and experienced stress, how overwhelmed with or uncontrollable they consider their life during the last month). This scale includes four items related to general situations (e.g., "in the last month, how often have you felt that you were unable to control the important things in your life?") ranging from 0 "never" to 4 "very often." Two of the four items' scores had to be inverted. This questionnaire was introduced to the participants explaining that they will answer questions about their feelings and thoughts during the last month.

5.4 Statistical analyses

Following Lifshitz-Vahav et al. (2017), we applied three successive two-wave cross-lagged models, using the SPSS extension AMOS (Arbuckle, 2014). We used a latent variable of TMT performance constructed from scores in TMT parts A and B and a latent variable of neuroticism constructed from the two neuroticism items of the BFI-10. Specifically Model 1 included (a) autoregressive paths from neuroticism and TMT performance at Wave 1 to the same variables at Wave 2, (b) cross-lagged reciprocal paths between neuroticism and TMT performance over time, and paths from neuroticism and TMT performance at Wave 1 to MMSE at Wave 2. In Model 2, we added the latent variable of perceived stress to the previous model to test whether stress mediated the relationship between neuroticism at W1 and TMT performance at Wave 2. In Model 3, we tested the reverse causation hypothesis that is whether TMT mediated the relationship between neuroticism and perceived stress. In all models, we controlled for the effects of gender, education, and age on neuroticism, TMT, and MMSE of Wave 2. All predictors of interest and control variables were allowed to correlate. All three models presented a posterior predictive p-value close to 0.50, indicating a good model fit (see van de Schoot et al., 2014).

We tested the normality of our data which showed that the normality was not fulfilled, indicated by p-values of both Kolmogorov–Smirnov and Shapiro–Wilk tests being lower than 0.05. For the subsequent analyses, we applied Bayesian structural equation modeling (Bayesian SEM), as Bayesian analyses do not require normality to obtain robust results (Kelava et al., 2012)[1]. Moreover, Bayesian analyses allow firm conclusions for maintaining the null hypothesis, meaning that we can conclude that there is no effect between variables. This is a great advantage compared to the frequentist approach because in our case, it would help to conclude whether there is or not a longitudinal relationship between neuroticism and the TMT. In sum, Bayesian analyses seem to be the best statistical tools because they will be less sensitive to the size of our sample and will help us determine whether there is a link between neuroticism, TMT, MMSE, and perceived stress. The analysis of our model resulted in a posterior predictive p-value of 0.50, which indicates a good model fit (see van de Schoot et al., 2014). We assessed significance of posterior means (further called estimates) for model paths using bounds (95% credible intervals; e.g., van de Schoot et al. 2014). When the confidence interval does not contain the value 0 (meaning that both ends of the interval are either larger or smaller than 0), we reject H0 and conclude that the path is significant.

5.5 Results

[1] Results presented in this paper are based on Bayesian estimation because normality assumptions for maximum likelihood estimation were not fulfilled. However, post hoc analyses show that classical inferential estimation would provide the same pattern of results, both for the cross-lagged and the mediation cross-lagged models.

5.5.1.1 Descriptive statistics. Table 1 shows descriptive statistics of the variables of interest and the results of Bayesian t tests of variables to analyze change between both waves. These tests indicate anecdotal evidence supporting that there was no difference between TMT-A in W1 and TMT-A in W2 scores (BF_{10} = 0.366; 95% CI [0.002 ; 0.172]). Bayes factor indicates extremely strong evidence supporting a difference between TMT-B at Wave 1 and TMT-B at Wave 2, meaning that performance was lower at Wave 2 than at Wave 1 (BF_{10} = 43,247.593; 95% CI [0.149; 0.328]). Bayes factor indicates moderate evidence supporting no difference for participants' neuroticism across time (BF_{10} = 0.358; 95% CI [− 0.154; − 0.004]).

We also conducted a Bayesian repeated-measures ANOVA to explore whether there were differences between Wave 1 and Wave 2 on neuroticism scores at an individual level. Results indicate anecdotal evidence supporting H_0(BF_{10} = 0.304; 95% CI [− 0.004; 0.064]), thereby suggesting stability of neuroticism (rather than change) between Wave 1 and Wave 2. Further, we examined within-person changes in neuroticism (i.e., participants' scores of Wave 2 minus Wave 1). This showed that mean change between the two measurement waves was small (M = − 0.14, SD = 1.79). Indeed, 74% of the sample changed by 2 points or less, and only 5% changed by more than 3 points. Taken together, although a small number of individuals displayed larger changes in neuroticism, overall this again suggested that neuroticism was rather stable across six years and that there was relatively little within-person variability.

Table 1

Descriptive Statistics and Bayesian t-tests Between Each Variable for Both Waves with Their Credibility Interval.

Variables	*M*	*SD*	*T*-tests Bayes Factor$_{10}$	Estimated median effect size	95% Credibility Interval
Wave 1 Neuroticism	5.32	1.90	0.358	-0.079	[-0.154;-0.004]
Wave 2 Neuroticism	5.24	1.79			
Wave 2 MMSE	28.47	1.82	-	-	-
Wave 1 TMT-A completion time	51.12	20.81	0.366	0.087	[0.002;0.172]
Wave 2 TMT-A completion time	53.12	22.18			
Wave 1 TMT-B completion time	102.7	29.7	43247.593	0.239	[0.149;0.328]
Wave 2 TMT-B completion time	111.3	32.8			
Wave 2 Perceived stress	5.88	2.47	-	-	-

Note. "*M*" = means and "*SD*" = standard deviation. Neuroticism mean scores are based on the sum of the two items of neuroticism for each wave divided by 2. A value of Bayes Factor $_{10}$ (BF_{10}) higher than 3 indicates that data are in favor of the alternative hypothesis rather than the null hypothesis. The credibility interval indicates significance of the BF_{10}: when the confidence interval does not contain the value 0 (meaning that both ends of the interval are either larger or smaller than 0), we reject H0 and conclude that the path is significant. Analyses indicate anecdotal evidence for H0 for neuroticism and TMT-A, meaning there was no significant difference between mean scores at W1 and W2. Analyses indicate extreme evidence for H1 for TMT-B, meaning there was a significant difference between mean scores at W1 and W2.

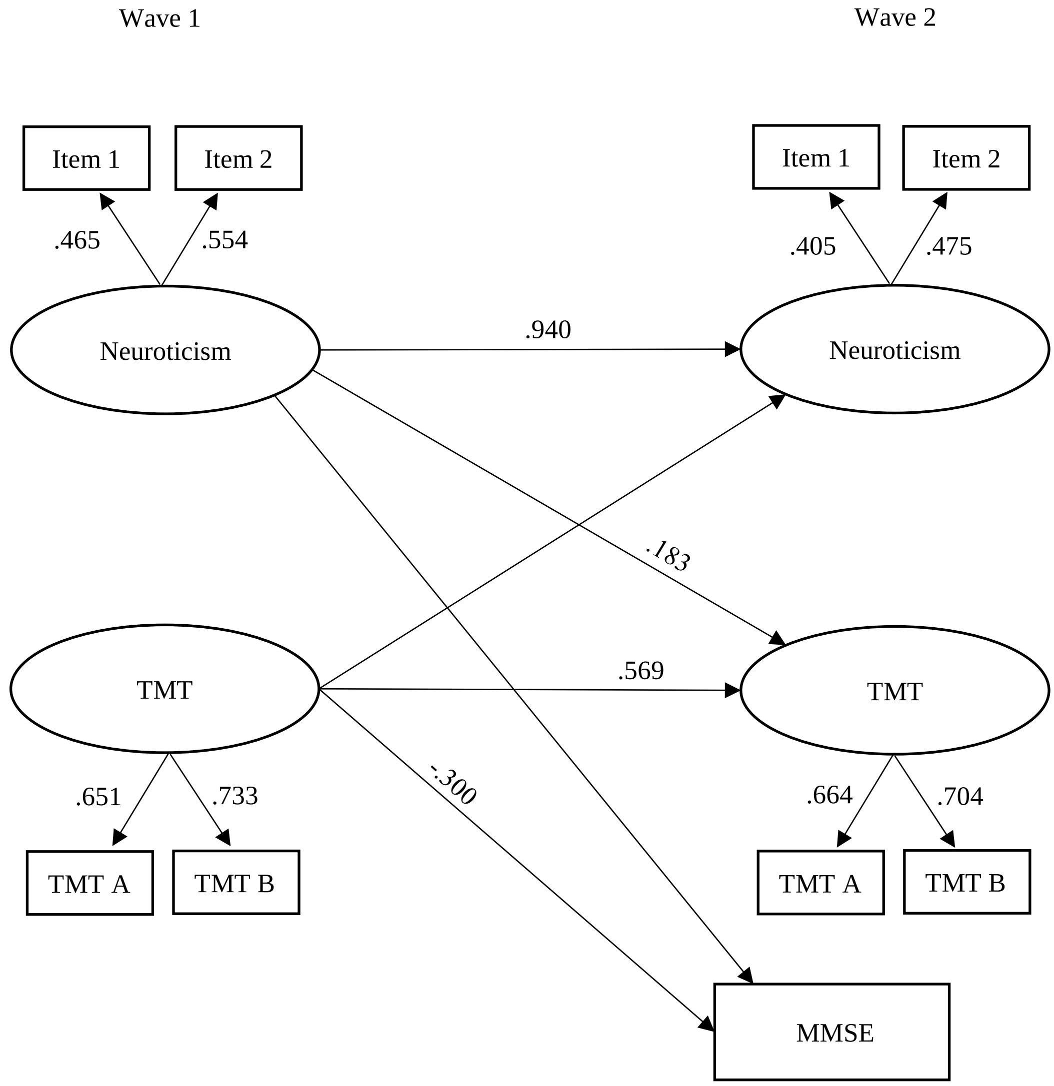
5.5.1.2 Relationships between neuroticism and TMT across the two waves (Model 1). Figure 3 depicts a synthesized version of Model 1, whereas Table 2 details estimates, standard errors, standard deviations, convergence, and the lower and upper bounds for credible intervals. Results showed that neuroticism at Wave 1 positively predicted neuroticism at Wave 2 ($\beta = 0.940$; 95% CI [0.740; 1.174] and that TMT at Wave 1 positively predicted TMT at Wave 2 ($\beta = 0.569$; 95% CI [0.431; 0.716]). Neuroticism and TMT at Wave 1 did not correlate ($\beta = 0.087$; 95% CI [− 0.076; 0.250]). Neuroticism at Wave 1 predicted TMT at Wave 2 ($\beta = 0.183$; 95% CI [0.044; 0.324]), but TMT at Wave 1 did not predict neuroticism at Wave 2 ($\beta = -0.064$; 95% CI [− 0.249; 0.117]). Hence participants who had a higher level of neuroticism at Wave 1 had longer completion times on the TMT and thus worse EF performance at Wave 2. Regarding the predictors of coarse cognitive functioning, longer TMT completion times at Wave 1 predicted poorer MMSE performance ($\beta = -0.300$; 95% CI [− 0.419; − 0.186]), while the level of neuroticism at Wave 1 did not predict MMSE performance at Wave 2 ($\beta = 0.020$; 95% CI [− 0.099; 0.146]).

5.5.1.3 Mediation via perceived stress (Model 2). As a preliminary step to Model 2, we examined whether neuroticism at Wave 1 and perceived stress at Wave 2 were not redundant predictors of TMT performance at Wave 2. As indicated by tolerance value greater than 0.10 and a VIF value smaller than 10, there was no collinearity between neuroticism and perceived stress. We therefore proceeded with examining a potential mediation of the relationship between neuroticism and TMT through perceived stress. Figure 4 depicts a synthesized version of Model 2, whereas Table 3 details estimates, standard errors, standard deviations, convergence, and the lower and upper bounds for credible intervals. As expected, neuroticism at Wave 1 positively predicted perceived stress at Wave 2 ($\beta = 0.520$; 95% CI [0.367; 0.708]), meaning that the more neurotic participants were at Wave 1, the higher was their perceived stress during the last month before Wave 2. In turn, perceived stress negatively predicted TMT

($\beta = 0.204$; 95% CI [0.044; 0.394]), meaning that the more stressed participants were at Wave 2, the lower their cognitive performance at that same wave. Critically, while the indirect effect was significant ($\beta = 0.108$; 95% CI [0.022; 0.254]), the direct effect from neuroticism at Wave 1 to TMT at Wave 2 was no longer significant ($\beta = 0.029$; 95% CI [− 0.223; 0.224]). Hence, perceived stress fully mediated the relationship between neuroticism at Wave 1 and the TMT performance at Wave 2 and explained 78.83% of the direct path from neuroticism at Wave 1 to TMT at Wave 2.

Figure 3

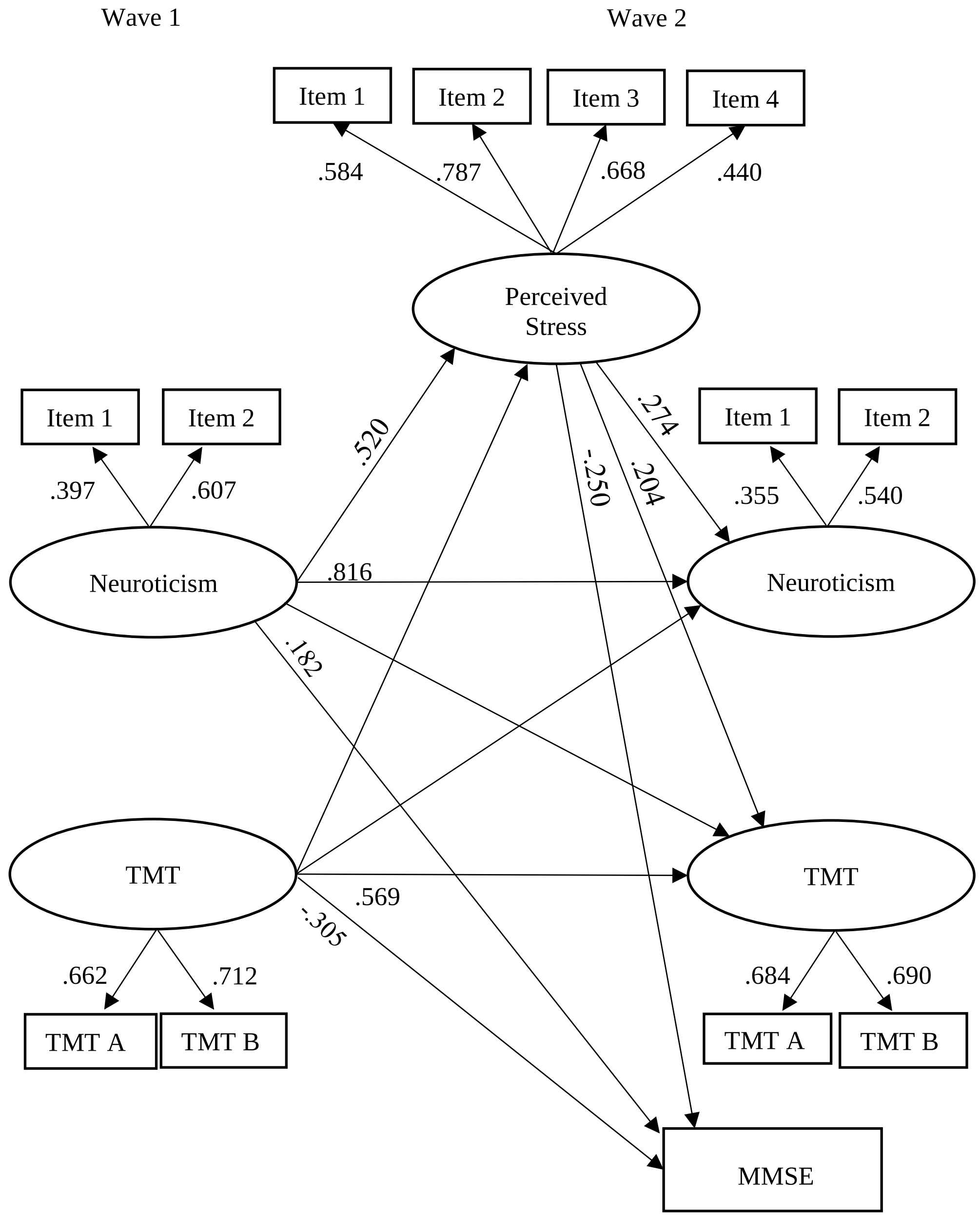
Two-Waves Cross-Lagged Model Between Neuroticism, Executive Functions, and Coarse Cognitive Functioning



Note. This figure illustrates the results for Model 1. Reported values correspond to standardized posterior means for regression coefficients. For the purpose of readability, covariances between predictors, residual variances and covariances between residual variances are not depicted. Similarly, control variables (age, sex, education) and corresponding paths and estimates are not depicted. Further, only significant parameter estimates are reported. Parameter estimates that are not depicted here are reported in Table 2. "Neuroticism" = self-reported neuroticism on items of Big Five Inventory-10; "TMT" = Trail Making Test as index of executive functions; "MMSE" = Mini-Mental State Examination as index of coarse cognitive functioning.

Figure 4

Analysis with Perceived Stress as a Mediator of the Relationship Between Neuroticism at Wave 1 and Executive Functions at Wave 2



Note. This figure illustrates the results of path analyses for Model 2. The direct cross-lagged path between neuroticism at Wave 1 and TMT at Wave 2 is not significant anymore after the addition of perceived stress as a mediator. Reported values correspond to standardized posterior means for regression coefficients. For the purpose of readability, covariances between predictors, residual variances and covariances between residual variances are not depicted. Similarly, control variables (age, sex, education) and corresponding paths and estimates are not depicted._Further, only significant parameter estimates are reported. Parameter estimates that are not depicted here are reported in Table 3. “Neuroticism” = self-reported neuroticism on items of Big Five Inventory-10; “TMT” = Trail Making Test as index of executive functions; “MMSE” = Mini-Mental State Examination as index of coarse cognitive functioning. “Perceived stress” = self-reported perceived stress on PSS-4 items of the Perceived Stress Scale.

Table 2

Estimates, Standard Errors, Standard Deviations, Convergence Statistic, Lower and Upper Bounds of the Paths of our Cross-Lagged Model

	Estimate	*SE*	*SD*	Convergence Statistic	95% Lower Bound	95% Upper Bound
Loadings						
Neuro1 → Neuro1Item1	0.465*	0.005	0.081	1.002	0.331	0.656
Neuro1 → Neuro1Item2	0.554*	0.004	0.098	1.001	0.360	0.745
Neuro2 → Neuro2Item1	0.405*	0.004	0.078	1.001	0.276	0.592
Neuro2 → Neuro2Item2	0.475*	0.004	0.090	1.001	0.306	0.658
TMT1 → TMT1A	0.651*	0.001	0.044	1.000	0.565	0.738
TMT1 → TMT1B	0.733*	0.001	0.054	1.000	0.625	0.837
TMT2 → TMT2A	0.664*	0.001	0.042	1.000	0.583	0.745
TMT2 → TMT2B	0.704*	0.001	0.043	1.000	0.620	0.789
Direct Effects for Variables of Interest						
Neuro1 → Neuro2	0.940*	0.002	0.108	1.000	0.740	1.174
TMT1 → TMT2	0.569*	0.001	0.073	1.000	0.431	0.716
Neuro1 → TMT2	0.183*	0.002	0.072	1.000	0.044	0.324
TMT1 → Neuro2	-0.064	0.001	0.094	1.000	-0.249	0.117
Neuro1 → MMSE2	0.020	0.001	0.063	1.000	-0.099	0.146
TMT1 → MMSE2	-0.300*	0.001	0.059	1.000	-0.419	-0.186
Neuro1 ↔ TMT1	.087	0.002	0.082	1.000	-.076	.250
Control Variables						
Age → Neuro2	0.052	0.001	0.069	1.000	-0.079	0.189
Age → TMT2	-0.237*	0.001	0.052	1.000	0.134	0.336
Age → MMSE2	-0.019	0.001	0.042	1.000	-0.099	0.064
Sex → Neuro2	-0.017	0.001	0.066	1.000	-0.150	0.112
Sex → TMT2	0.081	0.001	0.046	1.000	-0.171	0.009
Sex → MMSE2	0.063	0.001	0.038	1.000	-0.012	0.136
Educ → Neuro2	-0.043	0.002	0.065	1.000	-0.169	0.088
Educ → TMT2	-0.098*	0.001	0.048	1.000	-0.192	-0.002
Educ → MMSE2	0.144*	0.001	0.037	1.000	0.069	0.215
Age ↔ Neuro1	-.041	0.001	0.057	1.000	-.154	.070
Age ↔ TMT1	.313*	0.001	0.049	1.000	.213	.408
Age ↔ Sex	-.047	0.001	0.037	1.000	-.121	.025
Age ↔ Educ	-.037	0.001	0.036	1.000	-.107	.035
Sex ↔ Neuro1	.204*	0.001	0.058	1.000	.089	.316
Sex ↔ TMT1	.036	0.001	0.051	1.000	-.063	.137
Sex ↔ Educ	-.175*	0.001	0.035	1.000	-.244	-.106

Educ ←→ Neuro1	-.028	0.001	0.058	1.000	-.144	.082
Educ ←→ TMT1	-.171*	0.001	0.051	1.000	-.271	-.068
<u>Residual Covariances</u>						
Neuro1Item1 ←→ Neuro2Item1	0.184	0.005	0.091	1.002	-0.036	0.326
Neuro2Item1 ←→ Neuro2Item2	0.447*	0.006	0.136	1.001	0.153	0.686
TMT1A ←→ TMT2A	0.004*	0.001	0.002	1.000	0.001	0.008
TMT1B ←→ TMT2B	0.003	0.001	0.005	1.000	-0.007	0.012

Note. "Neuro1" = neuroticism at Wave 1, "Neuro2" = neuroticism at Wave 2, "TMT1" = executive functions at Wave 1, "TMT2" = executive functions at Wave 2, "MMSE2" = MMSE at Wave 2, "Age" = control variable Age, "Sex" = control variable Sex, "Educ" = control variable Education. Single headed arrows → indicate regression weights. Double headed arrows ←→ indicate correlations between control variables while they indicate covariances for residual covariances. The direct paths from Neuro1 to Neuro2, Neuro 1 to TMT2, TMT1 to TMT2 are significant, which is not the case for the path from TMT1 to Neuro2.* indicates significance based on the credibility intervals.

5.5.1.4 Reverse causation (Model 3). To examine potential reverse causation, we tested an alternative model in which the relationship between neuroticism at Wave 1 and perceived stress at Wave 2 was mediated by TMT at Wave 2 (see Table 4). Neuroticism at Wave 1 positively predicted perceived stress at Wave 2 ($\beta = 0.467$; 95% CI [0.312; 0.648]) and TMT at Wave 2 positively predicted perceived stress ($\beta = 0.301$; 95% CI [0.064; 0.568]). However, neither the direct effect of neuroticism at Wave 1 on TMT at Wave 2 nor the indirect effect of neuroticism at Wave 1 on perceived stress at Wave 2 was significant ($\beta = 0.141$; 95% CI [− 0.009; 0.281] and $\beta = 0.039$; 95% CI [− 0.006; 0.094], respectively). Hence, these results exclude a reverse causation hypothesis.

Table 3

Estimates, Standard Errors, Standard Deviations, Convergence Statistic, Lower and Upper Bounds of the Paths of our Cross-Lagged Model with Perceived Stress as a Mediator

	Estimate	*SE*	*SD*	Convergence Statistic	95% Lower bound	95% Upper bound
Loadings						
Neuro1 → Neuro1Item1	0.397*	0.002	0.043	1.001	0.312	0.483
Neuro1 → Neuro1Item2	0.607*	0.002	0.065	1.001	0.480	0.737
Neuro2 → Neuro2Item1	0.355*	0.001	0.044	1.000	0.268	0.442
Neuro2 → Neuro2Item2	0.540*	0.002	0.061	1.000	0.419	0.660
TMT1 → TMT1TMTA	0.662*	0.001	0.043	1.000	0.575	0.747
TMT1 → TMT1TMTB	0.712*	0.002	0.051	1.001	0.609	0.809
TMT2 → TMT2TMTA	0.684*	0.001	0.038	1.000	0.607	0.759
TMT2 → TMT2TMTB	0.690*	0.001	0 .039	1.000	0.612	0.769
Stress2 → Stress2Item1	0.584*	0.001	0.032	1.000	0.518	0.644
Stress2 → Stress2Item2	0.787*	0.001	0.027	1.000	0.734	0.838
Stress2 → Stress2Item3	0.668*	0.001	0.028	1.000	0.611	0.722
Stress2 → Stress2Item4	0.440*	0.001	0.036	1.000	0.369	0.510
Direct Effects for Variables of Interest						
Neuro1 → Neuro2	0.816*	0.005	0.143	1.000	0.554	1.123
TMT1 → TMT2	0.569*	0.002	0.074	1.001	0.427	0.718
Neuro1 → TMT2	0.029	0.006	0.111	1.002	-0.223	0.224
TMT1 → Neuro2	-0.102	0.003	0.084	1.001	-0.272	0.060
Neuro1 → Stress2	0.520*	0.004	0.085	1.001	0.367	0.708
TMT1 → Stress2	0.011	0.003	0.077	1.001	-0.149	0.153
Neuro1 → MMSE2	0.182*	0 .006	0.108	1.002	0.009	0.448
TMT1 → MMSE2	-0.305*	0.002	0.063	1.001	-0.436	-0.186
Stress2 → TMT2	0.204*	0.005	0.088	1.001	0.044	0.394
Stress2 → Neuro2	0.274*	0.004	0.122	1.000	0.011	0.499
Stress2 → MMSE2	-0.250*	0.005	0.084	1.002	-0.441	-0.110
Neuro1 ←→ TMT1	.141	0.003	0.085	1.000	-.021	.312
Indirect Effect for Variables of Interest						
Neuro1 → TMT2	0.108*	0.004	0.060	1.002	0.022	0.254
Control Variables						
Age →Neuro2	-0.003	0.002	0.070	1.000	-0.136	0.140
Age →TMT2	0.182*	0.002	0.057	1.001	0.065	0.292
Age →MMSE2	0.040	0.009	0.049	1.001	-0.051	0.144

Age →Stress2	0.219*	0.002	0.051	1.001	0.119	0.324
Sex →Neuro2	-0.026	0.002	0.062	1.001	-0.154	0.092
Sex →TMT2	-0.065	0.002	0.047	1.001	-0.156	0.029
Sex →MMSE2	0.047	0.002	0.043	1.001	-0.043	0.125
Sex →Stress2	-0.030	0.002	0.052	1.000	-0.137	0.064
Educ →Neuro2	-0.047	0.002	0.058	1.001	-0.162	0.066
Educ →TMT2	-0.081	0.001	0.048	1.000	-0.174	0.016
Educ →MMSE2	0.123*	0.001	0.040	1.000	0.042	0.196
Educ →Stress2	-0.064	0.001	0.048	1.000	-0.158	0.027
Age ←→Neuro1	-.039	0.002	0.057	1.000	-.152	.074
Age ←→TMT1	.314*	0.001	0.049	1.000	.216	.411
Age ←→Sex	-.049	0.001	0.037	1.000	-.122	.024
Age ←→Educ	-.037	0.001	0.037	1.000	-.108	.035
Sex ←→Neuro1	.214*	0.002	0.056	1.000	.104	.325
Sex ←→TMT1	.034	0.001	0.049	1.000	-.063	.131
Sex ←→Educ	-.174*	0.001	0.036	1.000	-.245	-.105
Educ ←→Neuro1	-.021	0.001	0.057	1.000	-.134	.092
Educ ←→TMT1	-.175*	0.001	0.051	1.000	-.276	-.076
<u>Residual Covariances</u>						
Neuro1Item1 ←→ Neuro2Item1	0.243*	0.001	0.051	1.000	0.144	0.345
Neuro2Item1 ←→ Neuro2Item2	0.359*	0.001	0.092	1.000	0.170	0.534
TMT1A ←→ TMT2A	0.004*	0.001	0.002	1.000	0.001	0.008
TMT1B ←→ TMT2B	0.004	0.001	0.005	1.000	-0.005	0.013
Stress2Item1 ←→ Stress2Item4	0.132*	0.001	0.028	1.000	0.078	0.188

Note. "Neuro1" = neuroticism at Wave 1, "Neuro2" = neuroticism at Wave 2, "TMT1" = executive functions at Wave 1, "TMT2" = executive functions at Wave2, "Stress2" = perceived stress at Wave 2, "MMSE2" = MMSE of Wave 2, "Age" = control variable Age, "Sex" = control variable Sex, "Educ" = control variable Education. Single headed arrows → indicate regression weights. Double headed arrows ←→ indicate correlations between control variables while they indicate covariances for residual covariances. The direct path from Neuro1 to TMT2 is not significant anymore, while the direct paths from Neuro1 to Stress2, Stress2 to TMT2 are significant. The indirect path from Neuro1 to TMT2 is significant. * indicates significance based on the credibility intervals.

Table 4

Estimates, Standard Errors, Standard Deviations, Convergence Statistic, Lower and Upper Bounds of the Paths of the Reverse Causation Cross-Lagged Model with Executive Functions as a Mediator of the Relationship between Neuroticism and Perceived Stress

	Estimate	*SE*	*SD*	Convergence Statistic	95% Lower bound	95% Upper bound
Loadings						
Neuro1 → Neuro1Item1	0.401*	0.001	0.044	1.000	0.315	0.488
Neuro1 → Neuro1Item2	0.613*	0.001	0.063	1.000	0.488	0.739
Neuro2 → Neuro2Item1	0.357*	0.001	0.044	1.000	0.270	0.443
Neuro2 → Neuro2Item2	0.542*	0.001	0.061	1.000	0.419	0.661
TMT1 → TMT1A	0.660*	0.001	0.044	1.000	0.572	0.744
TMT1 → TMT1B	0.714*	0.001	0.051	1.000	0.610	0.812
TMT2 → TMT2A	0.678*	0.001	0.040	1.000	0.599	0.756
TMT2 → TMT2B	0.688*	0.001	0 .040	1.000	0.607	0.766
Stress2 → Stress2Item1	0.586*	0.001	0.033	1.000	0.520	0.648
Stress2 → Stress2Item2	0.789*	0.001	0.027	1.000	0.735	0.840
Stress2 → Stress2Item3	0.669*	0.001	0.028	1.000	0.611	0.722
Stress2 → Stress2Item4	0.445*	0.001	0.036	1.000	0.371	0.514
Direct Effects for Variables of Interest						
Neuro1 → Neuro2	0.821*	0.002	0.141	1.000	0.556	1.113
TMT1 → TMT2	0.574*	0.001	0.074	1.000	0.434	0.722
Neuro1 → TMT2	0.141	0.001	0.074	1.000	-0.009	0.281
TMT1 → Neuro2	-0.103	0.001	0.086	1.000	-0.280	0.062
Neuro1 → Stress2	0.467*	0.002	0.085	1.000	0.312	0.648
TMT1 → Stress2	-0.165	0.003	0.128	1.000	-0.439	0.061
Neuro1 → MMSE2	0.173*	0 .003	0.099	1.000	0.008	0.388
TMT1 → MMSE2	-0.302*	0.001	0.061	1.000	-0.427	-0.185
TMT2 → Stress2	0.301*	0.003	0.128	1.000	0.064	0.568
Stress2 → Neuro2	0.274*	0.002	0.116	1.000	0.040	0.497
Stress2 → MMSE2	-0.245*	0.002	0.077	1.000	-0.407	-0.112
Neuro1 ←→ TMT1	.141	0.001	0.082	1.000	-.019	.304
Indirect Effect for Variables of Interest						
Neuro1 → Stress2	0.039	0.001	0.025	1.000	-0.006	0.094
Control Variables						

Age →Neuro2	-0.004	0.001	0.068	1.000	-0.133	0.135
Age →TMT2	0.230*	0.001	0.053	1.000	0.123	0.331
Age →MMSE2	0.037	0.001	0.048	1.000	-0.052	0.136
Age →Stress2	0.150*	0.001	0.054	1.000	0.043	0.257
Sex →Neuro2	-0.024	0.001	0.062	1.000	-0.149	0.097
Sex →TMT2	-0.075	0.001	0.046	1.000	-0.165	0.016
Sex →MMSE2	0.050	0.001	0.041	1.000	-0.033	0.128
Sex →Stress2	-0.003	0.001	0.051	1.000	-0.107	0.095
Educ →Neuro2	-0.043	0.001	0.058	1.000	-0.160	0.070
Educ →TMT2	-0.096*	0.001	0.047	1.000	-0.187	-0.002
Educ →MMSE2	0.124*	0.001	0.039	1.000	0.045	0.199
Educ →Stress2	-0.036	0.001	0.048	1.000	-0.129	0.058
Age ←→Neuro1	-.038	0.001	0.057	1.000	-.150	.073
Age ←→TMT1	.314*	0.001	0.049	1.000	.217	.411
Age ←→Sex	-.048	0.001	0.036	1.000	-.119	.022
Age ←→Educ	-.037	0.001	0.037	1.000	-.109	.035
Sex ←→Neuro1	.212*	0.001	0.056	1.000	.103	.322
Sex ←→TMT1	-.036	0.001	0.050	1.000	-.063	.135
Sex ←→Educ	-.175*	0.001	0.035	1.000	-.243	-.105
Educ ←→Neuro1	-.022	0.001	0.057	1.000	-.133	.089
Educ ←→TMT1	.175*	0.001	0.051	1.000	-.274	-.075
Residual Covariances						
Neuro1Item1 ←→ Neuro2Item1	0.241*	0.001	0.052	1.000	0.141	0.344
Neuro2Item1 ←→ Neuro2Item2	0.355*	0.001	0.095	1.000	0.160	0.531
TMT1A ←→ TMT2A	0.004*	0.001	0.002	1.000	0.001	0.008
TMT1B ←→ TMT2B	0.004	0.001	0.005	1.000	-0.005	0.013
Stress2Item1 ←→ Stress2Item4	0.131*	0.001	0.028	1.000	0.076	0.187

Note. "Neuro1" = neuroticism at Wave 1, "Neuro2" = neuroticism at Wave 2, "TMT1" = executive functions at Wave 1, "TMT2" = executive functions at Wave2, "Stress2" = perceived stress of Wave 2, "MMSE2" refers to MMSE at Wave 2, "Age" = control variable Age, "Sex" = control variable Sex, "Educ= control variable Education. Single headed arrows → indicate regression weights. Double headed arrows ←→ indicate correlations between control variables while they indicate covariances for residual covariances. The direct paths from Neuro1 to Stress2, Neuro1 to TMT2, TMT2 to Stress2 are significant. The indirect path from Neuro1 to Stress2 is significant. * indicates significance based on the credibility intervals.

5.6 Discussion

The present study examined the relationship of neuroticism and cognitive abilities (evaluated with the TMT and MMSE) in older adults across six years. The first aim of this study was to determine the existence of a link between neuroticism and EF in older adults. Although certain of the previous studies reported negative cross-sectional links between neuroticism and EF in younger adults (Crow, 2019; Murdock et al., 2013; Purić & Pavlović, 2012; Schretlen et al., 2010), other cross-sectional studies reported inconsistent results in older adults (Bell et al., 2020; Booth et al., 2006; Boyle et al., 2010; Chapman et al., 2017; Denburg et al., 2009; Hill et al., 2015; Kim et al., 2022; Turunen et al., 2020; Williams et al., 2010b). Importantly, the only longitudinal study so far did not find a longitudinal link between neuroticism and EF among older adults when assessed across a relatively short period of time (i.e., two years, Waggel et al., 2015).

The present findings indicate that neuroticism at Wave 1 predicted TMT performance at Wave 2, meaning that the more neurotic participants were at the first wave, the lower their cognitive performance was six years later. This is in contrast to the study by Waggel et al. (2015) who investigated the link between neuroticism and TMT in a longitudinal design of two years. Interestingly, their results showed that neuroticism was negatively correlated cross-sectionally to TMT performance, but there was no significant 2-year longitudinal prediction from neuroticism to TMT performance. In contrast, in our study neuroticism and EF were unrelated at Wave 1, but higher levels of neuroticism predicted worse TMT performance six years later. A possible explanation for this difference of results between Waggel's study (2015) and ours might be the difference in time intervals (two versus six years) and in populations. In the latter regard, our participants were community-dwelling older adults randomly drawn from the general population aged 65 and above for Wave 1 (see Ludwig et al., 2014 for a description of the study), while in Waggel's study (2015) certain participants already had mild cognitive impairment (MCI) at Wave 1, others importantly declined in cognitive status and were then diagnosed with MCI or dementia before/at Wave 2 (note that this may also have compromised the validity of their assessment in using self-report personality questionnaires). Although our sample was composed of non-clinical participants, performance on TMT was significantly lower at Wave 2 than Wave 1, indicating indeed a decline in performance at Wave 2. Regarding longitudinal links, Waggel and colleagues (2015) indicated in their study that a longer time interval seems to be necessary for neuroticism effects to longitudinally manifest its effect. In contrast to Waggel et al.'s (2015) suggestion, our study did not demonstrate significant differences in neuroticism scores at the group level across six years. Similarly, on an individual level, results showed that only few individuals importantly changed in neuroticism across six years and that, in general, there was relatively little within-person variability. However, although neuroticism was rather stable between Wave 1 and Wave 2, results demonstrate a longitudinal effect of neuroticism on EF. To our knowledge, this is the first study to demonstrate a significant longitudinal relationship from neuroticism to EF among older adults. As EF are related to older adults' daily functioning (Engel-Yeger & Rosenblum, 2021; Suchy, 2020; Vaughan & Giovanello, 2010), this finding is of relevance because it could enable to develop prevention programs to help older adults preserving their autonomy in daily life. Further, our initial findings do not indicate a link between neuroticism at Wave 1 and MMSE at Wave 2. This is in line with previous studies finding no relationship between neuroticism and coarse cognitive functioning (Arbuckle et al., 1998; Baker & Bichsel, 2006; Jelicic et al., 2003; Pearson, 1993), but is in contrast with other studies demonstrating that neuroticism is negatively associated with the performance on coarse cognitive functioning. Such differences may partially be related to differences in assessment, and future studies will therefore have to replicate our results using similar measures of coarse cognitive functioning. Further, although our participants were healthy community-dwelling older adults who lived autonomously, were willing to participate in the study, and who managed to participate in a rather long cognitive assessment, the mean age at Wave 2 was 79.53 years, with the oldest participants being up to 97 years old. Thus, although the oldest individuals may have still been rather autonomous and cognitively functioning in their daily life, other negative aspects of old age may have impacted their daily living and well-being, such as loneliness, reduction of positive affect, and of life satisfaction (Baltes & Smith, 2003; Gilleard & Higgs, 2010; Higgs & Gilleard, 2021; Yang et al., 2018). It would therefore be important for future studies to control for or examine in more detail these and other factors that are linked to older age and may impact cognition.

Our second aim was to explore the link between neuroticism and EF with perceived stress as a mediator in our model. Bayesian analyses revealed a full mediation. Results indicate that the more neurotic older adults were, the more they perceived stress six years later, and in parallel, the worse their cognition at that time. This full mediation between neuroticism and EF across time is congruent with previous studies showing that stress can have a negative influence on EF performance (Diamond, 2013; Ihle et al., 2020; Liston et al., 2009; Oaten & Cheng, 2005; Orem et al., 2009; Wolff et al., 2021). Our results support the idea that individuals with higher levels of neuroticism experience more stress, which finally has an influence on their EF performance. In our analyses, we also examined a potential reverse causation between neuroticism at Wave 1, perceived stress and TMT at Wave 2. Specifically, we tested an alternative model in which the relationship between neuroticism at Wave 1 and perceived stress at Wave 2 was mediated by EF. This model enabled us to rule out a potential reverse causation mechanism. Hence, our findings support our hypothesis that perceived stress mediates the effect of neuroticism on EF across time, and are in accordance with previous studies demonstrating an association between EF and stress (Diamond, 2013; Ihle et al., 2020; Liston et al., 2009; Oaten & Cheng, 2005; Orem et al., 2009; Wolff et al., 2021). In the present study, perceived stress explained 78.83% of the effect of neuroticism at Wave 1 on EF at Wave 2.

As our findings suggest that perceived stress plays a major role in the relationship between neuroticism and the loss of EF abilities, this could further be crucial for daily autonomy in older adults. For example, when considering real-life implications of the current findings and future directions, it seems essential to prevent older adults from being affected by stress to avoid the potential decline in EF. Previous research suggests that mindfulness-based interventions can reduce stress in younger and in older adults (Armstrong & Rimes, 2016; Berk et al., 2018; Hanley et al., 2019). For example, Armstrong and Rimes (2016) presented an intervention that indirectly targets neuroticism through training sessions that aim to make participants understand why some individuals are more sensitive to certain types of stressful events, to improve how they react to stress, and how they can manage stress. Two meta-analyses and two more recent studies demonstrated that mindfulness-based programs are able to reduce stress levels in healthy younger and older adults as well as in those suffering from chronic conditions like cardiovascular diseases and diabetes, but also anxiety, depression, and stress disorders (Chiesa & Serretti, 2009; Felsted, 2020; Grossman et al., 2004; Perez-Blasco et al., 2016). Moreover, previous research and reviews also demonstrate that mindfulness-based stress reduction programs can improve performance on different components of EF, including cognitive flexibility (Gallant, 2016; Hazlett-Stevens et al., 2019, 2019; Moynihan et al., 2013). These intervention programs are promising and may help older adults to improve or preserve their EF as they allow simultaneously targeting EF as direct outcome as well as stress as mediator between neuroticism and EF and thereby might help them maintain their daily autonomy.

Although our study presents a large sample with both cross-sectional and longitudinal data, it also has certain limitations. First, neuroticism was assessed with the BFI-10, which includes only two items to estimate participants' neuroticism levels. Even though this test is standardized and should reflect actual levels of participants' neuroticism (Courtois et al., 2020; Rammstedt et al., 2013), future studies will have to further examine and replicate the role of neuroticism using a more comprehensive test battery. Second, in the present study, EF were assessed with the TMT, which is a reliable tool used in neuropsychological screening to assess cognitive flexibility. However, according to Miyake et al.'s (2000) conception, EF are composed of multiple separate yet related core facets: updating (i.e., enabling individuals to update and monitor the content in working memory), inhibition (i.e., enabling individuals to inhibit predominant responses), shifting (also referred to as cognitive flexibility; i.e., enabling individuals to shift between mental sets, tasks, or instructions). Although the different facets are interrelated and EF tasks typically deploy more than one facet at a time (Burgess, 1997; Hughes & Graham, 2002; Miyake et al., 2000; Miyake & Friedman, 2012; Phillips, 1997), the TMT mainly focuses on assessing cognitive flexibility (Gallant, 2016; Godefroy, 2001; Ihle, Gouveia, et al., 2019; Moll et al., 2002; Oosterman et al., 2010; Perrochon & Kemoun, 2014; Senior et al., 2018; Zhang et al., 2019). In the future, it would be important to examine additional measures that target other components of EF (i.e., working memory updating or inhibitory control) and explore their relationship to neuroticism in a longitudinal design to understand whether our pattern of results is specific to cognitive flexibility or present for other EF components. Third, when considering the mediation via perceived stress, further research across at least three waves would be necessary to replicate and investigate in more detail how perceived stress influences the relationship between neuroticism and EF across longer time intervals. This would also enable to confirm the absence of a potential reverse causation.

Taken together, the present study adds to the literature on personality, EF, and stress in older age. To our knowledge, this is the first longitudinal study to investigate neuroticism, TMT, MMSE, and perceived stress in a cross-lagged model across six years using Bayesian analyses. In detail, it introduces neuroticism as a longitudinal predictor of EF six years later and perceived stress as a relevant mediator of this relationship, thereby providing novel insights into the possible mechanisms behind personality and EF interaction. Further, our study supports the importance of developing prevention and intervention trainings to counteract cognitive decline due to neuroticism and stress using promising mindfulness-based programs.

6 Study 2: The Relationship Between Depressive Symptoms, Metamemory and Prospective Memory in Older Adults

6.1 Abstract

Introduction: Depression has been associated with impairments in different cognitive domains in younger adults, including prospective memory (PM; the ability to plan and execute intended actions in the future). However, it is still not well documented nor understood whether depression is also associated with impaired PM in older adults. The current study aimed to examine the association between depressive symptoms and PM in young-old and old-old adults, and to understand the potential influence of underlying factors such as age, education, and metamemory representations (one's belief about their memory abilities). Method: Data of 394 older adults from the Vivre-Leben-Vivere study were included in the analyses (M_{age} = 80.10 years, *SD* = 6.09; range = 70 – 98 years). Results: Bayesian ANCOVA revealed a 3-way interaction between depressive symptoms, age, and metamemory representations, indicating that the association between depressive symptoms and PM performance depended on age and metamemory representations. In the lower depressive symptoms group, old-old adults with higher metamemory representations performed as well as young-old adults independently of their metamemory representations. However, in the higher depressive symptoms group, old-old adults with higher metamemory representations performed more poorly than young-old adults with higher metamemory representations. Conclusion: This study indicates that metamemory representations may buffer the negative effect of age on PM performance only in old-old individuals with low depressive symptoms. Importantly, this result provides new insight into the mechanisms underlying the association between depressive symptoms and PM performance in older adults as well as into potential interventions.

6.2 Introduction

The World Health Organization (2017) estimates that currently 7 % of older adults worldwide live with depression, making it one of the most common psychological disorders in older adulthood. Depression is considered a leading cause for disability as depressive individuals experience multiple impairments in their daily life such as reduced work-related activity, loneliness, reduced social skills, and somatization leading to reports of physical pain (Enns et al., 2018; Fernández-theoduloz et al., 2019; Gilmour & Patten, 2007; Joiner & Timmons, 2009; Lim et al., 2018; Singh & Misra, 2009; World Health Organization, 2017; Yap et al., 2004). Importantly for the present study, depression also influences cognitive abilities such as autobiographic, episodic, and working memory (Dietsche et al., 2014; Evans et al., 2019; Joormann & Gotlib, 2008; Salazar-Villanea et al., 2015; Söderlund et al., 2014; Wilson & Gregory, 2018).

However, much less is known about the association between depressive symptoms and prospective memory (PM), that is, the ability to plan and remember delayed intentions (McDaniel & Einstein, 2000). PM can be evaluated through two types of tasks: 1) event-based tasks, which consist of executing the intention when a specific external cue is encountered (i.e., remember to buy bread when passing by the bakery), and 2) time-based tasks, which consist of executing the intention after a certain amount of time has elapsed (i.e., remember to take your medication 30 minutes after dinner). In terms of cognitive processes, PM is divided in two components: 1) a retrospective component, which refers to remembering the content of the intention to execute (i.e., taking a specific type of medication, related to episodic memory), and 2) a prospective component, which refers to remembering appropriate moment to execute the intention (i.e., 30 min after dinner, related to monitoring and executive functions). PM plays a crucial role in everyday autonomy as it predicts maintaining independence and higher quality of life: remembering to meet with friends, cooking one’s own meal, paying the bills on time but also taking medications are all examples of typical PM tasks that stress its importance for health, social functioning and autonomy (Hering, Kliegel, Rendell, et al., 2018; Kliegel et al., 2016; Laera et al., 2021; Woods et al., 2012).

Thus, the scarce literature on the relationship between depressive symptoms and PM in older adults can be considered as a particularly important knowledge gap. In younger adults, a meta-analysis demonstrated that individuals with higher levels of depressive symptoms were impaired on PM tasks (Zhou et al., 2017). In older adults, however, only two studies[2] have so far investigated the relationship between PM and depressive symptoms, leading to inconclusive results (Albiński et al., 2012; Livner et al., 2008). Assessing 332 older adults, Livner et al. (2008) demonstrated that depressive symptoms were associated with impaired performance on the retrospective component of an event-based PM task, but there was no association between depressive symptoms and the prospective component of this task. Interestingly, the second study revealed no significant link between depression and an event-based PM task, but a positive association between depression and a time-based PM task in a sample of 60 older adults (Albiński et al., 2012). Thus, the available literature is highly inconsistent and researchers have pointed out the need to further examine the relationship between depression and PM in older adults. As for possible factors underlying these inconsistencies across previous studies, considering different levels of depressive symptoms, education, metamemory representations, and age might be of interest. Indeed, previous research on these factors in relation to depressive symptoms demonstrated interesting results in other cognitive domains, including retrospective memory.

[2] In a previous study using the same data set as in the present study, the effects of socioeconomic condition in childhood, adulthood and later-life on PM were investigated (controlling for depressive symptoms; for further information, see Künzi et al., 2021).

6.2.1 Depressive Symptoms

Previous studies suggested that different levels of depressive symptoms may differentially relate to cognitive outcomes. In detail, an inverted U-shape relation was revealed in individuals with depressive symptoms for certain tasks such as contingency problems (Alloy & Abramson, 1979; Andrews & Thomson, 2009; Dobson & Cheung, 1990; Harkness et al., 2005; L. Lee et al., 2005; Marsh & Weary, 1994). Indeed, in these studies, individuals with relatively high but still subclinical levels of depressive symptoms performed better on cognitive tasks than individuals with lower depressive symptoms. Yet, interestingly, they also performed better than those with very high, clinical levels of depressive symptoms. This suggested that performance of individuals with subclinical levels of depressive symptoms might benefit from the analytical rumination associated with depressive affect. The analytical rumination hypothesis consists of two components activated in individuals with depressed affect: (a) the causal analysis, which aims to understand the origins of the depression-related problems, and (b) the problem-solving analysis, which focuses on the manner to solve these problems (Andrews & Thomson, 2009; Bartoskova et al., 2018; Sevcikova et al., 2020). Other previous studies investigating rumination indicated that rumination is composed of two subcomponents: the brooding and reflection components (Krys, 2020; Schoofs et al., 2010; Treynor et al., 2003). Brooding is to compare one’s own present situation to unachieved goals and standards and is considered maladaptive, while reflection is defined as engaging into cognitive problem-solving by allocating attention and effort to a task and is, therefore, an adaptive component (Krys, 2020; Schoofs et al., 2010; Treynor et al., 2003). Thus, individuals suffering from subclinical depressive symptoms may rely on the analytical rumination and reflection, enabling them to outperform individuals with lower depressive symptoms and clinically depressed individuals. This could explain why in Albiński et al.'s study (2012), participants with higher levels of depressive symptoms performed better on a time-based PM than participants with lower levels of depressive symptoms. Discriminating between individuals with and without depressive symptoms seems very relevant to understand how they can be associated with episodic memory and PM in particular. However, additionally to rumination, educational attainment could be a factor helping depressive individuals to perform well on cognitive tasks as it is protective against cognitive impairment in this population (James et al., 2021).

6.2.2 Education

In their meta-analytic review, James et al., (2021) demonstrated that individuals with depressive symptoms performed as well as controls on retrospective memory tasks when they have higher education compared to lower education (e.g., McLaren et al., 2015; Murphy & O'Leary, 2009). Regarding PM performance, Huppert & Beardsall (1993) and Simard et al. (2019) have shown that lower education impaired PM performance in older adults compared to higher education. Surprisingly, both available studies on the relationship between depressive symptoms and PM functioning in older adults did not investigate the association between education and PM performance (Albiński et al., 2012; Livner et al., 2008). However, when inspecting the study samples, they systematically differed in participants' mean education (i.e., 12 years versus 9.38 years; Albiński et al., 2012; Livner et al., 2008). To explain this relationship between educational attainment and performance on episodic memory in older adults, certain authors postulated an influence of cognitive reserve (i.e., the cognitive stimulation accumulated across the lifespan that preserves cognitive functioning in older adults) and metamemory (Guerrero-Sastoque et al., 2021; Stern, 2009, 2012; Szajer & Murphy, 2013).

6.2.3 Metamemory Representations

Metamemory refers to the knowledge that individuals possess about their own memory abilities (Flavell, 1979; Nelson & Narens, 1990). Having higher education may improve metamemory accuracy, meaning that individuals' representations of their memory abilities are more accurate than participants with less education. Accuracy of one's representations is crucial for memory performance as it is related to the implementation of effective strategies (Nelson & Narens, 1990; Szajer & Murphy, 2013). A discrepancy between subjective performance and the actual performance, such as an overconfidence, may prevent individuals from implementing strategies to improve their memory performance (e.g., putting heart medication on the dinner table to remember to take it while eating). This is of particular importance 1) for PM, as PM failures represent half of the memory failures that occur in daily-life , suggesting that strategies might be needed to improve PM (Crovitz & Daniel, 1984; Haas et al., 2020); 2) for older adults, as their memory is declining with age, possibly creating a gap between their representations and actual performance, and impairing their autonomy. Previous studies focusing on older age, metamemory, and PM demonstrated that older adults are overconfident in their PM abilities, which may lead to less implementation of strategies and a higher rate of PM failures (Cauvin, et al., 2019). Metamemory representations may also be influenced by depressive symptoms as they are associated with dysfunctional representations about the world, the future, and oneself (Beck, 1976; Wells, 2008b, 2008a). Indeed, depressive symptoms have been associated with more memory complaints, with lower representations of performance and lower accuracy on retrospective memory tasks (Balash et al., 2013; Cipolli et al., 1996; Metternich et al., 2009; Zandi, 2004). Moreover, in older adults, the influence of depression on retrospective memory might be mediated by the relationship between metamemory and retrospective memory. As for PM specific effects, to our knowledge, only one study investigated the association between depressive symptoms and metamemory representations with PM performance in younger adults (Huber et al., 2022b). The authors indicated that the depressed and healthy groups did not differ in their PM performance nor in the correlation between PM metamemory representations and actual performance. However, they reported that depressed younger adults had more PM complaints than the healthy group. This relationship between depressive symptoms, metamemory and PM has never been investigated in older adults. Yet this is of great importance to understand whether and how metamemory representations are associated with depressive symptoms and PM performance in older adults too. Considering that with increasing age older adults are overconfident in their PM abilities, but that depressive symptoms elicit negative representations of one's own abilities, depressive symptoms and age may have opposite effects on metamemory representations. Then, categorically discriminating between higher and lower depressive symptoms, higher and lower metamemory representations, but also young-old and old-old may be interesting to explore and disentangle these effects.

6.2.4 Age

Age might play a role on metamemory representations as mentioned previously, but also differentially relate to depressive symptoms and PM. Previous studies demonstrated that several factors may influence and characterize depressive symptoms differently depending on age. For example, it has been shown that depressive symptoms are particularly influenced by family relationships and apathy in old-old adults (S.-W. Lee et al., 2020; Mehta et al., 2008). As PM performance is not spared by age-related decline, several authors distinguished between young-old and old-old adults, demonstrating that young-old adults often perform better than old-old participants (for a meta-analysis on age-related decline see Henry et al., 2004; see also Kvavilashvili et al., 2009; Zimmermann & Meier, 2006; Zuber & Kliegel, 2020). Moreover, as previously mentioned, a recent meta-analysis of James et al. (2021) indicates that depression is related to deficits in episodic memory which are larger in older age. Interestingly, the available two studies investigating depressive symptoms and PM have sampled from two different decades in the lifespan (68.3 years old in Albiński et al., 2012 versus 84.65 years old in Livner et al., 2008). Despite the fact that most studies consider older age as a homogenous group, previous studies draw our attention towards possible differences between young-old and old-old which deserves further investigation.

6.2.5 Gender

Finally, gender might play an important role in the relationship between depressive symptoms and PM in old age as women experience more depression in old age (Girgus et al., 2017; Newman & Brach, 2001). In addition, until the 1970s, there was an important gender gap in education, meaning that older women born in the 1940s may not have benefitted from the same education as their male counterparts (Sundstrom, 2004). Considering these associations, it seems relevant to consider gender in the relationship between depressive symptoms, education, age, and metamemory representations on PM performance.

6.2.6 The present study

Taken together, considering all of those potential factors of influence, we aimed to examine the role of 1) lower and higher depressive symptoms, 2) lower and higher education, 3) lower and higher metamemory representations, 4) age in a young-old versus old-old groups, and finally 5) how these effects may interact together on PM performance in a large-scale population-based cohort of older adults aged 70 and older, while controlling for gender. Based on the analytical rumination hypothesis and results of previous studies presented in Andrews and Thomson's (2009) paper, we expected higher PM performance for participants presenting higher depressive symptoms. Considering previous findings on the link between education and cognition, we expected that participants with higher educational levels will perform better on the PM task than participants with lower educational levels. We expected that participants with higher metamemory representations will perform better on the PM task than participants with lower metamemory representations. Finally, as supported by previous findings, we expected that young-old participants will perform better than old-old participants on the PM task, as they may have more cognitive resources available. Considering that this is the first study to investigate depressive symptoms, education, metamemory and age, we did not have specific hypothesis regarding the effects of all these variables together, especially because opposite effects may emerge.

6.3 Method

Data stem from the second wave of the longitudinal study "Vivre – Leben – Vivere" (VLV), which investigated healthy aging across the lifespan in Switzerland (for more details on the procedure, see Ihle et al., 2018; Mella et al., 2018; Vallet et al., 2020). Participants were assessed in 2017 in a face-to-face computer-assisted personal interview (Ihle et al., 2018). Participants were included in the present analyses if their global cognitive functioning assessed by the Mini Mental State Examination (MMSE; Folstein et al., 1975) was equal and above 24 and if they had no missing data on any variables of interest (depressive symptoms, MSE, education, age, PM and MMSE). Then, to compare PM performance depending on depressive symptoms levels, we selected participants with the highest and lowest levels based on the first versus fourth quartiles of depressive symptoms. The final sample consisted of 394 older adults (47.6% females) with a mean age of 80.10 years (*SD* = 6.09; range = 70 – 98 years). Their MMSE mean score was 28.50 (*SD* = 1.62; range = 24 – 30), and their educational mean level was 3.93 (*SD* = 1.38; range = 1 – 6), which indicates that on average participants' educational level was just below 'high-school graduation'. All participants gave their written informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki (World Medical Association, 2000), and the ethics commission of the Faculty of Psychology and Social Sciences of the University of Geneva had approved the protocol (project identification code: CE_FPSE_05.04.2017).

6.3.1 Measures

6.3.1.1 Depressive Symptoms. Participants' depressive symptoms were assessed with the Brief Self-Assessing Depression Scale (SADS; Wang et al., 1975). The SADS was administered to participants in their native tongue, which was either French or German. They indicated on a 4 points-Likert scale ranging from 0 (never) to 3 (always) how frequently in their present life situation they experienced sadness, good appetite (inverse-coded), crying, sleep issues, self-confidence (inverse-coded), interests in doing things (inverse-coded), irritability, being hopeful for the future (inverse-coded), being anxious and being tired. The SADS does not provide cut-off values to identify mild, moderate, and severe depressive symptoms. The higher the score, the more participants experienced depressive symptoms. Participants' scores could range from 0 to 30. Reliability for the SADS in our sample was good, as indicated by a Cronbach's alpha of 0.84 (Gliem & Gliem, 2003; Pallant, 2020).

6.3.1.2 Metamemory Representations. Metamemory representations were assessed with the validated French Version of the Memory Self-Efficacy Questionnaire (MSE; Beaudoin et al., 2008; Desrichard & Köpetz, 2005) in which participants evaluated their ability to execute various memory tasks with different levels of difficulty. The questionnaire describes six memory tasks: three laboratory-type memory tasks like recalling a list of numbers, and three everyday-type memory tasks like remembering a list of grocery shopping items. Participants indicated between five levels of difficulty the one they think they will successfully complete (e.g. "if someone showed you the pictures of 16 familiar objects (e.g., lamp, umbrella, etc.), would you be able to look at them once and recall the names... of all 16 objects, of 12 of the 16 objects, of eight of the 16 objects, of four of the 16 objects, of two of the 16 objects?"). Answers were recoded so that 0 indicated that participants thought they would recall the minimum number of items, while 4 indicated that participants thought they would recall the maximum. Participants' score could range from 0 to 30 points. The higher the score, the better participants thought they would perform on the different memory tasks, and therefore had higher representations of their memory abilities.

6.3.1.3 Education. Participants were asked to indicate the highest educational level they reached between "primary school" (coded "1"), "inferior secondary school" (coded "2"), "apprenticeship graduation" (coded "3"), "superior secondary school" (coded "4"), "superior vocational college" (coded "5") and "university degree" (coded "6").

6.3.1.4 Prospective Memory. PM performance was assessed using four event-based single-trial PM tasks embedded into the interview session (for other studies using the same PM task setting and reliability analyses of this approach see Cuttler & Graf, 2007; Dobbs & Rule, 1987; Ihle et al., 2019; Zeintl et al., 2007). Specifically, participants were instructed 1) to remember to say "red pencil" when the interviewer talked about a red pencil later during the interview (i.e., red-pencil task), 2) to remember to knock twice on the table when the interviewer talked about physical activities (i.e., knock-on-table task), 3) to remember to tell the interviewer their year of birth when talking about activities in the course of the participant's life (i.e. year-of-birth task), and 4) to remember to remind the interviewer to switch on the mobile phone at the end of the interview (i.e., mobile phone task). Each task was scored 1 point when successfully remembered and 0 when the participants did not remember to execute the task. Participants' total scores ranged from 0 to 4.

6.3.2 Analytical Approach

Based on the analytical rumination hypothesis, we treated depressive symptoms categorically in our study**.** To compare PM performance depending on depressive symptoms levels, we selected participants with the highest and lowest levels based on the first versus fourth quartiles of depressive symptoms. We created age groups based on the recommendations of the WHO and the American Geriatric society who consider that individuals aged 80 years and older represent the "old-old" (Escourrou et al., 2020). Thus, participants younger than 80 years old were included in the “young-old” age group (*M* = 75.48, *SD* = 2.54), while participants aged 80 years and older were included in the “old-old” age group (*M* = 85.93, *SD* = 3.83). We also created education groups based on categories of lower education (consisting of “primary school”, “inferior secondary school”, “apprenticeship graduation”) and higher education (consisting of “superior secondary school”, “superior vocational college” and “university degree”; Gabriel et al., 2015; for another VLV study using these cut-off see Ihle et al., 2018). We performed a median split based on our participants' answers to examine metamemory representations (“higher MSE” vs “lower MSE”; for a similar procedure see Iacullo et al., 2016).

Considering the ambiguous results provided by the two previous studies on our research topic, we conducted Bayesian analyses as they allow to clearly quantify which of the null or alternative hypothesis is more plausible. Age, education, metamemory representations, and depressive symptoms were entered as factors in the model while PM was entered as a continuous dependent variable. Then, for the Bayesian ANCOVA, independent variables were depressive symptoms (“higher depressive symptoms” vs “lower depressive symptoms), metamemory (“higher MSE” vs “lower MSE”), education (“higher education” vs “lower education”), age (“old-old” vs “young-old”) and the dependent variable was PM. We controlled for gender. We investigated the main effects and interactions between the dichotomous variables on PM. To further explore significant interactions, we performed Bayesian Independent Samples t-tests. As this is the first study considering depressive symptoms, education, metamemory, and age, we decided to use default priors and parameters set by JASP (Version 0.16.0.0; JASP Team, 2021). Default priors are recommended when knowledge provided by previous studies is not clear (van Doorn et al., 2019). In our case, only two previous studies investigated the relationship between depressive symptoms and PM. These studies demonstrated results going in opposite directions, encouraging the use of a default prior.

Moreover, they did not investigate the combined effect of depressive symptoms, age, education, metamemory representations, and gender. Then, defining an informative prior based on these previous results might bias our results because the direction is unclear, but also because our model does not match previous studies. Default priors are used in our study, meaning that the r scale fixed effects' coefficient is 0.5, the r scale random effects' coefficient is 1, and the r scale covariates' coefficient is 0.354. We examined which model was the best model among possible models by comparing the Bayes Factors. According to Lee and Wagenmakers (2013), Bayes Factors superior to 100 indicate extreme evidence for H1, 30 to 100 indicate very strong evidence, 10 to 30 indicate strong evidence, from 3 to 10 indicate moderate evidence, from 1 to 3 indicate anecdotal evidence for H1, while 1/3 to 1 indicate anecdotal evidence for H0, 1/3 to 1/10 indicate moderate evidence for H0, 1/10 to 1/30 indicate strong evidence for H0, 1/30 to 1/100 indicate very strong evidence for H0 and Bayes Factors inferior to 1/100 indicate extreme evidence for H0. We assessed significance of posterior means (further called estimates δ) for independent variables using Bayes factors and bounds (95% credible intervals; e.g., van de Schoot et al., 2014). Bayes factors indicate whether the data are in favor of the alternative (H1) or the null (H0) hypotheses, while the credible intervals indicate significance (Lavine & Schervish, 1999; van de Schoot et al., 2014). When the credible interval did not contain the value 0 (meaning that both ends of the interval are either larger or smaller than 0), we rejected H0 and concluded that the effect is significant. In order to disentangle interaction effects between our variables of interest, we conducted multiple comparisons using Bayesian t-tests and applied adequate corrections based on the Westfall approach (for a similar approach, see e.g., de Jong, 2019).

6.4 Results

6.4.1 Descriptive Statistics

Table 5 shows descriptive statistics describing means and standard deviations for depressive symptoms, MSE, education, and MMSE according to age groups. This table indicates that depressive symptoms and metamemory representations differed between young-old and old-old adults. We performed Bayesian t-tests on these data to assess possible differences in our sample. Bayesian t-test between young-old (M_{age} = 75.48) and old-old adults (M_{age} = 85.93) indicate they indeed differ on age. The higher depressive symptoms group has significantly higher levels of depressive symptoms, in the young-old age group (BF_{-0}= $4.56x10^{92}$) and in the old-old age group (BF_{-0}= $2.48x10^{68}$). In the young-old participants with lower depressive symptoms, participants in the lower MSE group (*M*=16.07) have significantly lower MSE than the higher MSE group (*M*=20.99; BF_{-0}= $2.30x10^{22}$). This effect was replicated in the young-old participants with higher depressive symptoms, the lower MSE group (*M*=14.52) has significantly lower MSE than the higher MSE group (20.44; BF_{-0}= $4.13x10^{14}$). In the old-old participants with lower depressive symptoms, the lower MSE group (M= 15.05) has significantly lower MSE than the higher MSE group (*M*=22.07; BF_{-0} = $8.37x10_{14}$). This effect was also replicated in the old-old adults with higher depressive symptoms, indeed, the lower MSE group (*M*=14.95) has significantly lower MSE than the higher MSE group (*M*=20.74; BF_{-0}= $5.41x10^{13}$). All Bayes factor provided indicate extreme evidence for significant differences between these groups. Figure 5 describes the percentage of PM success in each group of age and depressive symptoms.

Table 5

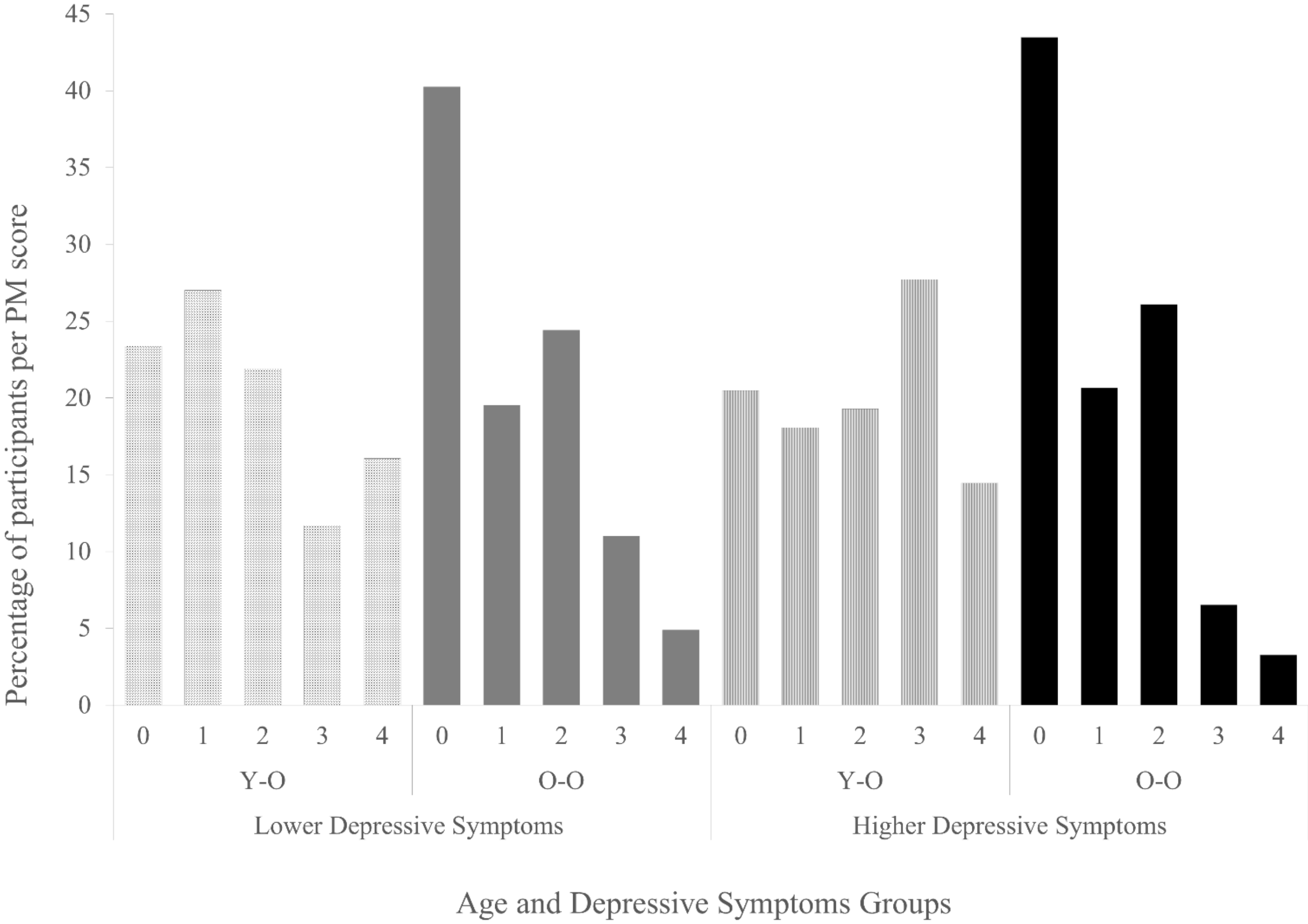
Descriptive Statistics and Bayesian T-Tests of Variables of Interest by Age, Depressive Symptoms and Metamemory Representations Groups

Variables	Young-Old Adults				Old-Old Adults			
	Lower Depressive Symptoms		Higher Depressive Symptoms		Lower Depressive Symptoms		Higher Depressive Symptoms	
	Lower MSE (n=42)	Higher MSE (n=95)	Lower MSE (n=42)	Higher MSE (n=41)	Lower MSE (n=37)	Higher MSE (n=45)	Lower MSE (n=65)	Higher MSE (n=27)
Age	75.47 *(2.81)* [71 – 79]	75.61 *(2.58)* [70 – 79]	75.95 *(2.39)* [71-79]	74.70 *(2.21)* [70 – 79]	86.07 *(3.76)* [80 – 93]	86.93 *(4.38)* [80 – 95]	85.50 *(3.66)* [80 – 98]	85.13 *(3.16)* [80 – 91]
Gender (female)	33.3%	43.2%	64.3%	58.5%	40.5%	42.2%	52.3%	48.1%
Depressive Symptoms	3.64 (*1.51*) [0 – 5]	3.36 *(1.40)* [0 – 5]	12.17 *(1.97)* [10-17]	11.85 *(1.97)* [10- 17]	3.54 *(1.43)* [0 – 5]	3.49 (1.*16*) [2 – 5]	11.95 *(2.25)* [10 – 22]	11.26 *(1.58)* [10 – 15]
MSE	16.07 *(1.44)* [11 – 18]	20.99 *(2.27)* [18 – 28]	14.52 *(2.66)* [8-17]	20.44 *(2.28)* [18 – 27]	15.05 *(2.81)* [6 - 18]	22.07 *(2.89)* [18 – 29]	14.95 *(2.78)* [7 – 18]	20.74 *(1.58)* [19 – 24]
Education	3.76 (*1.14*) [1 – 6]	3.87 (*1.48*) [1 – 6]	3.90 *(1.41)* [1 – 6]	4.32 *(1.3)* [1 – 6]	3.43 (*1.32*) [1 – 6]	3.96 (*1.46*) [1 – 6]	4.09 *(1.33)* [1 – 6]	4.07 *(1.41)* [1 – 6]
MMSE	28.43 *(1.35)* [25 – 30]	28.72 *(1.47)* [24 – 30]	28.07 *(1.93)* [24 - 30]	28.95 *(1.38)* [25 – 30]	28.22 *(1.65)* [24 – 30]	28.91 *(1.47)* [24 – 30]	28.05 *(1.79)* [24 – 30]	28.59 *(1.76)* [24- 30]
PM	1.88 *(1.33)* [0 – 4]	1.62 *(1.39)* [0 – 4]	1.79 *(1.38)* [0 – 4]	2.17 *(1.36)* [0 – 4]	0.84 *(1.09)* [0 – 4]	1.51 *(1.25)* [0 – 4]	1.06 *(1.12)* [0 – 4]	1.04 *(1.16)* [0 – 4]

Note. This table shows the means, standard deviations and range of age, depressive symptoms, memory self-efficacy (MSE), education, Mini-Mental State Examination (MMSE) and prospective memory (PM) for each age, depressive symptoms and metamemory groups (“Young-Old” vs “Old-Old” adults and “Higher Depressive Symptoms” vs “Lower Depressive Symptoms” and “Lower MSE” vs “Higher MSE” groups).

Figure 5

Percentage of Participants per PM Score depending on Groups of Age and Depressive Symptoms



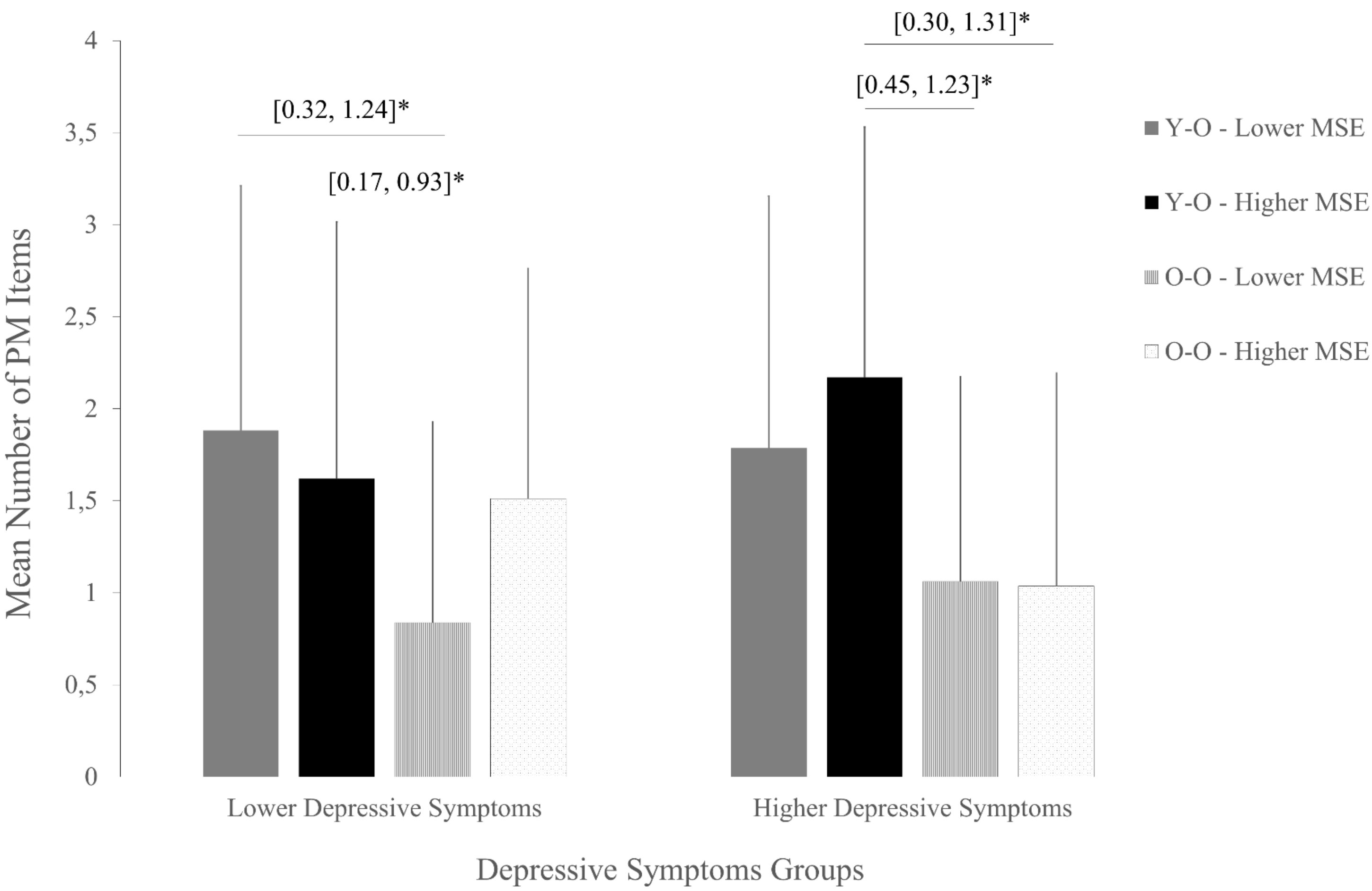
Note. This figure represents the distribution of participants per PM score for Young-Old (Y-O) and Old-Old (O-O) participants in lower and higher depressive symptoms groups.

6.4.2 Bayesian ANCOVA

A 2 Age (young-old vs old-old) x 2 Education (lower education vs higher education) x 2 Depressive Symptoms (lower depressive symptoms vs higher depressive symptoms) x 2 MSE (lower MSE vs higher MSE) x Gender Bayesian ANCOVA was conducted. Bayesian model comparison revealed extreme evidence that the model with age, education, depressive symptoms, and MSE and a 3-way interaction between MSE, age, and depressive symptoms was the best model compared to the null model (BF_{10} = 203.89). It means that the data were 203.89 times more likely to occur under this model than under the null model (Supplementary Material Table S1 details estimates, standard deviations, credible intervals for all independent variables, and interactions of the model). This model explained in mean 8% of the variance of the data (R^2= 0.08; 95%CI [0.04; 0.12]). Results indicated main effects of age and education, meaning that young-old participants (*M* = 1.80, *SD* = 1.38) had a better PM performance than old-old participants (*M* = 1.13, *SD* = 1.17) and that participants with higher education (*M* = 1.65, *SD* = 1.37) performed better than participants with lower education (*M* = 1.32, *SD* = 1.27). A 3-way interaction between depressive symptoms, age, and MSE was significant (see Figure 6). Further Bayesian t-tests were performed to explain the direction of this 3-way interaction. First, results indicated that for participants with lower depressive symptoms and lower MSE, the young-old (*M* = 1.88, *SD* = 1.33) outperform the old-old individuals on the PM task (*M* = 0.84, *SD* = 1.09; BF_{10} = 15.71, δ = 0.78, 95% CI [0.32, 1.24]). Second, for participants with lower depressive symptoms, young-old adults with higher MSE (*M* = 1.62; *SD* = 1.39) perform better on PM than old-old adults with lower MSE individuals (*M* = 0.84; *SD* = 1.09; BF_{10} = 2.34 δ = 0.54, 95% CI [0.17, 0.93]). Third, for participants with higher depressive symptoms and lower MSE, the young-old (*M* = 1.79; *SD* = 1.37) performed better than the old-old individuals on PM (*M* = 1.06; *SD* = 1.12; BF_{10} = 1.94, δ = 0.54, 95% CI [0.16, 0.94]). Fourth, for participants with higher depressive symptoms and higher MSE, PM performance was higher in young-old (*M* = 2.17; *SD* = 1.36) than in old-old adults (*M* = 1.04; *SD* = 1.16; BF_{10} = 7.98, δ = 0.80, 95% CI [0.30, 1.31]). Fifth, for participants with higher depressive symptoms, young-old adults with higher MSE (*M* = 2.17; *SD* = 1.36) performed better than old-old adults with lower MSE (*M* = 1.06; *SD* = 1.12; BF_{10} = 254.62, δ = 0.86, 95% CI [0.45, 1.23]). This effect was not present for the lower depressive symptoms group.

Figure 6

Representation of the 3-way Interaction between Depressive Symptoms, Age, and MSE on PM Performance



Note. This figure represents the 3-way interaction between depressive symptoms, age and memory self-efficacy on the prospective memory performance (error bars represent standard errors). “Y-O” and “O-O” respectively represent the Young-Old and Old-Old participants, while “Higher MSE” and “Lower MSE” respectively refer to higher and lower metamemory groups of participants. Numbers in brackets represent the 95% confidence interval of the posterior distribution for each respective comparison, while * indicates significant differences.

6.5 Discussion

The aims of the present study were to examine the role of levels of 1) depressive symptoms, 2) education, 3) metamemory representations, 4) age, and finally 5) how these effects may interact together on PM performance. The present findings reveal that age and metamemory representations are indeed important variables to consider when aiming to understand if and how depressive symptoms may be related to interindividual differences in older adults' PM performance, while education does not seem to be a key factor in this area. In detail, results indicate that the association between depressive symptoms and PM performance is (a) limited to individuals with higher metamemory representations and that (b) the direction of this impact depends on age. In the following, we will discuss the respective main effects and interactions in more detail.

6.5.1 Age effects on PM within Old Age

The fact that young-old adults perform better on PM than old-old adults is consistent with previous literature on aging and cognition in general and on PM and aging in particular (Ballhausen et al., 2019; Kvavilashvili et al., 2009; Zimmermann & Meier, 2006; Zuber & Kliegel, 2020). Thus, these results emphasize the fact that discriminating between young-old and old-old adults is an important factor when investigating PM in older adults.

6.5.2 Education effects on PM

Results indicate that participants with higher levels of education perform better than participants with lower levels of education. This confirms the general literature indicating that education is associated with better cognitive and PM performance which can be explained by the concept of cognitive reserve (Cherry & Lecompte, 1999; Huppert & Beardsall, 1993; Lövdén et al., 2020; Simard et al., 2019; Stern, 2009, 2012). Across the lifespan, individuals accumulate cognitive reserve through professional and leisure activities, but also education, subsequently helping them to perform cognitive tasks, including PM tasks. Yet, importantly for present purposes, education did not interact with the impact of depressive symptoms on older adults' PM performance. Thus, one has to conclude that education exerts a global effect cognitive performance in old age as suggested by Lövdén et al. (2020).

6.5.3 Depressive Symptoms

Contrary to our hypothesis that individuals with higher depressive symptoms would outperform individuals with lower depressive symptoms because of the analytical rumination hypothesis, we did not demonstrate any main effect of depressive symptoms on PM performance in our sample. As explained previously, Andrews & Thomson (2009) postulate the existence of an inverted U-shape curve of cognitive performance in individuals without and with depressive symptoms: individuals with subclinical symptoms would perform better than both individuals with clinical and without symptoms. As the SADS does not provide a clear cut-off for discriminating between mild, moderate, and severe depressive symptoms, we selected participants in the lowest and highest quartiles of the depressive symptoms scores. However, this could have resulted in merging participants suffering from subclinical and clinical depressive symptoms into the same group (i.e., the higher depressive symptoms group). This merging could have led to 1) an averaging of the differences in PM performance within the higher depressive symptoms group, 2) and, consequently, to a reduction of the difference in PM performance between both depressive symptoms' groups. However, the effect of depressive symptoms emerges in a 3-way interaction with metamemory representations and age, suggesting that the relationship between depressive symptoms and PM performance may be more complex than a main effect.

6.5.4 *Interaction effects between Depressive Symptoms, Metamemory Representations, and Age*

As a key result, a 3-way interaction between depressive symptoms, metamemory representations, and age emerged in our sample of participants. Having higher metamemory representations seems to have differential consequences on young-old versus old-old adults depending on their depressive symptoms level. In the lower depressive symptoms group, old-old adults with higher metamemory representations perform as well as young-old adults independently of their metamemory representations. On the contrary, in individuals with higher depressive symptoms and higher metamemory representations, old-old adults perform more poorly than young-old adults. Why might this be?

Previous models considering affect and motivation described that people with low ability need to invest more effort to perform as well as people with high ability. When the task difficulty is subjectively perceived as too challenging, individuals will disengage from the task, meaning they do not mobilize effort to succeed (Brinkmann, 2008; Gendolla, 2004). Moreover, this threshold of disengagement happens "earlier" for people with low ability than for people with high ability (see the Attributional Theory of Performance and Risk-Taking Model, respectively from Kukla, 1972, and Atkinson, 1957 cited in Gendolla, 2004). These theories and research on affect and motivation also included participants with depressive symptoms. They indicate that the threshold of disengagement supposedly happens "earlier" for individuals experiencing depressive symptoms than for individuals without depressive symptoms (Brinkmann, 2008; Brinkmann & Gendolla, 2008). In their study, Brinkmann and Gendolla (2008) demonstrated that for a memory task, participants with depressive symptoms were judging the task as more difficult than participants in the same condition but without depressive symptoms. Moreover, the authors concluded that individuals with depressive symptoms can be very engaged (i.e., mobilize effort) in tasks that they consider easy, while they disengage and withhold effort for tasks that they perceive as difficult.

In the light of these theories and previous studies, we can interpret our 3-way interaction results. First, we will focus on the mechanisms that contribute to performance for participants in the lower depressive symptoms group. Young-old participants outperform old-old participants on PM performance when metamemory representations are lower, but not when metamemory representations are higher. Hence, old-old adults might not be as confident as young-old adults in their memory abilities because they perceive the task as too difficult considering their remaining cognitive resources, leading them to disengage from the task. Indeed, with greater age comes greater cost to engage in cognitive task which elicit fatigue (Hess, 2014). Thus, older adults would wisely select in which tasks they are willing to engage effort and disengage earlier for those requiring too many resources to succeed (Hess, 2014). While for participants with higher metamemory, old-old adults may see themselves as high performers who can achieve the PM task, subsequently mobilizing effort and performing similarly to young-old adults. Thus, having higher metamemory representations seems protective against age-related cognitive decline.

Second, we now focus on the mechanisms that contribute to performance for participants in the higher depressive symptoms group. Old-old adults perform similarly independently of their metamemory representations. In turn, the two old-old groups performed significantly worse than the young-old adults with higher metamemory representations. Hence, when depressive symptoms are higher, the protective effect of higher metamemory representations on PM performance seem to disappear as depressive symptoms might take over and disrupt task engagement, regardless of old-old adults' metamemory representations. As Brinkmann and Gendolla (2008) included only younger adults in their study, we extend previous findings and thereby provide new insights on older age to the field of affect, metamemory and cognitive performance.

Interestingly, even though certain old-old adults with higher depressive symptoms have higher metamemory representations, these representations might be an overestimation of their actual abilities, as it was demonstrated in a previous study (Cauvin et al., 2019a), creating a gap between their representations and abilities. Yet, if old-old adults do not update these representations, they will not be able to implement new – and more effective- strategies to compensate for the negative influence of their depressive symptoms on PM abilities. Importantly, depressive symptoms often elicit worry which has been related to impairment in cognitive functioning in older adults (de Vito et al., 2019). Indeed, it has been demonstrated that worry interferes with processing speed, working-memory, and attention (Eysenck et al., 2007; Pietrzak et al., 2015; Schoen & Holtzer, 2017). It is then also possible that old-old individuals are overwhelmed by worry about their future performance on PM which distracts their attention from planning PM intentions.

For example, research shows that when older adults are confronted with the memory demands of a PM task, they perform worse compared to when the same task is presented as a non-memory task (e.g., Zuber et al., 2019). It would therefore be interesting to further investigate the relation between depressive symptoms, worry, and metamemory in older adults to offer possible interventions targeting PM. Indeed, a recent meta-analysis indicates that metacognitive interventions works as well as psychological treatment to alleviate depressive symptoms (Philipp et al., 2019). Moreover, a study by Pearman et al. (2020) indicates that metacognitive intervention helps reduce PM failures in everyday life in older adults. However, fewer studies focused on both affective and cognitive outcomes using metacognitive interventions. This is a gap that future studies should consider investigating.

6.5.5 Limitations and Perspectives

Noteworthy is that, in this secondary-analysis study, depressive symptoms were assessed by the SADS, which is not a diagnostic scale (yet, it has been used in several studies see Lalive d'Epinay & Bickel, 2003; Perrig-Chiello et al., 2016; Vedder et al., 2022, and its items are very similar to the Beck Depression Inventory, Beck et al., 1996). Even though participants in the lower and higher depressive groups were significantly different, and that the reliability of the SADS reached a Cronbach's alpha of 0.84 for our sample, we recommend that future studies use more clinical and validated assessment tools, like the Geriatric Depression Scale (GDS; Brink et al., 1982; Yesavage et al., 1983), to ensure that participants present meaningful levels of depressive symptoms.

Considering that mechanisms of depressive symptoms on PM performance are currently still not well understood, future studies should consider investigating the rumination process and other possible factors. For instance, it would be interesting to use a rumination questionnaire like the Ruminative Responses Scale (RRS; Treynor et al., 2003) or the Analytical Rumination Questionnaire (ARQ; Barbic et al., 2014) to disentangle the possible effects of depression levels and ruminations on cognitive tasks.

Metamemory representations were measured with the French Version of the Memory Self-Efficacy Questionnaire (Beaudoin et al., 2008; Desrichard & Köpetz, 2005). This self-report questionnaire relies on participants representations but do not inform on the accuracy of these representations. Also, this questionnaire has not been specifically designed to assess PM representations, but it focuses on retrospective memory. As PM does not only rely on retrospective memory, it would be interesting to conduct future studies using questionnaires about both retrospective memory and PM like the PRMQ (Crawford et al., 2003) which provides normative data. Using a questionnaire focusing on both retrospective and prospective memory would also enable the comparison of representations with actual performance. Indeed, understanding whether participants have accurate representations of their memory abilities is very informative as it could explain cognitive impairment and help to implement interventions on representations and the use of strategies.

Future studies should consider examining depressive symptoms, metamemory, and PM in longitudinal designs. Moreover, as a 3-way interaction and the t-tests applied to disentangle its effect are not equal to a moderation test, we suggest that they investigate this relationship using formal moderation tests. It would enable to better understand how the relationship between age, depressive symptoms and PM depends on metamemory representations, and how they develop together across the lifespan.

6.5.6 Conclusion

Taken together, the present study critically adds to the scarce literature on depressive symptoms and PM in older adults by introducing new important factors to consider, such as age, and metamemory representations. These findings are of great importance as they provide new insights into the effects of depressive symptoms on PM in older adults, which are still not well documented nor understood. In more detail, the present findings indicate that the association between depressive symptoms and PM performance depends on age and metamemory representations. Indeed, metamemory representations buffer the negative effect of age on PM performance only in old-old adults with low depressive symptoms. On the contrary, old-old adults with higher metamemory representations suffering from depressive symptoms might need interventions, not only to reduce their depressive symptoms and increase their well-being, but also to help them to adapt their representations and implement new strategies. The aim is to enable these individuals to perform as well as young-old adults on PM, and thus help them to maintain their autonomy as long as possible.

6.6 Supplement (Study 2)

Table S1

Estimates, Standard Deviations, Lower and Upper Bounds of the Credible Intervals for the Independent Variables and Interactions of the Model

Independent Variables	Level	Estimate	SD	95% Lower Bound CI	95% Upper Bound CI
Intercept		1.456	0.066	1.324	1.586
Age	1	0.329	0.066	0.196	0.459
	2	-0.329	0.066	-0.460	-0.198
Depressive Symptoms	1	-0.025	0.066	-0.159	0.105
	2	0.025	0.066	-0.107	0.158
MSE	1	-0.061	0.066	-0.193	0.068
	2	0.061	0.066	-0.071	0.192
Gender		0.110	0.128	-0.144	0.365
Education	1	-0.162	0.064	-0.291	-0.035
	2	0.162	0.064	0.032	0.288
Age✻ Depressive Symptoms	1 & 1	-0.101	0.065	-0.231	0.026
	1 & 2	0.101	0.065	-0.029	0.230
	2 & 1	0.101	0.065	-0.028	0.230
	2 & 2	-0.101	0.065	-0.232	0.026

Age✻ MSE	1 & 1	0.099	0.065	-0.031	0.228
	1 & 2	-0.099	0.065	-0.230	0.028
	2 & 1	-0.099	0.065	-0.230	0.029
	2 & 2	0.099	0.065	-0.030	0.229
Depressive Symptoms✻ MSE	1 & 1	0.025	0.067	-0.110	0.157
	1 & 2	-0.025	0.067	-0.157	0.108
	2 & 1	-0.025	0.067	-0.158	0.108
	2 & 2	0.025	0.067	-0.109	0.157
Age✻ Education	1 & 1	-0.067	0.063	-0.194	0.059
	1 & 2	0.067	0.063	-0.061	0.192
	2 & 1	0.067	0.063	-0.061	0.192
	2 & 2	-0.067	0.063	-0.194	0.059
Depressive Symptoms✻ Education	1 & 1	0.012	0.064	-0.117	0.138
	1 & 2	-0.012	0.064	-0.142	0.115
	2 & 1	-0.012	0.064	-0.140	0.115
	2 & 2	0.012	0.064	-0.117	0.138
MSE✻ Education	1 & 1	0.050	0.063	-0.076	0.176
	1 & 2	-0.050	0.063	-0.178	0.075
	2 & 1	-0.050	0.063	-0.178	0.075
	2 & 2	0.050	0.063	-0.077	0.175
Age✻ Depressive Symptoms✻ MSE	1 & 1 & 1	0.140	0.066	0.008	0.271
	1 & 1 & 2	-0.140	0.066	-0.275	-0.011
	1 & 2 & 1	-0.140	0.066	-0.273	-0.010
	1 & 2 & 2	0.140	0.066	0.008	0.271

	2 & 1 & 1	-0.140	0.066	-0.273	-0.010
	2 & 1 & 2	0.140*	0.066	0.009	0.273
	2 & 2 & 1	0.140*	0.066	0.008	0.271
	2 & 2 & 2	-0.140*	0.066	-0.274	-0.010
Age✻ Depressive Symptoms✻ Education	1 & 1 & 1	0.045	0.063	-0.080	0.172
	1 & 1 & 2	-0.045	0.063	-0.174	0.080
	1 & 2 & 1	-0.045	0.063	-0.173	0.078
	1 & 2 & 2	0.045	0.063	-0.081	0.172
	2 & 1 & 1	-0.045	0.063	-0.174	0.079
	2 & 1 & 2	0.045	0.063	-0.080	0.172
	2 & 2 & 1	0.045	0.063	-0.080	0.172
	2 & 2 & 2	-0.045	0.063	-0.174	0.079
Age✻ MSE✻ Education	1 & 1 & 1	0.023	0.062	-0.101	0.147
	1 & 1 & 2	-0.023	0.062	-0.149	0.101
	1 & 2 & 1	-0.023	0.062	-0.149	0.100
	1 & 2 & 2	0.023	0.062	-0.101	0.147
	2 & 1 & 1	-0.023	0.062	-0.149	0.100
	2 & 1 & 2	0.023	0.062	-0.102	0.147
	2 & 2 & 1	0.023	0.062	-0.101	0.147
	2 & 2 & 2	-0.023	0.062	-0.149	0.101
Depressive Symptoms✻ MSE✻ Education	1 & 1 & 1	-0.073	0.064	-0.204	0.054
	1 & 1 & 2	0.073	0.064	-0.055	0.201
	1 & 2 & 1	0.073	0.064	-0.056	0.202
	1 & 2 & 2	-0.073	0.064	-0.204	0.054
	2 & 1 & 1	0.073	0.064	-0.056	0.202
	2 & 1 & 2	-0.073	0.064	-0.203	0.054

	2 & 2 & 1	-0.073	0.064	-0.204	0.054
	2 & 2 & 2	0.073	0.064	-0.055	0.202
	1 & 1 & 1 & 1	-0.010	0.061	-0.136	0.112
	1 & 1 & 1 & 2	0.010	0.061	-0.113	0.134
	1 & 1 & 2 & 1	0.010	0.061	-0.114	0.134
	1 & 1 & 2 & 2	-0.010	0.061	-0.136	0.112
	1 & 2 & 1 & 1	0.010	0.061	-0.114	0.134
	1 & 2 & 1 & 2	-0.010	0.061	-0.135	0.112
	1 & 2 & 2 & 1	-0.010	0.061	-0.136	0.112
Age✻ Depressive Symptoms✻ MSE✻ Education	1 & 2 & 2 & 2	0.010	0.061	-0.113	0.134
	2 & 1 & 1 & 1	0.010	0.061	-0.114	0.134
	2 & 1 & 1 & 2	-0.010	0.061	-0.135	0.112
	2 & 1 & 2 & 1	-0.010	0.061	-0.136	0.112
	2 & 1 & 2 & 2	0.010	0.061	-0.114	0.134
	2 & 2 & 1 & 1	-0.010	0.061	-0.136	0.112
	2 & 2 & 1 & 2	0.010	0.061	-0.113	0.134
	2 & 2 & 2 & 1	0.010	0.061	-0.114	0.134
	2 & 2 & 2 & 2	-0.010	0.061	-0.135	0.112

Note. This table displays the estimates, standard deviations, lower and upper bounds of the credible intervals for the independent variables and interactions of the model. A value of Bayes Factor 10 (BF10) higher than 3 indicates that data are in favor of the alternative hypothesis rather than the null hypothesis, while a value of Bayes Factor 10 (BF10) lower than 1/3 indicates that data are in favor of the null hypothesis rather than the alternative hypothesis The credible interval indicates significance of the BF10: when the credible interval does not contain the value 0 (meaning that both ends of the interval are either larger or smaller than 0), we reject H0 and conclude that the path is significant. “MSE” refer to memory self-efficacy.

7 Study 3: Exploring the Relationship Between Emotional Valence and Prospective Memory Metamemory in Younger and Older Adults

7.1 Abstract

Prospective memory (PM) plays a crucial role in daily-life autonomy. Metamemory and emotional valence have both separately been shown to influence PM performance in younger and older adults. However, when considered together, the relationship between emotional valence, metamemory and PM has not been examined yet, especially whether metamemory PM representations develop with task-experience (i.e., before versus after performing a task). We collected data from 25 younger and 19 older adults using an event-based PM task with emotional cues (positive, negative, neutral). Results revealed that younger adults' predictions underestimated performance for neutral and negative cues. After performing the task, they showed more accurate representations for neutral cues, indicating that they monitored their representations. Older adults' predictions overestimated performance for negative PM cues, and they did not modify representations after performing the task. Thus, we do not find evidence that older adults are able to coherently monitor their PM representations. These findings highlight the importance of understanding PM representations, especially in older adults, as they may lead to less strategy use and more impaired PM performance in negative everyday situations.

7.2 Introduction

Prospective memory (PM) is the ability to remember to execute intended actions in the future (Grob et al., 2022; Kliegel et al., 2008; McDaniel & Einstein, 2000). Research differentiates between two types of PM tasks : 1) event-based PM tasks, which consist of remembering to execute the intended actions when a specific event or cue occurs, such as remembering to take your medication after dinner, , and 2) time-based PM tasks, which consists of remembering to execute the intended actions at a specific time or after a certain amount of time has elapsed, such as remembering to take the cake out of the oven after 30 minutes. PM has been identified as an important cognitive process that is highly predictive for independence and daily-life autonomy, making it particularly relevant for older adults (Hering, Kliegel, Bisiacchi, et al., 2018; Laera et al., 2021). Although PM is highly frequent in everyday life (Haas et al., 2020), available research suggests that, at least in controlled laboratory PM tasks, older adults perform worse than younger adults (Aberle et al., 2010; Schnitzspahn et al., 2020; for metaanalyses see also Ihle et al., 2013; Kliegel et al., 2008). This decline of PM performance in older adults may partially be explained by reduced general cognitive abilities, such as working-memory (WM). As WM is involved in maintaining PM intentions while performing other tasks, PM performance is influenced by WM load, with older adults being more affected due to their age-related decline in WM (Burkard et al., 2014; Zeintl et al., 2007). However, decline in WM or other associated cognitive abilities such as episodic memory or executive functions does not fully explain PM performance in older age, suggesting that other factors may be at play as well (Ball et al., 2018; Burkard et al., 2014; Gonneaud et al., 2011).

Recently, a new and promising line of research has emerged focusing on the additional role of metamemory in PM performance in older age (Cauvin et al., 2019a; Cauvin et al., 2019b; Grob et al., 2022; Mcdonald-Miszczak et al., 1999; Meeks et al., 2007; Ng et al., 2018). Metamemory is defined as one’s knowledge about the functioning, development, use, and capacities of the memory system in general, as well as of their own memory in particular (Dixon & Hultsch, 1983a; Kuhlmann, 2019; Nelson & Narens, 1990). It is composed of two processes: 1) metacognitive monitoring, which reflects the information about our memory performance provided by the environment that individuals use to shape their memory representations, such as predicting one’s memory performance and/or being confident or not about our memories and in our memory abilities; and 2) metacognitive control, which is a regulation process that individuals use to shape their memory representations, such as activating and using specific strategies for a given task at encoding, maintenance and/or retrieval. Both components are interdependent as the accuracy of individuals' representations is important for individuals to implement effective strategies for memory tasks (Dixon & Hultsch, 1983a; Nelson & Narens, 1990). Indeed, if there is a discrepancy between metamemory representations and the actual memory performance, such as high representations while having actually poor memory performance, individuals will not look for and implement strategies as they are not aware of their poor performance in memory. As PM failures represent half of the reported memory failures by younger and older adults in their daily-life, it seems essential to understand whether they have accurate metamemory representations of their PM performance on which they can rely to implement effective strategies and succeed at PM tasks (Crovitz & Daniel, 1984; Haas et al., 2020).

What is known about this in the context of PM? Certain of the previous studies on metamemory and PM asked participants to make predictions (i.e., how well participants think they will perform at a task) to assess the accuracy of their representations compared to their actual performance. They demonstrated that younger adults are underconfident in laboratory PM tasks, meaning that they actually perform better than they predicted, while older adults are overconfident, meaning that they perform worse than they predicted (Cauvin, et al., 2019a; Cauvin et al., 2019b; Meeks et al., 2007). Even though the previous studies have not examined what may have influenced participants' representations, these results established the importance of differential discrepancies between metamemory representations for PM tasks and the actual PM performance in both younger and older adults. Interestingly, a more recent study of Ng et al. (2018) indicated that at an individual level, after having performed the PM task, predictions of some participants age 50 years and older became more accurate (i.e., they became closer to their actual PM performance). This is of particular interest as it suggests that updating abilities may be preserved, subsequently enabling older adults to adjust their representations. Thus, older adults could benefit from interventions targeting metamemory representations and the implementation of strategies.

However, at least two main conceptual questions remain open. First, what is influencing individuals PM representations? Emotions may be a particularly interesting factor to consider. Indeed, Phelps (2006)explains that emotions may have an influence on three components of episodic memory: encoding, consolidation and subjective remembering. The author indicated that during the appraisal of stimuli, the amygdala evaluates their relevance and modulates the thresholds of attentional and perceptual processes in favor of emotional stimuli compared to neutral stimuli. Consistent with this idea, previous reviews indicated that emotional stimuli facilitate memory performance, as they may be considered as more relevant than neutral stimuli, subsequently enhancing encoding and retrieval (Kensinger, 2009; Talmi, 2013). Regarding age differences, certain studies demonstrated that younger adults, driven by “learning” goals, would be more sensitive to negative stimuli, which would lead them to perform better for these stimuli compared to other valences (see for example Hourihan, 2020). In older adults, certain studies demonstrated a positivity-bias, meaning that older adults tend to remember positive stimuli more than negative ones as they would be driven by “hedonic” goals valences (see for example Hourihan, 2020). However, this positivity bias is still debated in the literature with other authors advocating for a negativity-avoidance bias in older adults (Wolfe et al., 2022). As it shares common factors with retrospective memory, these questions also emerged in the context of PM, with a meta-analysis by Hostler et al. (2018) suggesting the existence of positivity bias in PM. These findings led researchers focusing on metamemory to wonder whether these effects would also apply in metamemory representations. However, they demonstrated inconsistent results. In terms of possible dimensions and factors that may moderate age-related and individual PM representations, studies on retrospective memory demonstrated that emotional valence has an important influence on predictions, meaning that both younger and older adults judged that they were more likely to remember emotional than neutral stimuli (Hourihan, 2020; Hourihan & Bursey, 2017; Sanders & Berry, 2021; Tauber et al., 2017; Tauber & Dunlosky, 2012; Witherby & Tauber, 2018). However, participants' predictions for emotional stimuli did not necessarily match their actual performance, as in some studies participants reported higher predictions for specific emotional stimuli (e.g., positive stimuli), while their performance was actually either influenced by another valence or by neutral stimuli (Hourihan, 2020; Hourihan & Bursey, 2017), or not influenced at all by stimuli valence (Hourihan & Bursey, 2017; Sanders & Berry, 2021; Tauber & Dunlosky, 2012; Witherby & Tauber, 2018). This suggests an interesting dissociation indicating that participants might have biased representations of their memory abilities when emotional stimuli are encountered and that this may be valence-specific (and possibly also age-dependent). Importantly, however, as the relationship between metamemory, emotions and PM has not been studied yet, it currently remains unclear whether these findings apply to PM. The present study sets out to explore this open question as a first aim.

A second open question is whether PM representations are sensitive to prior task experience as suggested by Ng et al.'s study (2018). This is of particular importance because if younger and older adults are able to update their metamemory representations according to the task, they subsequently may implement and use effective strategies to succeed at the task in the future. Only one previous study demonstrated that younger adults were underconfident, and that their metamemory representations for PM did not change with task experience (Meeks et al., 2007). However, this has not been investigated in older adults yet. Thus, additionally, to predictions, it seems relevant to consider postdictions (i.e., how well participants think they have performed *after* experiencing the task). The inclusion of both predictions and postdictions may allow us to establish whether participants, and especially older adults, are able to change their metamemory representations for PM. The present study sets out to explore this issue as its second aim.

Taken together, based on the previous but scarce literature, this exploratory study aimed to explore the role of metamemory in age-related PM performance. More specifically, it targeted two currently open questions and investigated the relationship between metamemory and PM in younger and older adults with emotional stimuli. We aimed to explore the effects of cue valence on the relationship between predictions, postdictions and actual PM performance depending on PM cues' valence and age. Based on previous findings, we expected that younger adults would outperform older adults on the event-based PM task, we also expected that younger adults would be underconfident regarding their metamemory PM representations, while older adults would be overconfident. Regarding the effect of cues' emotional valence on metamemory representations and PM performance, we explored this relationship without specific hypotheses as the literature demonstrated inconsistencies.

7.3 Method

The study was conducted in accordance with the Declaration of Helsinki and the ethics commission of the University of Geneva had approved the protocol (project identification code: PSE.20200604.06). The initial sample consisted of 38 younger adults (undergraduate students; 18-30 years old) and 33 community-dwelling older adults (65 years old and older) from the Geneva area (Switzerland). We had to exclude data because of 1) computer technological problems (n=9), 2) exclusion criteria such as cognitive screening being below threshold (n=11), indication of neurological or psychiatric diseases (n=4), 3) voluntary dropout (n=2), or 4) misunderstanding of the task (n=1). Thus, the final sample consisted of 25 younger adults and 19 older adults with 77.3% of female (thus, gender will be controlled for in the analyses). Younger adults mean age was 22.12 years (SD= 2.47), while mean age in older adults was 73.37 years (SD= 4.40; see Table 6 for descriptive data).

Table 6

Descriptive Statistics for both Age Groups

	Younger Adults (*n=25*)	Older Adults (*n=19*)	*T*-test
Age M*(SD)*	22.12 *(2.47)*	73.37 *(4.40)*	-
Gender (female)	76 %	78.9 %	-
MoCA M*(SD)*	28.12 *(1.45)*	26.84 *(1.12)*	3.18**

Note. This table displays the means and standard deviations of age and Montreal Cognitive Assessment scores (MoCA; Nasreddine et al., 2005) for younger and older adults. Percentage of female in each group is also displayed. T-tests results for number of years in school are also provided.

** $p < .01$.

7.3.1 Measures

7.3.1.1 Socio-Demographic Questionnaire. Participants answered a socio-demographic questionnaire to collect descriptive data and define whether they could be included in the study such as their current medical treatment, neurological and psychopathological history. Gender was assessed using an open-ended format, which allowed participants to self-identify without referring to predefined categories. All participants indicated “male” or “female”.

7.3.1.2 Cognitive prescreening: Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005). The MoCA is a brief screening tool to assess cognitive functioning. The screening duration is around 10 minutes. It is sensitive to very early cognitive impairment as it targets different cognitive domains as visuospatial and executive skills (e.g., drawing a clock with a specific time), language (e.g., naming depicted animals), short-term and long-term memory systems (e.g., repeating a list of five words after the experimenter, and recalling the same words five minutes after the first trial), attention (e.g., clapping when a specific letter is named by the experimenter), abstraction (e.g., explicating the similarities between two objects like a banana and an orange, which are both fruits) and orientation (e.g., being able to give the date and location to the experimenter). Total scores ranging from 26 to 30 indicate a normal cognitive functioning, scores ranging from 18 to 25 indicate a mild cognitive impairment (MCI), scores from 10 to 17 indicate moderate cognitive impairment, while scores under 10 indicate severe cognitive impairment. Participants were administered a French standardized version of the MoCA. Only participants with scores equal and superior to 26 were included in the study.

7.3.1.3 Ongoing task: 2-back task. We used a similar paradigm to the ones used by Cona et al. (2015) and Hering et al. (2018) in which a PM event-based task is embedded in a 2-back WM task. Participants were instructed to press the keys “m” (No) or “n” (Yes), which were counterbalanced, on a French-Swiss keyboard to indicate whether the picture displayed on the computer’s screen has been displayed two pictures before. Even though the pictures were displayed for 1000 milliseconds (ms), participants’ answers were registered for 2500ms. For the following analyses, all reaction times below 100ms were excluded (Gajewski et al., 2018). Every picture was followed by a black screen during 1500ms. Then a fixation cross appeared for 2500ms. The task was composed of a baseline block followed by 6 experimental blocks. During the baseline block participants practiced the 2-back task. After that, instructions for the

PM task were given for the next 6 blocks. Each block was composed of 60 emotional pictures (IAPS, Lang et al., 1997), including five emotional PM cues. The pictures were of positive, neutral and negative valence and each block contained an equal number of pictures of all three valence categories. For the PM cues, positive pictures' ratings for arousal was 5.42 and 7.31 for valence; for neutral pictures, arousal was 3.16 and valence was 5.01; for negative pictures, arousal was 4.91 and valence was 2.71. For the 2-back task stimuli, positive stimuli' ratings were 4.93 for arousal and 7.39 for valence; for neutral stimuli, arousal was 3.18 and valence was 5.03; for negative stimuli, arousal was 5.18 and valence was 3.08. These scores are based on the Self-Assessment-Manikin Likert scale and were provided by the IAPS norms. ANOVAs with the arousal values as dependent variable and valence as a fixed factor were performed respectively for the PM cues and 2-back stimuli. For the PM cues, the ANOVA revealed a significant main effect of valence $F(2, 27) = 58.96$, $p < .001$, $\eta^2_p = .81$. Further comparisons indicated that arousal differed between neutral and negative stimuli ($p < .001$), and between neutral and positive stimuli ($p < .001$), but arousal was similar between negative and positive stimuli ($p > .05$). For 2-back stimuli, main effect of valence was significant, $F(2, 323) = 345.22$, $p < .001$, $\eta^2_p = .68$. Further comparisons indicated that neutral stimuli were significantly different from positive and negative stimuli ($p < .001$), and positive stimuli were significantly different than negative ones ($p < .01$). For the experimental blocks, in total there was 23.3% of 2-back hits in the ongoing task.

7.3.1.4 Event-based Prospective Memory Task. The event-based PM task was embedded in the ongoing task. Participants were instructed to remember to press the red-dot key of the keyboard (i.e., the "c" key) whenever PM target pictures appeared on the screen instead of performing the ongoing task. Five target emotional pictures were presented to the participants before each block (30 PM cues in total). Each five PM target pictures was presented during 4000ms before the block to be memorized by the participants. For two of the six blocks the PM target pictures were of positive valence, for two others of the six blocks they were of neutral valence, for the last two of the six blocks they were of negative valence. The presentation order of the blocks was counterbalanced. To assess retrospective memory of the PM targets, at the end of the six experimental blocks, participants performed a recognition block. During this recognition block, the 30 PM cues were presented on the screen along with 60 different emotional pictures that had been previously used for the 2-back task. Each picture was displayed on the screen until participants answered.

7.3.1.5 Metamemory assessment: Predictions and Postdictions. For each block, after the presentation of the five PM targets, participants were asked to make predictions on their performance. They had to type the percentage of probability that they think they would remember to perform the PM task ("According to you, what is the probability in percentage from 0 to 100% that you will press the red-dot key when these five pictures will be displayed? 0% meaning that you won't answer correctly at all, 100% meaning that you will answer correctly to every picture."). In order to avoid stressing the importance of the PM task over the ongoing task, the same question was asked for the 2-back task ("According to you, what will be your percentage of success from 0 to 100% at the task of pressing for the same or different images? 0% meaning that you won't answer correctly at all, 100% meaning that you will answer correctly to every picture). After executing each block, participants were asked to make postdictions on their performance. They had to type the percentage of success they think they had performed on the PM task ("According to you, what was your success rate in percentage from 0 to 100% at the task of pressing the red-dot key for the five pictures? 0% meaning that you answered correctly to any pictures, 100% meaning that you answered correctly to every picture."). The same question was asked for the 2-back task ("According to you, what was your success rate in percentage from 0 to 100% at the task of categorizing the same or different pictures? 0% meaning that you answered correctly to any pictures, 100% meaning that you answered correctly to every picture.").

7.3.2 Procedure

After obtaining their informed consent, the experimenter administered the MoCA to participants. Following this, instructions for the ongoing-task were displayed on the computer screen and the experimenter asked participants whether they had questions, and asked them to explain the task with their own words. Participants performed a practice block for the ongoing-task which included emotional pictures of the three different valences (positive, neutral and negative). After completion of this practice block, participants received the instructions for the PM task. The experimenter asked participants whether they had any question, if not, they were presented with the first five PM emotional target cues (positive, neutral or negative) of the first PM block. To avoid confusion, the target PM pictures were never used for the ongoing-task. Before performing each block, participants had to predict their PM performance in percentage both for the PM and the ongoing tasks. Similarly, at the end of each block, participants provided their postdictions both for the PM and the ongoing tasks. Participants underwent two blocks of combined ongoing and PM tasks for each valence (positive, neutral and negative), meaning that there were six experimental blocks in total. Finally, the recognition block was instructed and completed by participants.

7.3.3 Analytical approach

Statistical analyses were performed using the software JASP (version 0.16.4.0; JASP Team, 2022). To test our hypotheses, we conducted ANOVAs with gender as a covariate to test potential differences between age groups and across valences on PM and 2-back accuracy and reaction times. Similarly, ANOVAs with gender as covariate were conducted to test potential differences in predictions and postdictions between age groups and across valences of PM cues. In order to disentangle interaction effects between our variables of interest, Bonferroni post-hoc comparisons were applied when required. *P*-values under the threshold of .05 were considered significant.

7.4 Results

7.4.1 Descriptive Statistics

Independent sample *t*-tests demonstrated no significant differences on mandatory, secondary and university levels of education between younger and older adults (see Table 6). On the MoCA, younger adults performed better than older adults (see Table 6).

7.4.2 Prospective Memory

7.4.2.1 Accuracy. We conducted a repeated measures ANOVA with age (younger adults vs older adults) as a between factor, cues' valence as a within factor (positive vs neutral vs negative), gender and MoCA as a covariates and PM mean performance for each PM cue's valence as dependent variables. A main effect of age was present, indicating that younger adults (M = 0.77, SD = 0.18) performed better on PM than older adults (M = 0.52, SD = 0.31; see Table 7), $F(1, 40) = 4.77$, $p = .03$, $\eta^2_p = .11$. Effects of PM cues' valence and gender were not significant. Analyses revealed that the main effect of the covariate MoCA was significant, indicating that participants with higher global functioning performed better on the PM task than other participants independently of their age, and valence of PM cues, $F(1, 40) = 4.77$, $p = .01$, $\eta^2_p = .14$. Results demonstrated a significant interaction effect between age and valence, $F(2, 80) = 3.3$, $p = .04$, $\eta^2_p = .08$. Bonferroni post-hoc comparisons indicated that younger adults (M = 0.80, SD = 0.16; see Table 7) were more accurate than older adults on negative cues (M = 0.46, SD = 0.32; $p_{bonf} = .03$), but not on positive and neutral cues (all other comparisons $p_{bonf} > .05$)[3].

[3] Post-hoc power analyses were performed for all our analyses using G*Power 3.1 (Faul et al., 2007). They revealed high power ranging from 0.98 to 1 for all the analyses presented in this paper, except for the interaction between valence and age in the 2-back task. We still included this result in the paper, however it must be interpreted carefully.

Table 7

Means and Standard Deviations for Each Task by Age and Stimuli Valence

	Younger Adults *(n=25)*			**Older Adults** *(n=19)*		
	Positive	Neutral	Negative	Positive	Neutral	Negative
Ongoing Task						
Correct Hits						
M*(SD)*						
Correct YES	0.79 *(0.13)*	0.78 *(0.16)*	0.82 *(0.15)*	0.58 (0.28)	0.52 *(0.29)*	0.51 *(0.25)*
Correct NO	0.84 *(0.19)*	0.86 *(0.12)*	0.83 *(0.12)*	0.54 (0.32)	0.57 *(0.31)*	0.49 *(0.31)*
RT						
M*(SD)*						
Correct YES	649.94 *(88.84)*	675.16 *(98.51)*	662.13 *(96.50)*	775.98 *(72.72)*	766.04 *(61.80)*	790.57 *(76.31)*
Correct NO	689.46 *(72.31)*	672.76 *(68.76)*	700.32 *(66.91)*	784.26 *(71.95)*	765.14 *(84.10)*	785.97 *(75.57)*
PM						
Accuracy M*(SD)*	0.75 *(0.26)*	0.75 *(0.21)*	0.80 *(0.16)*	0.52 *(0.37)*	0.60 *(0.35)*	0.46 *(0.32)*
RT M*(SD)*	779.90 *(76.91)*	774.93 *(68.02)*	793.64 *(59.27)*	862.41 *(55.19)*	835.38 *(51.09)*	856.26 *(48.15)*
Recognition of PM cues						
Accuracy M*(SD)*	0.86 *(0.22)*	0.85 (0.*12*)	0.83 *(0.19)*	0.78 *(0.25)*	0.76 (0.*28*)	0.77 *(0.24)*

7.4.2.2 Reaction Times. We conducted a repeated measures ANOVA with age (younger vs older adult) as a between factor, cues' valence as a within factor (positive vs neutral vs negative), gender and MoCA as a covariates and PM mean reaction times for each PM cue's valence as dependent variables. A main effect of age was present, indicating that younger adults (*M* =780.41, *SD* = 66.02) answered faster than older adults adults (*M* = 853.68, *SD* = 49.65) to the PM cues, $F(1, 33) = 7.79$, $p < .01$, $\eta^2_p = .19$. No other effects emerged (all effects $p > .05$)[3].

7.4.3 Ongoing Task: Correct Hits

7.4.3.1 Accuracy. We performed a repeated measures ANOVA with age (younger and older adults) as a between factor, stimuli valence (positive vs neutral vs negative) and correct hits (correct "Yes" vs correct "No") as a within factor, gender and MoCA as covariates and means of 2-back performance for each valence and correct hits categories as dependent variables. Results indicate no significant effect of valence, gender, correct hits (respectively $F(2, 80) = .03$, $p = .97$, $\eta^2_p < .01$; $F(1, 40) = .28$, $p = .60$, $\eta^2_p < .01$; $F(1, 80) = .14$, $p = .71$, $\eta^2_p < .01$). There was a significant main effect of age, indicating that younger adults (*M* =0.80, *SD* = 0.15) performed better than older adults (*M* =0.53, *SD* = 0.26) on the 2-back task, $F(1, 40) = 14.22$, $p < .001$, $\eta^2_p = .26$. Results also revealed a significant interaction effect between age and valence, $F(2, 80) = 3.3$, $p = .04$, $\eta^2_p = .08$. Post-hoc t-tests using Bonferroni corrections revealed that older adults' performance for negative stimuli (*M* = 0.50, *SD* = 0.28) was worse than for positive (*M* =0.56, *SD* = 0.30; $p_{bonf} < .001$) and neutral stimuli (*M* =0.54, *SD* = 0.30; $p_{bonf} = .02$). This difference in performance depending on valence was not found in younger adults (for all younger adults' comparisons $p_{bonf} = 1$)[3].

7.4.3.2 Reaction Times. We performed a repeated measures ANOVA with age (younger and older adults) as a between factor, stimuli valence (positive vs neutral vs negative) and correct hits (correct same vs correct different answers) as a within factor, gender and MoCA as covariates and means of reaction times for each valence and correct hits categories as dependent variables. Results indicated a main effect of age, meaning that younger adults (*M* = 674.96, *SD* = 81.97) were faster to answer to the 2-back stimuli than older adults (*M* = 777.99, *SD* = 73.74), $F(1, 38) = 12.8$, $p < .001$, $\eta^2_p = .25$. Moreover, analyses revealed that the main effect of the covariate MoCA was significant, indicating that participants with higher global functioning performed faster on the 2-back task than other participants independently of their age, and valence of the stimuli, $F(1, 38) = 7.58$, $p = .001$, $\eta^2_p = .17$. Other effects were not significant (all effects $p > .14$)[3].

7.4.3.3 Predictions. We performed a repeated measures ANOVA with age (younger vs older adult) as a between factor, PM cues' valence as a within factor (positive vs neutral vs negative), gender and MoCA as covariates and means of predictions for PM performance as dependent variable. There was no main effect of age, of valence, nor interaction effect between age and valence ($F(1, 41) = 1.17$, $p = .29$, $\eta^2_p = .03$; $F(2, 80) = 0.35$, $p = .71$, $\eta^2_p < .01$; $F(2, 80) = 1.52$, $p = .23$, $\eta^2_p = .04$, respectively)[3].

7.4.3.4 Postdictions. Following the same approach, we conducted a repeated measures ANOVA with age (younger vs older adults) as a between factor, PM cues' valence as a within factor (positive vs neutral vs negative), gender as a covariate and means of postdictions for PM performance as dependent variables. It revealed no main effect of age, of valence, nor interaction between age and valence ($F(1, 40) < .01$, $p = .98$, $\eta^2_p < .01$; $F(2, 80) = 0.57$, $p = .57$, $\eta^2_p = .01$; $F(2, 80) = 0.59$, $p = .56$, $\eta^2_p = .02$, respectively)[3].

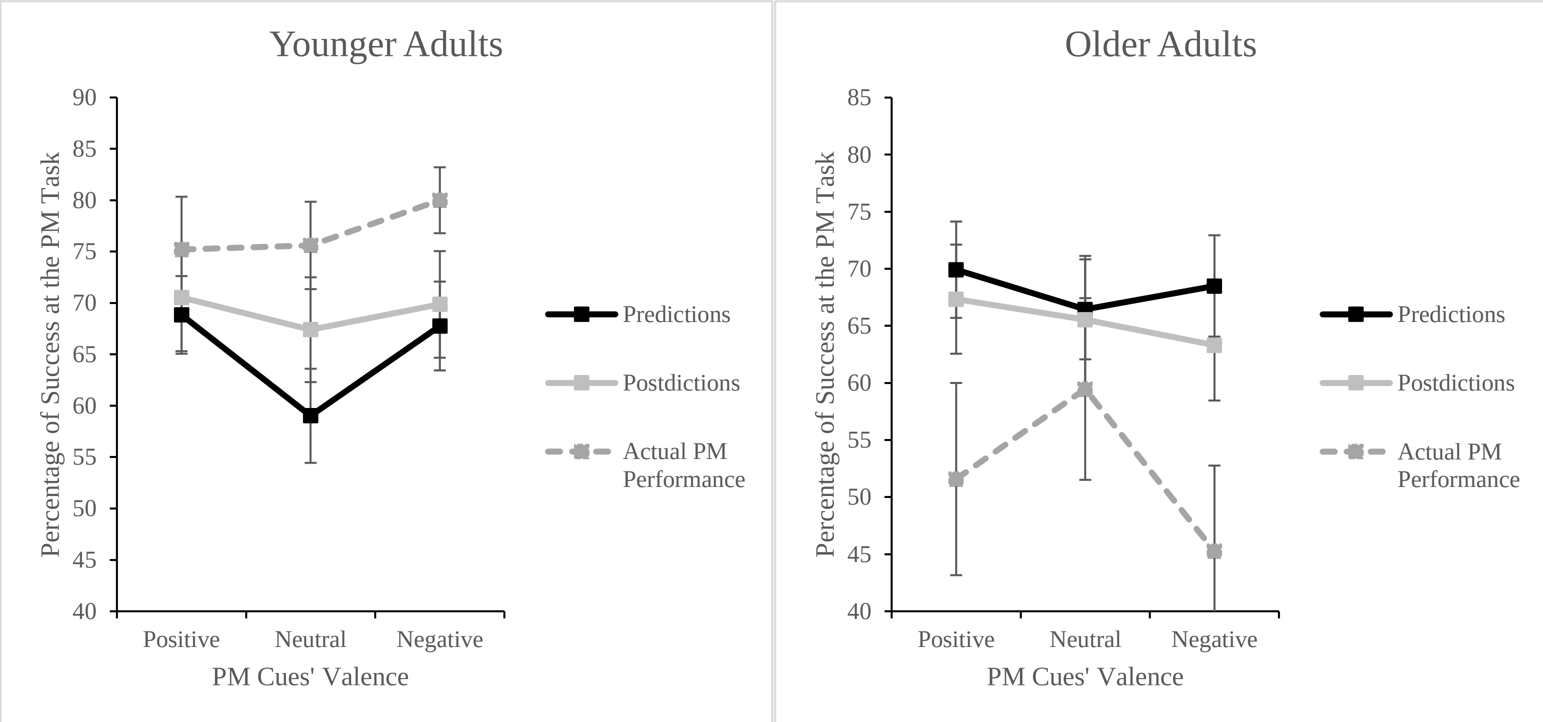
7.4.3.5 Prediction Accuracy: Difference Between Predictions and Actual PM Performance. The difference scores were calculated by substracting participants'mean prediction for each valence to their actual PM performance for each valence respectively. This resulted either in positive scores which indicated that participants overestimated their PM performance, or negative scores which indicated that they underestimated their PM performance.

A repeated measures ANOVA was conducted with age (younger vs older adults) as a between factor, PM cues' valence as a within factor (positive vs neutral vs negative), gender and MoCA as covariates and the difference scores between predictions and actual PM performance for performance as dependent variables[4]. This repeated measures ANOVA revealed a main effect of age, meaning that older adults (*M* = 16.28, *SD* = 37.56) had a higher difference score between predictions and actual performance than younger adults (*M* = -11.73, *SD* = 22.31), $F(1, 40) = 12.34$, $p = <.001$, $\eta^2_p = .24$. In details, older adults seemed to overestimate their later PM performance, while younger adults seem to underestimate their performance (see Figure 7). The main effects of valence and the interaction between age and valence were not significant ($F(1.81, 72.23) = 0.46$, $p = .61$, $\eta^2_p = .04$; $F(1.81, 72.23) = 1.17$, $p = .31$, $\eta^2_p = .03$, respectively). To confirm that we actually observed reliable over- and underestimation in the predictions, we performed further t-tests to test whether the difference scores were different from 0. In younger adults, results indicated that the negative and neutral difference scores between predictions and actual PM performance were significantly different from 0, meaning that younger adults' predictions were significantly lower than their actual PM performance for these stimuli (t(24) = -2.75; *p* =.01, d = -.55; t(24) = -3.61; *p* <.01, d = -.72, respectively). This was not the case for positive PM targets (t(24) = -1.47; *p* =.16, d = -.29). In older adults, t-tests revealed that the negative difference score between predictions and actual PM performance was significantly different from 0, meaning that older adults' predictions were significantly higher than their actual performance for negative stimuli (t(18) = 2.85; *p* =.01, *d* = .66). This was not the case for neutral or positive PM targets (respectively, *t*(18) = 0.78; *p* =.45, *d* = .18; *t*(18) = 2.10; *p* =.05, *d* = .48)[3].

[4] As the assumption of sphericity was violated, we applied Huyn-Feldt corrections and provide corrected values.

Figure 7

Representation of PM Predictions, Postdictions, and Actual Performance of Younger and Older Adults by Valence of PM Cues



Note. These graphics represent the means of PM actual performance, predictions and postdictions for each valence of PM cues, and their respective standard error of the mean for both younger and older adults.

7.4.3.6 Postdiction Accuracy: Difference Score Between Postdictions and Actual PM Performance. Similarly to prediction difference scores, the postdiction difference scores were calculated by substracting participants'mean postdiction for each valence to their actual PM performance for each valence respectively. This resulted either in positive scores which indicated that participants overestimated their PM performance, or negative scores which indicated that they underestimated their PM performance after performing the PM task.

We performed a repeated measures ANOVA with age (younger vs older adults) as a between factor, PM cues' valence as a within factor (positive vs neutral vs negative), gender and MoCA as covariates and the difference scores between postdictions and actual PM performance for PM performance as dependent variable. Results revealed a main effect of age, meaning that older adults (M = 13.29, SD = 36.38) showed a higher difference scores between postdictions and actual PM performance than younger adults (*M* = -23, *SD* = 20.38), $F(1, 40) = 8.28$, $p < .01$, $\eta^2_p = .17$. In more detail, mirroring the results on predictions older adults seemed to overestimate their PM performance, while younger adults seem to underestimate their PM performance (see Figure 7). Again, further t-tests were conducted to understand whether these difference scores were significantly different from 0. For both younger and older adults, only the negative difference score between postdictions and actual PM performance was significantly different from 0, respectively $t(24) = -2.38$; $p = .03$, $d = -.48$; $t(18) = 2.85$; $p = .01$, $d = .66$. This indicates that younger adults' postdictions were lower than their actual PM performance for negative PM cues, while in older adults postdictions were higher than their actual PM performance for these same negative PM cues. This was not the case for neutral or positive PM targets respectively for younger adults, $t(24) = -1.78$; $p = .09$, $d = -.36$; $t(24) = -1.39$; $p = .18$, $d = -.29$; for older adults, $t(18) = .67$; $p = .51$, $d = .15$; $t(18) = 1.83$; $p = .08$, $d = .42$)[3].

7.4.4 Recognition Task

A repeated measures ANOVA with gender and MoCA as covariates was performed on the recognition task. It revealed no significant effect of age ($F(1, 40) = 3.05$, $p = .09$, $\eta^2_p = .07$), of valence ($F(2, 80) = 0.93$, $p = .40$, $\eta^2_p = .02$), nor interaction between age and valence ($F(2, 80) = 0.23$, $p = .80$, $\eta^2_p < .01$), indicating that younger and older adults remembered the PM cues similarly and independently of their valence[3].

7.5 Discussion

The aims of this study were to explore for the first time the relationship between metamemory, emotions and PM. In detail, our objectives were to investigate whether emotional valence influences PM representations, and whether PM metamemory representations are sensitive to task experience, especially in older age. We hypothesized that younger adults would outperform older adults on the event-based PM task. Additionally, we expected that younger adults would be underconfident regarding their metamemory PM representations, while older adults would be overconfident. As for the effect of cues' emotional valence on metamemory representations and PM performance, we explored this relationship without specific hypotheses due to the inconsistencies described in previous literature. Results indicated that younger adults' PM performance was higher than older adults' performance. Moreover, younger adults were more accurate than older adults for negative PM cues. Despite the absence of difference between younger and older adults' predictions and postdictions on PM performance, results demonstrated that younger adults' predictions underestimated performance for neutral and negative PM cues. After performing the task, they showed more accurate representations for neutral cues. Older adults' predictions overestimated performance for negative PM cues, and they did not modify representations after performing the task.

7.5.1 Emotional Valence Influence on PM Performance

Similarly to previous studies investigating PM and age, we observed higher accuracy and faster reaction times for younger adults on the PM task compared to older adults. These age effects are common for PM laboratory-tasks and can be explained by age-related decrements that occur in normal cognitive aging (Ballhausen et al., 2019; Kvavilashvili et al., 2009; Zimmermann & Meier, 2006; Zuber & Kliegel, 2020). Similarly, observed effects on reaction times are in line with the general cognitive slowing reported in older adults across multiple cognitive tasks (Salthouse, 1996).

In terms of the effect of cue valence on PM performance, we observed interaction effects between age and emotional valence on the PM task: while younger adults have a similar performance for all cues' valences, older adults perform worse for negative compared to positive and neutral cues. Moreover, younger adults outperform older adults for negative PM cues. Prior research indicated that negative pictures, independently of their arousal ratings, capture attention, which can potentially impair cognitive performance (Sutton & Lutz, 2019).

Other studies demonstrated that highly arousing pictures can also disrupt attentional processing and lead to greater errors, slower reaction times and difficulties in disengaging attention from these stimuli (De Houwer & Tibboel, 2010; Vogt et al., 2008). These previous findings could possibly be related to why older adults performed worse on negative stimuli both for the PM and 2-back tasks compared to other valence and compared to younger adults. Indeed, as there were mean differences in arousal across our stimuli, participants' performance may have been disrupted by stimuli of negative valence, and especially those higher in arousal, subsequently leading to an impaired performance. Why would this effect arise only in older adults? As greater age is related to cognitive slowing, they may be more sensitive to the effects of valence and arousal compared to younger adults who may compensate with better cognitive resources [40]. Indeed, certain authors demonstrated that IAPS negative pictures are rated as more negative and more arousing by older adults than younger adults (Grühn & Scheibe, 2008). Moreover, when considering metamemory representations, neither older nor younger adults were able to update their representations for negative cues. Thus, this effect of valence and arousal may not only impair cognitive performance, but also metacognitive processes in both younger and older adults. These laboratory findings imply the need to further investigate PM performance to understand how this could be transferred to daily-life, especially in the context of daily activities that may elicit negative emotions high in arousal. Indeed, such activities may then subsequently disrupt older adults' abilities to perform their PM intentions and, at a further extent, lead to a loss of autonomy.

While we did not replicate the positivity-bias ,which hypothesized that older adults would perform better for positive stimuli compared to neutral and negative ones because of emotional regulation processes (Carstensen & Mikels, 2005), our findings are in line with a so far heterogeneous pattern of results regarding valence effects on age-related PM performance, with some studies reporting higher accuracy for positive PM cues (Altgassen et al., 2011; Mioni et al., 2015; Rendell et al., 2011) and other not finding this effect (Altgassen, Phillips, et al., 2010; Ballhausen et al., 2015; Cona et al., 2015). Recent studies are in favor of the existence of a negativity-avoidance bias (Fairfield et al., 2022; Wolfe et al., 2022). Several experimental studies demonstrated that positive stimuli elicit approach , as they are motivationally associated with reward obtention, while negative stimuli usually elicit avoidance, as they are motivationally associated with negative consequences (Deuter et al., 2014; Elliot & Thrash, 2002; Fairfield et al., 2022; Krieglmeyer et al., 2010). A longitudinal study of Windsor et al. (2012) demonstrated that approach tendencies are significantly higher in younger adults than in older adults, and that these tendencies decrease with age, while avoidance tendencies remain stable across the lifespan. In other words, it seems that the ratio between approach and avoidance tendencies evolves with age, possibly leading to an increase of avoidance behaviors in older adults. Thus, in respect of previous research and our study's results, the hypothesis of negativity-avoidance seems credible to explain older adults' performance for negative PM cues. More importantly, the key focus of the present study was not the effect of valence on performance but rather the way metamemory predictions might change with different valence dimensions, how accurate those predictions are and how this may interact with task experience. We discuss those main research questions in the following section.

7.5.2 Sensitivity of Metamemory PM Representations to Task-Experience

We observed no difference on predictions and postdictions for emotional PM cues in younger adults nor in older adults, indicating that participants considered that they would (predictions) and that they have (postdictions) remembered the PM cues similarly, independently of their valence. Moreover, there was no difference in predictions nor postdictions between younger and older adults. However, when comparing these representations and the actual PM performance, we observed interesting new results. Results revealed that, before performing the task, younger adults had accurate predictions of their PM abilities for positive cues, while they underestimated their performance for neutral and negative PM cues. However, after having performed the task, younger adults had accurate postdictions for both positive and neutral cues, but still underestimated their PM performance for negative cues. Both before and after experiencing the task, older adults were accurate for positive and neutral PM cues, but they overestimated how well they have performed for negative PM cues.

The scarce available literature on pre- and postdictions (all of which was conducted on neutral tasks) indicated that younger adults underestimated their PM performance, while older adults overestimated their PM performance (Cauvin et al., 2019a; Cauvin et al., 2019b). The current findings extend this pattern by including emotional PM cues and demonstrating differences in age-related PM metamemory representations depending on cues' valence. We observed that younger adults were able to modify their representations of their PM abilities for neutral cues after having performed the task. However, for older adults, the picture was less clear as we were not able to demonstrate a change in their representations before and after experiencing the task.

As for possible mechanisms, we have to remain speculative at this point, but as previously mentioned studies have shown that, in general, positive stimuli tend to elicit approach tendencies while negative stimuli elicit avoidance tendencies (Deuter et al., 2014; Elliot & Thrash, 2002; Krieglmeyer et al., 2010). Moreover, younger adults seem to have a higher tendency to approach than to avoid. However, these tendencies evolve across the lifespan, leading to an increase of avoidance of negative stimuli in older age (Windsor et al., 2012; Wolfe et al., 2022). Thus, younger adults may be accurate about their metamemory representations for PM positive cue because they elicit approach tendencies, which are high in younger adults. Having higher approach tendencies compared to avoidance tendencies could lead younger adults to focus on positive PM cues and help them to remember to perform the PM task for these stimuli. For neutral PM cues, they may be underconfident before experiencing the task as these stimuli do not elicit action tendencies. However, after performing the task, they may conclude that their performance is higher than expected and subsequently, they may adjust their representations. When it comes to negative PM cues, as they are aversive, they elicit avoidance tendencies which may lead younger adults to have less confidence in their ability to remember to execute the intention.

As individuals age, they experience multiple life and emotional situations which may lead older adults to have accurate metamemory representations of their PM performance for positive and neutral cues. However, as their avoidance tendencies increase with greater age, they may focus less on negative PM cues than they expect, leading to overconfidence both before and after experiencing the task. It is possible that older adults are not aware of their increase of avoidance of negative cues, leading them to not adjust their PM metamemory representations for these stimuli. Another explanation might be that, because of age-related cognitive decline, older adults are not able to modify their metamemory representations based only on interoceptive cues. Indeed, previous studies indicated that interoception (i.e., the physical sensations that are perceived by individuals and may influence well-being and self-reports) decreases and is less associated with emotions in older adults compared to younger adults (MacCormack et al., 2021; Ulus & Aisenberg-Shafran, 2022). However, as underlined above, those explanations have to remain post-hoc interpretations and may only serve as stimulating thoughts for future research that will have to follow up our initial results.

7.5.3 Recognition Task

The recognition task aimed at checking whether participants forget which cues were the PM targets. We observed no difference between younger and older adults and participants recognized correctly the PM cues among the 2-back stimuli. This indicates that the retrospective memory component of PM (i.e., the content of the intention to be performed, such as which pictures are considered as target PM cues) was preserved, thus the poorer performance of older adults on PM performance is more likely related to an impaired prospective component of PM (i.e., remembering to execute the intended action, such as pressing the specific key when the target PM cue is displayed). This is consistent with previous findings, which specify that even when adjusting the difficulty of the ongoing task, age differences are still present on the prospective component of PM tasks (cited in (Deuter et al., 2014). Thus, older adults may have issues initiating the execution of the intentions, potentially because of a decreased in executive functions with age (Diamond, 2013; Lindenberger et al., 2000; Lustig et al., 2007). It is also possible that, during the task, pictures were displayed too fast for older adults to have time to process them and initiate the correct action, while during the recognition block they had unlimited time to recognize PM targets.

7.5.4 Limitations and Perspectives

Even though our exploratory study provides new interesting findings on the relationship between emotions, metamemory and PM, it has certain limitations. Noteworthy is the fact that we have a relatively small sample of participants although it is similar to other studies targeting affective PM in older adults (see e.g., Ballhausen et al., 2015; Hering et al., 2018). Nevertheless, future studies should replicate these results using a larger sample of participants to further explore the relationship between emotions, PM and metamemory.

Noteworthy is the fact that the valence and arousal ratings provided in our method section come from the IAPS norms (Lang et al., 1997). However, as explained in a paper of Grühn & Scheibe (2008), these norms may not be representative for the older adults population as they were obtained by soliciting younger adults psychology students. Indeed, the authors indicated that, in their study, older adults rated negative stimuli as more negative and arousing than the official norms, while positive stimuli were rated as more positive but less arousing than these norms. Thus, older adults may have been more sensitive to these dimensions compared to younger adults, and this may (partially) explain why they performed worse than younger adults on the 2-back and PM tasks for negative stimuli. Future studies should consider using different datasets of emotional pictures for younger versus older adults that would match their valence and arousal sensitivity.

Regarding metamemory and emotions, it would be interesting to investigate participant's approach and avoidance tendencies, for example by including the BIS-BAS scale (Carver & White, 1994). It would enable to assess whether the findings of Windsor et al. (2012) and Wolfe et al. (2022) relates to cognitive performance, and especially to PM performance. Moreover, other methods such as EEG measures may also be relevant to further investigate these questions, as it could indicate whether participants recruit more cognitive resources for specific valence cues, and as the Frontal Index Asymmetry Index seems to be a reliable measure to assess approach and avoidance tendencies (Bonassi et al., 2021; Hering, Kliegel, Bisiacchi, et al., 2018). On another level, it could be more precise to have item-by-item predictions and postdictions instead of having global ones by valence for the PM cues. This would enable to have a closer look at metamemory representations and how participants modify them depending on the content of the pictures. Indeed, a meta-analysis demonstrated that attentional biases were larger for stimuli representing food, erotic interactions, and babies compared to smiling faces and mixed stimuli (Pool et al., 2016). The authors explained that these stimuli are considered relevant for individuals as they relate to common concerns such as nourishment, reproduction and caretaking. Thus, it may be interesting to investigate whether this allocation of attention result in a higher PM accuracy and higher monitoring of PM representations for these types of PM cues in both younger and older adults.

Additionally, to further explore whether older adults can monitor their metamemory representations for PM performance, future studies should consider using external performance indicators, such as feedback. Indeed, it would enable older adults to not only rely on their potentially outdated representations and/or impaired interoception, but to consider more external and objective cues.

7.5.5 Conclusion

Taken together, this study is the first to explore emotions, metamemory and PM in both younger and older adults using predictions and postdictions. It confirms previous studies' findings on younger and older adults' confidence regarding their PM performance: younger adults tend to be underconfident in their pre- and postdictions, while older adults tend to be overconfident in their PM performance. Our results add to the literature on emotions, metamemory and PM by demonstrating that PM representations may differ depending on PM cues' valence and that those effects seem to be partially different in younger and older adults. Moreover, we demonstrated that younger adults are able to modify their metamemory representations for neutral PM cues, but not for negative ones. When it comes to older adults, they do not seem to modify their representations for negative PM cues and seem to benefit less from task experience. Hence, further studies examining the factors underlying the age- and valence-related development of PM representations will be an important avenue for future research as understanding whether older adults have the ability to modify their metamemory representations is crucial to comprehend how interventions and strategies learning may benefit them. Indeed, as older adults are overconfident in their PM performance when encountering negative cues, they may not feel the need to adopt strategies when confronted with PM tasks that elicit negative feelings in their daily-life (such as paying the bills or scheduling their dentist appointment), subsequently impacting their autonomy. Therefore, future studies should further investigate, in a larger sample of participants, the ability of older adults to monitor their metamemory representations for PM performance using emotional cues.

8 General Discussion

8.1 Discussion of Research Questions

This thesis was motivated by new and intriguing questions regarding the interplay between affect, metacognition and cognitive functioning in older adults. Indeed, previous research paved the way to the understanding each of these domains separately, however, scarce investigations were conducted on these domains combined together. Moreover, when it is the case, literature demonstrated inconsistencies. Indeed, previous research demonstrated that personality changes predict cognitive decline in older adults, however really few studies investigated the relationship between neuroticism and EF longitudinally, even though these abilities relate to daily-life autonomy (Balsis et al., 2005; Donati et al., 2013; Luchetti et al., 2016; Waggel et al., 2015). In the light of these previous findings, the focus of the first study was to understand whether and how neuroticism influences EF in cognitive aging using longitudinal data of community-dwelling older adults.

Moreover, as neuroticism is related to higher risks of developing affective psychological disorders (Banjongrewadee et al., 2020; Kendler et al., 2004), I wondered whether depressive symptoms could influence cognitive functioning in older adults, and especially PM as it is a necessary cognitive ability that older adults rely on to perform their daily-life intentions and stay independent (Hering, Kliegel, Rendell, et al., 2018). I was surprised by the fact that plenty of research has been conducted on retrospective memory in older age, demonstrating a detrimental influence (for a meta-analysis see James et al., 2021), while research on PM was left behind with only two inconclusive studies investigating this relationship (Albiński et al., 2012; Livner et al., 2008). As individuals with depressive symptoms experience distorted representations about the world, others and themselves including their cognitive abilities, metamemory representations may be an underlying factor explaining these inconsistencies in previous research (Wells, 2000, 2008b). The second objective of this thesis was to investigate the relationship between affect and metamemory on PM performance in both participants presenting, or not, depressive symptoms.

Research on metamemory representations and PM is an emerging and promising field as improving metamemory representations by sharpening their accuracy could allow older adults to implement more effective strategies and succeed at PM tasks. Previous studies demonstrated that older adults are usually overconfident in their PM performance (Cauvin, Moulin, Souchay, Kliegel, et al., 2019; Kuhlmann, 2019), however, certain grey areas need further exploration, especially when considering the factors influencing PM metamemory representations. In this regard, emotional valence is of interest as it has been demonstrated that different stimuli valences influence retrospective memory metamemory representations (Hourihan, 2020; Hourihan & Bursey, 2017; Tauber & Dunlosky, 2012). However, this has not been investigated in the context of PM, which demonstrates a serious gap in our understanding of the interplay between affect, cognition and metamemory. Moreover, it seems that previous research did not investigate whether PM metamemory representations are updated after experiencing PM tasks. This is unfortunate because it does not allow to understand whether the monitoring process of metamemory is properly functioning in older adults (meaning that it is able to update representations), even though this is crucial to implement effective strategies and perform accurately on PM tasks (Hertzog & Dunlosky, 2011). As third objective of this thesis, we explored whether emotional valence influenced metamemory representations and PM performance in both younger and older adults, and whether these representations evolve after having performed the task.

8.1.1 Objective 1: Understanding How Emotional (In-)Stability Longitudinally Influences Cognitive Aging in Executive Functioning

This research aimed at understanding the interplay between neuroticism and cognitive abilities in older adults over a span of six years. The first goal was to uncover a potential relationship between neuroticism and EF, as neuroticism has been previously associated with lower cognitive performance and EF are related to daily-life autonomy (Bell et al., 2020; Chapman et al., 2012; Laera et al., 2021). Specifically, certain authors found a negative correlation between neuroticism and EF in younger individuals, while results are inconsistent in the older age groups (Bell et al., 2020; Boyle et al., 2010; Crow, 2019; Murdock et al., 2013).

One key observation from the present study was that individuals who showed higher levels of neuroticism during the first wave demonstrated decreased cognitive performance six years later (during the second wave) as assessed by the TMT. This was interesting, especially when contrasted with the findings of a previous two-year longitudinal study by Waggel et al. (2015), which did not find a longitudinal relationship between these two variables. Once this relationship between neuroticism and EF was established, another aspect of the study aimed to understand how perceived stress might mediate this link. The study results confirmed that higher levels of neuroticism in older adults were associated with increased perceived stress six years later, which in turn, affected their cognitive performance. This direct influence of stress on EF performance is consistent with past studies, suggesting that individuals with elevated neuroticism levels often experience higher stress, which then impacts their EF abilities (Aggarwal et al., 2014; Pereira-Morales et al., 2019).

Perceived stress plays an important role in mediating the effect of neuroticism on EF over time, which emphasizes the importance of reducing stress to avoid potential declines in EF among older adults. Noticeably, perceived stress was assessed by asking participants whether during the last month they felt “unable to control important things in [their] life”, “confident about [their] ability to handle [their] personal problems”, “things were going [their] way”, “difficulties were piling up so high that [they] could not overcome them”. These questions are very similar to questions asked in metacognitive questionnaires relating to control and capacity dimensions, such as in the Metamemory in Adulthood (Dixon & Hultsch, 1983b).

Indeed, perceived stress has been previously positively associated to metacognition, meaning that higher beliefs that worry is uncontrollable and that thoughts need to be controlled are related to higher perceived stress (Spada et al., 2008). It is not surprising as affective states arise from an appraisal process which includes coping, meaning judging whether individuals have control, power and are able to adjust to the event or situation (Sander et al., 2005). Thus, higher perceived stress levels could arise from individuals' beliefs about their low ability to cope with stressful and demanding external situations or tasks. In turn, this indicates that in their daily-life older adults experiencing higher levels of neuroticism may perceive themselves as less able to manage daily-life stressful situations, potentially having negative consequences on daily-life tasks requiring EF abilities such as preparing a meal, driving and taking medication. Thus, this study highlights the fact that longitudinal aspects of personality are important to consider in the investigation of cognitive performance as it can have affective and metacognitive consequences, subsequently influencing cognitive performance.

In conclusion, this research provides a novel perspective on the long-term relationship between neuroticism, EF, perceived stress – and by extension metacognition, in aging populations. Not only does it highlight the importance of neuroticism as a predictor of EF after six years but also underscores the significant role of perceived stress in this relationship. The findings support the development of strategies and interventions, including mindfulness programs but also metacognitive interventions to prevent cognitive decline triggered by neuroticism and perceived stress. This first study results suggest that investigating the interplay between affect, cognition and metacognition is indeed relevant to understand older adults cognitive functioning and specifically their ability to be autonomous in daily-life for tasks that require EF.

8.1.2 Objective 2: Investigating the Relationship Between Affect, Metacognition and Prospective Memory Performance in Older Age Groups

This second study aimed to investigate how different factors, including depressive symptoms, education level, metamemory representations, and age, relate to PM performance in older adults. The results revealed interesting relationships between these variables.

Age played a significant role as differences in PM performance were observed between young-old and old-old adults, with young-old adults outperforming their old-old counterparts. These findings emphasize the importance of discriminating between these age groups when exploring PM in older age.

Interestingly, the relationship between depressive symptoms and PM performance was not straightforward. Based on the analytical rumination hypothesis, it was proposed that individuals with higher (but non-clinical) depressive symptoms might outperform those with lower symptoms (Andrews & Thomson, 2009). This idea stems from theories suggesting an inverted U-shaped performance curve in individuals with varying levels of depressive symptoms. Yet, the findings did not support this directly. The study's design did not allow to differentiate between sub-clinically and clinically depressive individuals, which might have influenced our findings. Despite the lack of a direct effect, the role of depressive symptoms emerged in a complex three-way interaction involving age and metamemory representations. The results of this interaction indicated that the protective effects of having higher metamemory representations depends on age and depressive symptoms. For older adults without depressive symptoms, those with higher metamemory representations performed as well as their younger counterparts. But when depressive symptoms were present, the benefits of this higher metamemory representations vanished. To understand this phenomenon, we refer to motivation and task-engagement theories as those with higher metamemory might feel more capable, leading them to engage further and perform better (Gendolla, 2004). However, when depressive symptoms come into the picture, the benefit of these higher metamemory representations seems to be lost because depressed individuals tend to avoid tasks perceived as too challenging (Brinkmann, 2008; Brinkmann & Gendolla, 2008). This is even more pertinent for older adults, as when they perceive tasks as demanding, they are more likely to disengage, to save cognitive resources (Brinkmann, 2008; Brinkmann & Gendolla, 2008). Therefore, considering depressive symptoms as a moderator of the relationship between memory self-efficacy and PM performance in older adults seems theoretically appropriate and suggested by this study' results (even though an actual moderating test has not been conducted).

Noteworthy is the fact that previous research indicated that individuals with depressive symptoms suffer from distorted metacognitive beliefs, and that depressive symptoms and metacognition have a bidirectional and complex relationship. Indeed, depression can influence metacognitive beliefs by leading individuals to adopt negative beliefs about their thinking and to contribute to worry, rumination (Papageorgiou & Wells, 2003; Wells & Matthews, 1996), while maladaptive metacognitive beliefs can contribute to the onset and maintenance of depressive symptoms by increasing feeling of uncontrollability and danger in stressful and challenging life events (Spada et al., 2008; Wells, 2000). Surprisingly, in this second study, metamemory representations did not significantly differ between individuals with lower and higher depressive symptoms. A potential explanation stems from the fact that our participants scored high on the depressive scale, but they were not clinically depressed. Thus, they may not have already developed distorted beliefs about their cognitive abilities, but keep these representations similar to individuals with lower depressive symptoms. However, the fact that their metamemory representations are similar to individuals with lower depressive symptoms while their actual performance on PM is worse, suggests a dissociation between metamemory representations and actual performance. This idea is supported by previous studies indicating that older adults are overconfident regarding their memory abilities (Cauvin et al., 2019b).

Interestingly, this has also been demonstrated once again in the third study of this thesis in the context of depressive symptoms, adding new relevant information for the interplay between affect, metacognition and cognition in older age.

To resume, this second study adds on the scarce literature on depressive symptoms and PM, by providing new findings. It highlights the intricate relationship between affect, particularly depressive symptoms, and metamemory representations such as self-efficacy, and their combined influence on cognitive tasks like PM. The present findings suggest that depressive symptoms moderate the relationship between metamemory representations and PM in older adults as depressive symptoms appear to undermine the benefits of higher metamemory representations, making tasks appear more discouraging, and reducing engagement and performance in PM tasks. Thus, longitudinal studies may offer more insights into this relationship and causal mechanisms involved between these variables. Nevertheless, metacognitive interventions exist and offer ways to reduce distorted and maladaptive metacognitive beliefs, depressive symptoms, which may potentially subsequently improve performance on cognitive tasks and especially on PM performance.

8.1.3 Objective 3: Exploring How Age-Related Differences and Emotional Valences Relate to Prospective Memory Metamemory Representations and Actual Prospective Memory Performance

In this third study, we focused on metamemory, emotions, and PM, under the influence of age. The main aims were to examine how emotional valence plays a role in PM performance and PM representations, and whether these PM metamemory representations evolve with task experience, especially in older age.

The hypothesis predicted that younger adults would perform better than older adults on an event-based PM task. It was also predicted that younger individuals would underestimate their PM abilities while older individuals would overestimate theirs. The study's results confirmed the initial hypothesis - younger adults did indeed outperform their older counterparts. Furthermore, regarding negative PM cues, younger adults demonstrated more accurate results than older ones.

An important finding was the interaction between age and emotional valence on PM tasks. While younger adults displayed consistent performance for all emotional PM cues, older adults encountered difficulties with negative cues. This deviates from the "positivity-bias" hypothesis which postulates that older adults are performing better with positive stimuli due to emotional regulation processes (Carstensen & Mikels, 2005). On the contrary, a "negativity-avoidance" bias seems to be emerging, suggesting that older adults might avoid negative stimuli more due to increased avoidance behaviours that grow with age (Windsor et al., 2012; Wolfe et al., 2022). But the aims of this study were not only to examine performance based on cue valence, it also aimed to explore how metamemory predictions could vary with different emotional valences and how age and experience might influence this.

Predictions and postdictions did not differ between younger and older adults, suggesting that older adults are not aware of their normal age-related cognitive decline. Interestingly, and on the contrary to the idea of Phelps (2006) that emotions influence subjective remembering, and to previous studies on retrospective memory indicating that individuals believe that they are more likely to remember emotional stimuli, this was not demonstrated in our study in the context of PM (Hourihan, 2020; Hourihan & Bursey, 2017; Sanders & Berry, 2021; Tauber et al., 2017; Tauber & Dunlosky, 2012, p. 201; Witherby & Tauber, 2018). Indeed, surprisingly, the study didn’t reveal any significant difference of valence on the predictions and postdictions for PM performance, indicating that participants expected to remember all PM cues similarly independently of their valence. This indicates that they have biased representations of their PM abilities when emotional stimuli are encountered, as when comparing these predictions and postdictions to actual performance, an influence of valence arises.

Indeed, effects of valence are present when comparing metamemory representations to actual PM performance. Younger adults displayed accurate predictions for positive cues and underestimated their abilities for neutral and negative cues. After experiencing the task, their representations (postdictions) improved for neutral cues but remained underestimated for negative cues. Older adults, in contrast, overestimated their abilities for negative cues both before and after performing the task. It provides new information on older adults' cognitive and metacognitive abilities, indicating that they are not impaired nor overconfident for all types of stimuli as they perform similarly to younger adults for the positive and neutral cues and have accurate representations of their abilities for these cues. This is important to notice as it depicts a less tragic picture of older adults' cognitive functioning than what is generally assumed in the aging literature. However, it clearly indicates that older adults are sensitive to negative stimuli, meaning that it negatively affects their performance and metamemory representations. This pattern adds to the scarce existing literature on PM metamemory representations. Younger adults appeared to adjust their predictions for neutral cues after performing the task, while older adults did not demonstrate this monitoring. As they are overconfident and do not update their metamemory representations across the task, this suggest that they may not involve more effort or implement more efficient strategies to perform better on PM tasks, especially for negative cues. This can have problematic consequences if transposed to daily-life as older adults may think they are performing well for intentions eliciting negative emotions, while it can actually not be the case. Several theories might explain this overconfidence and inability to monitor metamemory representations: younger adults might be driven by approach tendencies, expressed towards positive stimuli, while older adults might avoid negative stimuli more with age, affecting their metamemory predictions (Windsor et al., 2012; Wolfe et al., 2022). The decrease in interoception experienced by older adults could also play a role (MacCormack et al., 2021; Ulus & Aisenberg-Shafran, 2022). Indeed, as older adults integrate less well their bodily signals, they may be less able to establish when they are omitting PM cues, or making errors, as PM performance depends on the cue detection, which is supposed to elicit feelings of familiarity, which are interoceptive body signals similar to those present for metamemory judgements (such as feeling-of-knowing; Umeda et al., 2016). Thus, this lack in interoception can lead to the maintenance of erroneous representations of their PM abilities.

To resume, this study explored the relationship between emotions, metamemory, and PM across age groups, demonstrating biased representations of PM abilities for emotional cues in both younger and older adults. While younger adults are able to monitor their PM representations, we cannot draw conclusions based on the present findings for older adults. It underlines the need of further investigation of their metacognitive monitoring abilities, to understand how they process and predict their own cognitive abilities. Following on the results of the three studies presented in this thesis, we observe that differences on metacognitive representations and on cognitive performance arise when negative affect is at play. We will discuss this further in the integrated discussion.

8.2 Integrative Discussion: At the Intersection Between Affect, Metamemory, and Cognitive Abilities in Older Age

The overall aim of these studies was to examine the relationship between affect, metamemory and cognitive abilities in older age as these domains are crucial for independent and autonomous daily-living, but are still understudied. By integrating the results of these three studies, we can highlight the fact that a) affect influences cognitive performance and metacognitive representations, and that b) metacognitive processes play an important role for cognition, and should be integrated in cognitive models. In this discussion, implications for society, for clinical practice, and for research are discussed, and we proposed further research perspectives.

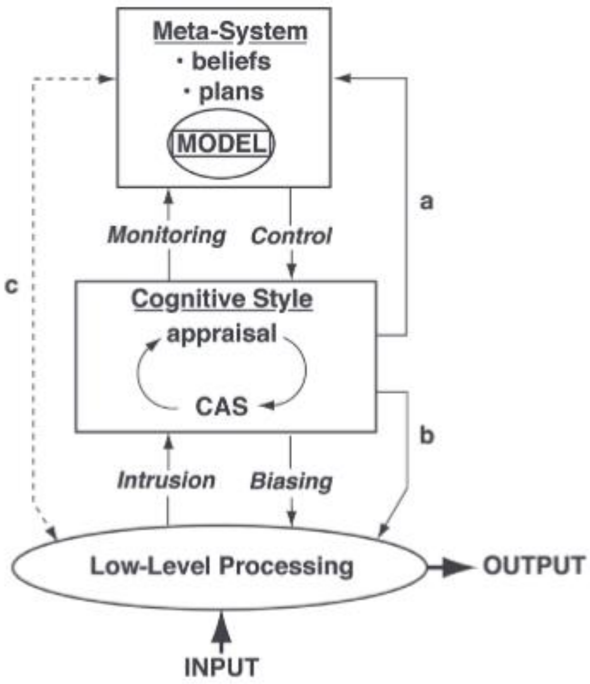
8.2.1 The interaction of Affect and Metacognition on Cognitive Performance

By integrating the results of these three studies, several key points emerge, leading to a greater understanding of the affective, metacognitive and cognitive dynamics in older adults. We can highlight the fact that emotional factors undeniably influence cognitive abilities in older age, which gives credit to previous authors' suggestion of studying emotions and cognition together (Phelps, 2006; Storbeck & Clore, 2007). While previous research indicated the existence of a positivity bias in older adults in response to emotional stimuli, and mixed results regarding the influence of stress and perceived stress on cognition, the present findings specifically draw our attention on negative affect (Aggarwal et al., 2014; Carstensen & Mikels, 2005; Hidalgo et al., 2019; Hostler et al., 2018). Indeed, when elicited by neuroticism, depressive symptoms and negative emotional valence, negative affect influences both metacognitive representations and cognitive performance. Higher levels of neuroticism directly influence metacognitive representations by increasing perceived stress (meaning lower sense of control and ability), and can also be the starting point of more complex affective psychological disorders, such as depression, which subsequently counteract the protective effect of metamemory on cognitive performance. This phenomenon can be explained by the S-REF model (see Figure 8; Wells, 2000, 2008), that I briefly presented in the introduction of this thesis. Indeed, this model indicates that maladaptive cognitive processes, especially rumination and attentional biases, but also personality traits such as neuroticism, underlie the maintenance of emotional disorders, notably depression in which individuals exhibit maladaptive metacognitive beliefs. According to this model, for individuals with depressive symptoms, the predominant metacognitive belief is about the benefit of rumination and worry, that are seen as helpful coping strategies to find solutions and/or prevent future negative events. However, this increased rumination may lead to a cognitive fatigue which reduces the available cognitive resources to engage in other cognitive tasks in an efficient manner (Wells, 2000, 2008b). Thus, not enough cognitive resources may be spared to focus on planning, inhibition and updating processes, intention formation, retention and retrieval of the PM intention, subsequently impairing EF and PM tasks. Over time, these overwhelmed cognitive processes can exacerbate long-lasting deficits (Wells, 2000, 2008b). Individuals with higher levels of neuroticism, and depressive symptoms may become less able to manage future-oriented tasks compared to their emotionally stable, and non-depressed counterparts, subsequently impairing their objective abilities to perform these tasks correctly.

Noticeably, the detrimental influence of negative affect on older adults' cognitive abilities also arises when considering external emotional sources, such as negatively valenced stimuli. While for neuroticism and depression reduced cognitive abilities can be explained by diminished cognitive resources and distorted metacognitive beliefs, for emotional negative stimuli, possible explanations come from emotional regulation strategies, and especially negativity-avoidance strategies. Previous authors advocate for a negativity-avoidance bias in older adults (Windsor et al., 2012; Wolfe et al., 2022). which is supported by other reviews indicating that emotional regulation strategies evolve with age, with older adults easily ignoring negative stimuli compared to younger adults (Mather, 2012). The authors indicated that this evolution is driven by changes in certain regions of the brain, such as an increase of activation in the prefrontal cortex, and a reduction of the amygdala activation when confronted with negative stimuli, indicating that reduced relevance is attributed to negative stimuli compared in older adults compared to younger adults. This avoidance of negative stimuli supposedly supports older adults' well-being, which seems to increase with age (Mather, 2012). However, even if supporting older adults' emotional well-being is crucial, it is clear that this bias has detrimental implications for cognitive performance (as presented in Study 3), and – at a further extent - may also impair social relationships, as older adults may ignore conflicts instead of communicating about them, and daily-life autonomy, as they may avoid negative information or unpleasant events such as health-issues and medical appointments. Indeed, negativity avoidance can compromise the quality of interpersonal relationships as it often involves the use of emotion regulation strategies such as suppression, which is associated with poorer interpersonal functioning and diminished relationship satisfaction (Gross, 2015). By avoiding conflicts and discussions, unresolved issues may persist, affecting health and social satisfaction (Gross & John, 2003). Furthermore, this avoidance pattern can reduce social engagement, which is crucial for cognitive functioning and acts as a protective factor against neuropsychological diseases such as dementia (Fratiglioni et al., 2004). Indeed, social engagement and support correlate with better mental and physical health outcomes, subsequently relating to well-being and daily-life autonomy (Fratiglioni et al., 2004; Hawkley & Cacioppo, 2010). Moreover, negativity avoidance can have consequences on decision-making, as if individuals consistently avoid negative stimuli, it will lead them to make choices based on incomplete information, which is particularly relevant in the context of health-related decisions (Sweeny et al., 2010). Negativity avoidance also influences health behaviors, for instance postponing participation in preventive measures such as regular medical appointments perceived as stressful, which are essential for maintaining health and autonomy (Howell & Shepperd, 2013). In terms of mental health, avoidance can increase feelings of anxiety and stress overtime as individuals may feel overwhelmed when they finally have to face avoided negative information or events (Barbour et al., 2012). Importantly, this negativity avoidance might be accompanied by unawareness, as older adults think they perform similarly for all emotional information, which would be even more problematic for their health. However, previous research suggest that this health-information avoidance can be reduced when improving coping self-efficacy (i.e., one's representation of their ability to cope with life challenges) and agency beliefs (i.e., perception of one's own ability to act independently, make free choices, to have control over the situation; Hua & Howell, 2022; Orom et al., 2021), which highlight once again how affect, metacognition and cognition are related for highly relevant situations such as health-related behaviours.

Figure 8

Representation of the S-REF Model (Wells, 2000; 2008)



To conclude, it seems important to further investigate the relationship between affect and metacognition on cognitive performance in older age. In the next section, we highlight the crucial role of metamemory representations for cognition and daily-life autonomy based on the findings presented in this thesis.

8.2.2 The Importance of Metacognition for Cognition in Older Age

The present findings indicate that metacognition helps to better understand and plays an important role in the relationship between affect and cognitive performance in older age. Indeed, negative affect seems to disturb metacognitive processes, subsequently influencing cognitive performance. These are new findings of major importance to consider in the context of cognitive aging as it has important implications.

In line with previous research on metacognition and cognitive performance, the present findings indicate that metacognitive representations are protective for cognitive performance, meaning that they are crucial for older adults (Angel et al., 2022; Hertzog et al., 1990; Hertzog & Dunlosky, 2011). Previous authors indicate that this protective effect of metacognition comes from the ability to adapt strategies to task difficulty, which is crucial for memory performance in aging (Angel et al., 2022; Hertzog & Dunlosky, 2011). Moreover, they point out that spared metacognitive monitoring accuracy is key to implement effective strategies, and especially compensatory strategies, to achieve the expected performance despite normal age-related decline in cognitive processes (Hertzog & Dunlosky, 2011). However, older adults' metacognitive monitoring does not seem to be always accurate as, consistent with prior research, discrepancies between individuals' metamemory representations and their actual PM performance exist (Cauvin et al., 2019a; Cauvin et al., 2019b; Kuhlmann, 2019). While younger adults update their metamemory representations towards more accurate ones, older adults display an overconfidence in both their predictions and postdictions on PM performance when encountering negative cues. These findings have great implications as if older adults, are not aware of their PM failures— such as missing appointments or neglecting medications—they are less likely to adopt compensatory strategies. Subsequently, being unaware of memory issues can severely compromise their daily-life autonomy.

On the contrary, if they are aware of these deficits, they might seek out both internal cognitive strategies (e.g., repetition) and external strategies (e.g., reminders) to implement and improve their performance. Interestingly, prior research has shown that as people age, they rely more often on external strategies, while the use of internal strategies decreases, possibly due to diminished cognitive resources (Bouazzaoui et al., 2010). A recent study demonstrated, in a PM task, that even when older adults are given the possibility to use external strategies they may not take this chance (Scarampi & Gilbert, 2021). Therefore, it seems urgent to identify the factors that prevent older adults from updating their metamemory representations, in order to enable them to apply this knowledge towards the implementation of effective strategies.

When considering the findings of the present studies, I hypothesized that older adults' overconfidence might be due to their potential difficulty in integrating interoceptive cues. Indeed, in event-based PM tasks, PM performance depends on the cue detection, which is supposed to elicit feelings of familiarity, which are interoceptive body signals similar to those present for metamemory judgements (such as feeling-of-knowing; Umeda et al., 2016). Interestingly, a review by Haustein et al. (2023) suggested that higher interoceptive sensitivity can improve cognitive performance. Thus, as the integration of interoceptive cues is decreased in older age, older participants may be overconfident because they rely on their past abilities (MacCormack et al., 2021; Ulus & Aisenberg-Shafran, 2022). Moreover, when considering depressive individuals, previous research indicated that they have lower levels of interoception (Haustein et al., 2023), which is consistent with the fact that they rate their metamemory self-efficacy similarly to non-depressed individuals while their actual performance is lower. Indeed, depressive older adults may evaluate their memory self-efficacy based on their past memory abilities, which existed before their depression started. However, they now seem to encounter difficulties to integrate interoceptive cues, leading them to poorer cognitive performance compared to other non-depressed individuals.

A feedback study might be beneficial to investigate whether these inaccurate representations are due to the integration of interoceptive cues or come from another issue with the metacognitive monitoring process. Indeed, by providing both healthy and depressed participants external cues (feedback) to monitor their metamemory representations, they could better understand their actual cognitive performance without relying on interoceptive (internal) cues, and subsequently adjust their metamemory representations based on this feedback (if their metacognitive monitoring process is working properly). Once we will have defined whether older adults are able to modify their metamemory representations, we can observe whether it influences their use of strategies. In Scarampi & Gilbert's study (2021), older adults did not use the strategies available, but this may be because they overestimated their performance. Indeed, as pointed out above, they may not see the point of using these strategies if they think that their performance is good and sufficient. If, despite an ability to update their metamemory representations, this "non-use" of available strategies persists, then this may mean that a) the communication between the monitoring and control processes of metacognition is impaired in older adults (see Figure 2), or b) the control process itself is impaired, not allowing to use the strategies even when older adults may acknowledge this need.

To resume, metacognitive abilities play an important role in cognitive functioning and could, by extension, influence daily-life autonomy and independence. In the light of the findings presented in this thesis, it seems relevant to consider including metacognitive processes in models of cognitive functioning.

8.2.3 Integrating Affect and Metacognitive Processes into Comprehensive Cognitive Models: The Example of Prospective Memory

Kuhlmann (2019) proposed a model integrating metacognitive processes within PM phases. She described how the metacognitive monitoring and control exert their effects on certain phases of PM, such as intention formation, retention, retrieval, and execution (see Figure 9).

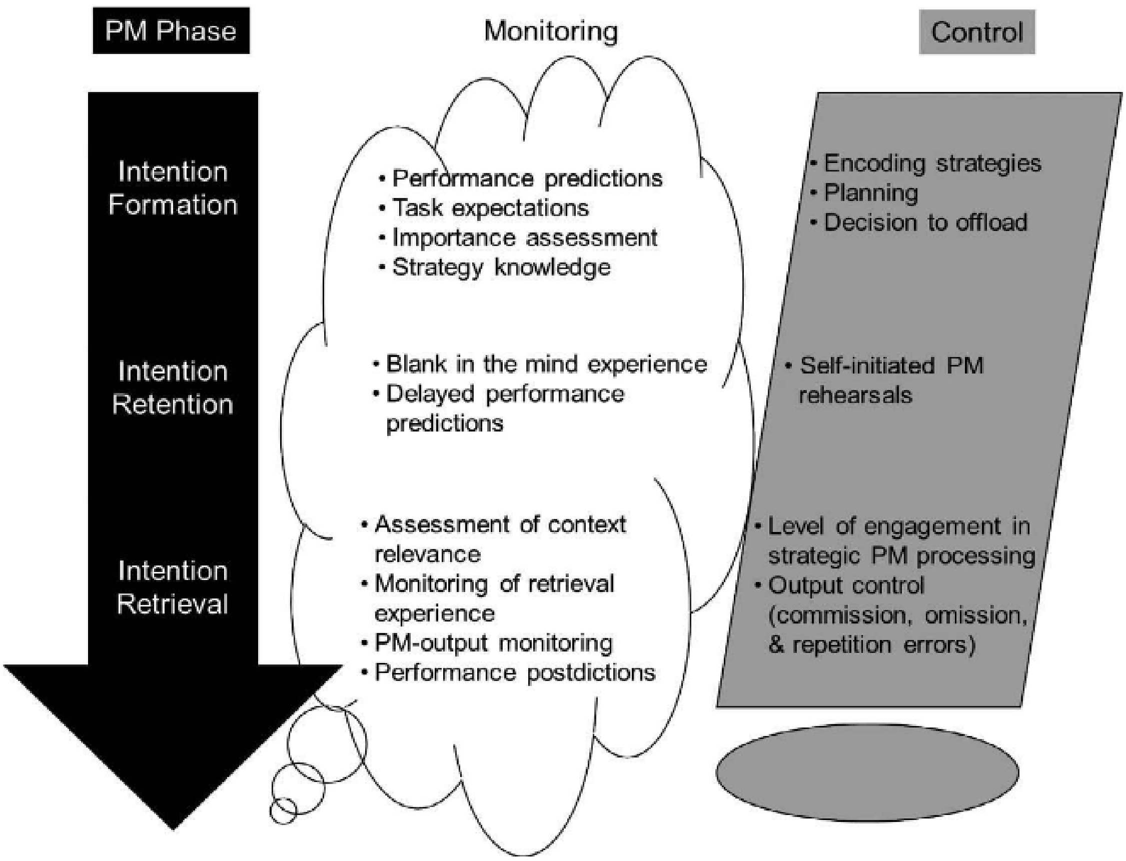
The inclusion of metacognitive processes in PM models provides a framework for understanding how individuals can optimize their PM abilities, reduce PM failures, and improve the management of future tasks and intentions. Present findings support the idea that affective factors, which are currently missing from PM models, significantly contribute to the relationship between metacognition and cognitive performance. Indeed, factors such as neuroticism, depressive symptoms, and negative emotions could be considered as moderators of this relationship, influencing various phases of PM. In the following paragraph, I propose to integrate affective factors into Kuhlmann's model and describe how they might affect each phase of PM and the associated metacognitive processes.

During the intention formation phase of PM, affect and emotions can influence how individuals form, plan, and prioritize their PM intentions. Kuhlmann's model indicates that PM intentions' "importance" is assessed during the intention formation. The emotions associated with PM intentions could influence the perceived importance of the PM intention, depending on whether they elicit positive or negative affect, subsequently leading to the allocation of more or less strategic resources and efficient planning. For instance, as it seems that older adults are impaired for negative PM cues, it is possible that less resources are attributed to encode these specific PM cues and implement strategies for them. During the retention phase, negative affect elicited by neuroticism or depressive symptoms may disrupt effort involvement in rehearsals and other strategies because of cognitive resources oriented toward regulating one's own affective state and/or occupied by metacognitive beliefs. Emotions can also influence the retrieval of intentions. For example, negative emotions elicited by negative stimuli may impair spontaneous recognition of PM cues in older adults as they seem to avoid these stimuli, leading to more omission and errors. In terms of monitoring and adjustment, affect could influence how individuals make postdictions and react to forgotten intentions. For instance, for individuals with higher levels of neuroticism or depressive symptoms, being aware of their omissions and errors could lead them to experience higher levels of stress, feelings of discouragement, reinforcement of negative representations about their ability, and subsequently lead them to decrease their effort and involvement in following trials or PM tasks.

The inclusion of metacognitive processes and affect in PM models offers a framework for understanding how individuals can optimize their PM abilities, manage future tasks and intentions more effectively, and reduce PM failures. Further studies need to be conducted in order to investigate more precisely how this combination of factors can influence PM performance, and daily-life activities and autonomy.

Figure 9

PM Process Model with Metacognitive Processes from Kuhlmann (2019)



Note. The intention formation is influenced by monitoring which predicts performance, evaluates the importance and the difficulty of the task, and holds strategy knowledge, while metacognitive control influences this phase by planning the intention and implementing strategies. During the retention intention phase, monitoring allows to make delayed predictions, while control enables to rehearse the intentions. During the retrieval phase, monitoring assesses whether the context or stimulus is relevant for the PM intention to allocate or not attention toward this stimulus, evaluates the actual performance, and allows to make postdictions, while control defines the engagement into strategic PM processing, and checks whether errors are committed.

8.3 Implications for Society, Clinical Practice, and Future Research

The three studies presented in thesis revealed interesting findings that may have implications for several domains such as society, clinical practice, and future research.

We believe that the findings highlighted in this thesis may potentially have implications for society and health-policies as they demonstrated that long term factors such as education, metacognitive representations and personality, that develop across the entire life course, may influence cognitive performance in older age, which is also supported by other studies (Künzi et al., 2021; Stern, 2009). Thus, it seems relevant to prioritize the access to education, and to dispense metacognitive interventions in school and universities to help individuals develop their metacognitive knowledge, strategies' management and keep these benefits in older age. Moreover, it would be interesting to propose interventions based on reduction of neuroticism, depressive symptoms and negative affect, as they are the most common psychological issues encountered by older adults, and subsequently may impair their daily-life autonomy by affecting cognitive abilities (World Health Organization, 2017, December). Previous research on health policies demonstrated that prevention is actually a financially interesting action that government can adopt in terms of cost-benefits ratio (Le et al., 2021), meaning that investing in prevention cost less than paying costs .

About clinical practice, we believe that the present studies highlighted the importance for clinicians and neuropsychologists to be aware that affect, but also representations of one's own abilities, may influence (and potentially bias) clinical and cognitive assessment of older adults. Most professionals are already sensitive and informed about this matter, however, precautions in the attitude of the interviewers and the setting of the room should be taken seriously to reassure patients and enable them to demonstrate their actual abilities. Therefore, we recommend to perform the interview and tests in a calm and non-stressful environment, to explain to patients the aims of the tests with chosen words. For instance, to avoid mentioning “memory test” to not activate age-related stereotypes in older adults, that could alter their self-efficacy and lead to under-performance. Moreover, as older adults consistently demonstrate overconfidence for PM tasks, it may be important for health professionals to not only rely on their older patients’ words about their adherence to medical treatments, and abilities to take care of daily chores, but to also include a spouse or informant point of view for these tasks to assess whether professional help might be required.

Regarding future research, it is obvious that further studies have to be conducted on the interplay between affect, metacognition and cognitive performance in older age. Indeed, even though this thesis demonstrated interesting new findings, it is raising new problematics that should be taken seriously to fully understand and acknowledge all the subtleties of this relationship. One major question remaining is whether older adults are able to adjust their metamemory representations. We develop possible ways of investigating this question in the next section.

8.4 Perspectives for Future Research

Future research could target different open questions that were raised by the studies presented in this thesis. Here, I focus on the ability of older adults to monitor their metamemory representations.

First, I think that it might be relevant to sequentially compare the predictions and postdictions of participants in PM tasks to understand whether a greater knowledge about their PM abilities is progressively acquired across the entire experiment. Indeed, the comparison between participants' predictions, then postdictions, and following predictions again in the subsequent block could reveal whether participants gain accuracy across the study. Certain participants, for instance, might require multiple trials to understand the task and apply their knowledge to subsequent blocks. By analyzing such data in a large sample, distinct participants’ profiles could be identified, each with their predictive tendencies and response patterns (e.g., perseverant, resignated) and help understanding how older adults involve or withdraw effort in PM tasks. Researchers could also link this performance to intra-individual variables, such as personality traits like conscientiousness (which is relevant in the context of PM; Smith et al., 2011) and neuroticism, but also emotional regulation strategies to establish profiles (for example measured by the Cognitive Emotion Regulation Questionnaire, CERQ, Jermann et al., 2006).

Second, as previously mentioned, it is possible that older adults are less sensitive to interoceptive (internal) cues, which would impair their lecture of their performance. To explore this idea, designing a new study in which older adults would receive feedback about their PM performance could be interesting, as it would enable older adults to rely on external cues. We describe here a proposition for a PM feedback study. In a time-based PM study, participants would engage in an ongoing-task, such as a lexical-decision task or a 2-back task. Participants' PM intentions would be to press a key at pre-specified times during several blocks. The advantage of a time-based PM task is the possibility to display a timer, enabling researchers to observe whether participants frequently check the clock to meet the expected time when they have to execute their intention. This can provide insights into whether participants implement strategies to monitor time to press the key at the right moment. In this study, we could introduce manipulated feedback. Indeed, if we only rely on actual feedback, it might not give a clear view of the ability of participants to monitor their representations: if there is only a small discrepancy between their representations and their actual performance, we might not see modifications if an actual feedback is provided, subsequently we will not be able to assess whether participants are able to monitor their representations. By using manipulated feedback, we can trick participants into believing that their representations of their performance are not accurate, thereby encouraging them to modify their predictions and postdictions. This would require participants to make a prediction before the first block and afterward. They would then receive manipulated feedback: either positive feedback (e.g., “You did better than you thought! Excellent!”) or negative feedback (e.g., "You are far from your expected performance, and far from ranking at top 1"). Additionally, a control group would not receive any feedback, they would be considered as a baseline to measure the natural monitoring of participants’ representations. The feedback, positive or negative, might also induce emotional responses, potentially influencing metamemory representations. By comparing data of younger and older adults in this design, we could determine if certain age groups are more sensitive to specific feedback types (positive or negative). To conclude, a manipulated feedback study could help us dig deeper into the interplay between affect, metacognition and cognitive performance by allowing us to determine whether older adults are able to update their metamemory representations or whether their monitoring process is impaired. This discovery could have real implications for research and interventions for older adults and their daily-life autonomy.

8.5 Overall Conclusion

The main objective of this thesis was to explore the intricate relationship between affect, metacognition, and cognitive performance in older age. By using longitudinal data, examining various age groups, and incorporating different affective modalities, we have shed new light on this complex interplay. While this work offers an interesting framework, certain unresolved questions require further research to understand the underlying mechanisms and the metacognitive abilities of older adults. We see this work as material for future studies, potentially encouraging the development of affective and metacognitive interventions. Such interventions could be crucial to slowdown or even counteract cognitive decline affecting daily-life autonomy of older adults.

9 Bibliographie

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